EVALUATION OF AN EDUCATION INTERVENTION ON ETCO2 MONITORING TO ENHANCE PROVIDER KNOWLEDGE AND UNDERSTANDING OF ETCO2 MONITORING TO GUIDE EXTUBATION CRITERIA IN POST-OPERATIVE CORONARY ARTERY BYPASS PATIENTS

By

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A capstone project submitted to the

School of Nursing

The State University of New York

In partial fulfillment of the requirements for the degree of Doctor of Nursing Practice

May 2019
Capstone Approval Form:

DNP Capstone Project Approval Form

This is to certify that Christopher Bona

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successfully defended his/her Capstone project entitled:

Evaluation of an Education Intervention on Etc02 Monitoring To Enhance Provider Knowledge and Understanding of Etc02 Monitoring to Guide Extubation Criteria in Post-Operative Coronary Artery Bypass Patients

on November 29, 2018

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Abstract

This capstone project evaluated an education intervention on the use of ETCO2 monitoring in the CVICU at Strong Memorial Hospital. The objective of this project was to improve provider knowledge and comfort with the use of ETCO2 monitoring to ultimately be used to improve time to extubation in post-op coronary artery bypass patients. The project used a quasi-experimental pretest-posttest design utilizing a test of knowledge and survey on comfort of use with ETCO2. Kurt Lewins theory of change was used to guide this capstone project. Participants consisted of fifteen CVICU providers who manage post-operative cardiac surgery patients. Data was collected through the use of a written survey on provider comfort with ETCO2 and a written test of knowledge on ETCO2. A paired T-test was used to compare data points from each of the providers. The results of the study showed a significant improvement in both provider knowledge (P <.004) and comfort with the use of ETCO2 (P<.003). This project has the potential to improve patient outcomes by improving provider knowledge to help manage post-operative CABG patients and minimize their time to extubation. This will enhance their progression through their hospital course as well as decrease healthcare costs by decreasing ABG analysis. Future research should look at ETCO2 in other ICUs as well as follow up on extubation times in the CVICU.
Acknowledgments

A sincere thank you to everyone who has supported me throughout the completion of this project and my education over the past several years. I would like to start by thanking my fiancé Holly, for her continued support throughout all of my education, I couldn’t have done it without you. Thank you to all of my co-workers at Strong Memorial Hospital; you were instrumental in my successful completion and approval of this project. You have all helped me grow as a professional and I will never be able to thank you enough.

Secondly, I would like to thank my advisor Dr. Faust for her continued guidance and patience through this capstone process. I cannot express enough the gratitude that I have for her commitment to my success throughout this portion of my journey.

Finally, I would like to thank both Dr. Korogoda for his guidance early in this process and guiding me through the early phases of capstone. I would also like to thank Dr. Spulecki for all of her guidance through the entire program both in the classroom and clinically.
Introduction

The use of ETCO2 monitoring is considered a standard of care when performing anesthesia in the operating room (OR) and outside of it in areas such as ambulatory clinics, post anesthesia recovery units, and areas that use conscious sedation such as endoscopy centers (Miller, Eriksson, Fleisher and Wiener-Kronish, 2015). It is an invaluable tool used to guide appropriate ventilatory and airway management for patients undergoing anesthesia. In addition to its value as a safety monitor, evaluation of expiratory carbon dioxide provides valuable information about important physiologic factors, including ventilation, cardiac output, metabolic activity, and proper ventilator function (Duke & Keech, 2016). With such a valuable instrument, and the vast amount of clinical data that can be extrapolated from it, it begs the question as to why providers are not using this tool outside of the OR in other areas of medicine such as critical care on a routine basis. Currently, data shows routine use of ETCO2 monitoring consistently in two areas of critical care medicine; the first being to guide resuscitation during cardiopulmonary resuscitation (CPR) (Duke & Keech, 2016). The second area in which ETCO2 is consistently used is in the neurosurgical intensive care unit (ICU) (Marino, 2014; Duke & Keech, 2016).

There is a large amount of information and literature with ETCO2 monitoring and its application in anesthesia, neurosurgical critical care medicine, and during CPR. There remains limited research on the role of ETCO2 monitoring as a standard in managing patients in the ICU for ventilator management with the goal of early extubation; particularly in fast track cardiac surgery patients who have undergone coronary artery bypass surgery (CABG). The limited research and application in ICU’s, particularly in the cardiovascular intensive care unit (CVICU), may be related to provider knowledge and comfort with ETCO2 monitoring.
Definition of Terms

The definition of terms for the capstone project are as follows:

1. **ETCO2**: The partial pressure or maximal concentration of carbon dioxide (CO2) at the end of an exhaled breath, which is expressed as a percentage of CO2 or mmHg. The normal values are 5% to 6% CO2, which is equivalent to 35-45 mmHg.

2. **Capnography**: Monitoring of the concentration of exhaled carbon dioxide in order to assess physiologic status or determine the adequacy of ventilation during anesthesia.

3. **Capnogram**: A graphic representation of inhaled and exhaled carbon dioxide concentrations in the form of continuous waves.

4. **Critical Care Provider**: A critical care provider is a physician, nurse practitioner, or nurse anesthetist who provides secondary health care where a patient receives active but short-term treatment for a severe injury or episode of illness, an urgent medical condition, or during recovery from surgery.

5. **Education**: The process of receiving or giving systematic instruction.

6. **Intervention**: Action taken to improve a situation.

7. **Understanding**: An individual's perception or judgment of a situation.

8. **Application**: The action of putting something into operation.

Research Question

The research question for this capstone project is as follows: Will provider education on ETCO2 monitoring enhance provider understanding and application of ETCO2 monitoring to guide extubation criteria and ultimately improve extubation times in post-op coronary artery bypass patients. Primary objectives were to show an improvement in knowledge and comfort with ETCO2 monitoring.
Background and Significance

With the rising cost of healthcare and pressure to move patients along quickly through various phases of care, providers need to be using every tool possible to help manage these expectations. If providers are to implement the use of ETCO2 monitoring in the CVICU then they have to be educated on the use of this monitoring device so they can feel comfortable making clinical decision with the data that is presented from using ETCO2. Not only do they have to be familiar with its use but also with any potential limitations or variations of normal values based on patient population and co-morbidities. The current capstone project aims to improve provider knowledge and comfort with ETCO2 monitoring to guide extubation criteria of patients undergoing coronary artery bypass surgery patients.

ETCO2 monitoring is a powerful clinical tool that can provide critical care providers with a multitude of patient information (Duke & Keech, 2016). There exist only a few monitoring devices in medicine such as Swan-Ganz Catheters, arterial lines, and Flo-Trac (Marino, 2014), that can be used to provide so much physiological data on a patient’s condition. As stated, there is endless research with the use of ETCO2 morning in anesthesia and in the OR, and especially areas such as the neurosurgical ICU, however, limited information exists with its use to guide extubation criteria for post-op cardiac surgery patients in the CVICU. The lack of ETCO2 monitoring in this patient population can be from a variety of factors such as lack of provider education and understanding involving the use of ETCO2, the ability to extrapolate clinical data, understanding of the accuracy with use as a surrogate for arterial carbon dioxide (PaCO2) and recognition of waveform capnography to help diagnose various conditions. Based on these predicted factors, the purpose of the current capstone project was to implement an education plan
to providers on the use of ETCO2 monitoring in post-op coronary artery bypass patients to help improve knowledge and comfort with ETCO2 monitoring.

**Theoretical Framework**

Kurt Lewin’s theory of change (1951) was used as the theoretical framework to guide this capstone project. Lewin’s theory encompasses three stages; Unfreezing, Moving or Changing, and Refreezing. Lewin states that change is a process that requires prior learning to be rejected and replaced with new learning/ideas. According to Lewin, the process is referred to as a behavior in which the behavior will have to have a dynamic balance of opposing forces, such is the meaning of change in most areas. Lewin’s theory goes well with action research as its purpose involves social research that involves people in the process of change (Kritsonis, 2004).

Basic concepts are incorporated into Lewin’s theory of change described by Kritsonis (2004). Driving forces are the variables and forces that require change to occur. These forces are considered contributors to change as they push the person or group in the direction of change. Restraining forces are those forces or variables that oppose change; these forces can have a hindering effect on change as they will push the individual or group in the opposite direction of the achievement of the desired change. Throughout this process, the concept of equilibrium can occur. Equilibrium is the state in which the forces of driving and restraining are equal and no change occurs.

According to Lewin (as cited in Kritsonis, 2004), unfreezing is the process involved in making it possible for individuals to let go of old ways of doing things or old logic that is considered counterproductive or dated and no longer efficient. This is a vital step in the process of change. It is necessary to overcome the strains of resistance amongst individuals and groups. Unfreezing can be accomplished by following three methods. The first method that can aid in
unfreezing is increasing the driving forces that can help move away from existing ways to the new approach. The next step is to decrease the restraining forces that can hinder the movement from existing equilibrium. The third method is to combine the concepts together to achieve change. The second stage in Lewin’s change theory (as cited in Kritsonis, 2004) is moving to a new level or changing. Throughout this process, individuals have a change in their thoughts, feelings, behavior, or a combination of all three. These changes are more productive than previous thought ideals. The third stage in Lewin’s change theory is Refreezing. During this stage the new change is established and becomes a habit. The change becomes a new way of doing or thinking. This stage is necessary to keep from returning to the old way of doing things (as cited in Kritsonis, 2004).

Application of Lewin’s Theory to Capstone Project

Lewin’s change theory was applicable to this capstone project; Lewin’s theory pertains to changing old ways of doing things to adopt new way that is more productive; it holds the ability to yield superior results and potentially improve provider knowledge and comfort and ultimately improve extubation criteria in post-op cardiac surgery patients leading to improved extubation times. The use of Lewin’s framework helped guide the study, particularly with follow up of the education intervention to assess whether there was an improvement in knowledge and comfort with ETCO2 monitoring Change can be facilitated utilizing the three states of Lewin’s change theory.

No specific literature could be found utilizing Lewin’s Change theory and ETCO2 monitoring to enhance extubation criteria in post-op coronary artery bypass patients; however; Lewin’s model can still be applied to the topic. Using Lewin’s change theory, the current researchers focus was to refreeze the new way of assessing extubation criteria in post-op cardiac
surgery patients. The overall goal of this capstone project was to show an improvement in knowledge and comfort with ETCO2 monitoring in post-op coronary artery bypass patients to improve knowledge and comfort of ETCO2 monitoring which will ultimately improve extubation times.

The first step was unfreezing; this stage involved getting critical care providers in the CVICU to acknowledge the need for change and forget their existing way of doing things. The most important part of this step was to help providers realize that there is a limitation in current practice and that this new way of thinking and managing these patient and provide better outcomes for their patients. They need to understand and realize their gap in knowledge with monitoring devices in critical care. The second step was the change stage. During this stage, the providers began to adapt to the “new way” of doings things and apply the new change. The attitude and beliefs of the critical care CVICU providers shifted to the direction of the supporting research and begin to treat their post-operative coronary artery bypass patients with the new technology to expedite patient care. The third and final step in the change theory is refreezing. During this step the changes become concrete and the providers utilized the new approach in their everyday management of patients. This process prevents the providers from slipping back into their “old ways” of ventilator and extubation management.

Literature Review

Most of the articles pertaining to using ETCO2 as a monitoring device are related to its use in the OR, however, minimal information on its use to guide early extubation in post-op cardiac surgery patients can be found nor any information pertaining to knowledge deficits of providers with the use of ETCO2. Therefore, in an effort to better support the need for clinical practice change and improve provider knowledge, many databases were accessed to review
literate on the topic. Databases used for identification of literature were CINHAL (Cumulative Index to Nursing & Allied Health Literature), MEDLINE, and EBSCOHost, and PubMed. Key words that were used were; “ETCO2”, “End-Tidal CO2”, ‘Capnography’, “Mechanical Ventilation”, “Intensive Care Unit”, “ICU”, “Early Extubation”, “Extubation Criteria”, and “Cardiac Surgery”.

Current practice in many ICU’s is the use of arterial blood gases (ABG) for weaning the ventilator and determining readiness for extubation (Rousselon et al., 2011). However, this common practice is invasive, expensive, and poor predictor of extubation success compared to other assessment information such as rapid shallow breathing index (RSBI), head lift off pillow greater than 5 seconds, and adequate tidal volumes 6-8ml/kg of ideal body weight (Marino 2014). An article by Pawson and DePriest (2004) looked at the routine of obtaining ABG’s prior to extubation in patients who successfully completed a spontaneous breathing trial. The authors conducted a retrospective chart review of 54 extubations with 52 patients. Of these patients 65% were extubated without performing an ABG after spontaneous breathing trial, and overall successful extubation was seen in 94% of patients regardless of ABG analysis. The patients who were extubated without use of ABG analysis were done so through use of various clinical factors such as RSBI, adequate tidal volume and vital capacity. The authors concluded that ABG analysis did not appear to predict successful extubation. The authors also concluded that further research is required to define criteria of minimally acceptable gas exchange. ABG’s may not be necessary, however, there still needs to be some measure of assessing adequate ventilation. Although this article does not specifically mention ETCO2 monitoring as a means of extubation criteria, this article helps support the need for ETCO2 monitoring as a minimally invasive and
Economically efficacious alternative to ABG’s for the analysis of adequate ventilation in assessing a patient’s readiness for extubation.

There is some speculation about the accuracy and reliability of ETCO2 monitoring in predicting the PaCO2 of patients, and whether this can reliably assess adequate ventilation and prediction for extubation. An article by Gaur, Harde, Gujjar, Deosarkar, and Bhadade (2017) looked at evaluating neurosurgical patients and the use of ETCO2 monitoring, as this population has the one of the highest utilizations outside of the OR. The purpose of their study was to evaluate the correlation between patients’ systemic partial pressure of carbon dioxide (PaCO2) and ETCO2 in the intra-operative and post-operative period on mechanical ventilation. The authors used a prospective observational study over a one-year period. When compared, PaCO2-ETCO2 gradient was 2.7-3.3 mmHg. The authors concluded that ETCO2 correlates with PaCO2 with acceptable accuracy. This study dealt with a population that is well observed with the use of ETCO2, however, the results can easily be applied to the use of ETCO2 monitoring in post-cardiac surgery patients. This article also helps eliminate the debate of whether ETCO2 is an acceptable surrogate of PaCO2 and should be considered a reliable marker for assessing gas exchange in the post-operative period.

Another controversy that has limited the use of ETCO2 monitoring outside of the OR for continued mechanical ventilation or to assess extubation criteria is the degree of accuracy with patients who may have increased ventilation: perfusion (V/Q) mismatch or other alterations in physiologic dead space. An article by McSwain et al. (2010) looked to identify if ETCO2 would reliably predict PaCO2 across all levels of physiologic dead space, if the provider expected a difference to occur. This study looked primarily at the pediatric population; the authors evaluated 56 mechanically ventilated pediatric patients with volumetric capnography. They compared
ABG values and accounted for dead space: tidal volume ratios (VD/VT). The results showed strong correlations between ETCO2 and PaCO2 in all VD/VT ranges (correlation coefficients between PETCO2 and PaCO2 were 0.95). The authors concluded that the gradient between PaCO2 and ETCO2 was predictably increased with increasing VD/VT ratios. This study supports that ETCO2 monitoring is a useful tool to guide weaning and early extubation even in patients with substantial lung disease, as long as providers expect the gradient to be increased. The authors also conclude the absolute benefit in continuous ETCO2 monitoring for assessment of the patient’s ventilator status allowing for optimization of mechanical ventilation and shortened weaning time. This article is relevant to this capstone project to help educate providers who may remain skeptical about reliability and accuracy of using ETCO2 as a measure of extubation criteria in patients with lung disease or alterations in physiologic dead space.

A follow up article from the study done by McSwain et al. (2010) was done by Novais de Oliveira and Moreira (2015). The authors discussed the broad range and utilization of ETCO2 monitoring. A major advantage that was discussed was the ability of capnography over invasive arterial blood gas is the ability to provide continuous CO2 monitoring, and make rapid clinical assessments on the patient’s condition. The authors did validate the degree of V/Q mismatch in patient with lung disease altering the PaCO2-ETCO2 gradient, however, like McSwain et al. (2010) discussed this gradient can be predicted and ETCO2 is an adequate means of trend. The authors concluded capnography is a feasible option of assessing adequate ventilation and should not be restricted to the experimental setting or clinical areas such as the OR. This article directly supports previous studies done confirming the consistency of the use of ETCO2 as a surrogate for PaCO2. This further supports the recommendations of the authors line up well with the
current capstone project in attempts to use ETCO2 in the clinical setting for ventilatory management and guidance for extubation.

Thrush, Mentis, and Downs (1991) looked to determine if monitoring patients peripheral capillary oxygen saturation (SpO2) and ETCO2 could be used to wean patients safely from mechanical ventilation following cardiac surgery. The authors used a prospective study comparing SpO2 and ETCO2 to ABG analysis of ten patients who underwent coronary artery bypass grafting. The results of the study showed a high correlation with SpO2 and SaO2 with 100% sensitivity for hypoxemia. The results for ETCO2 were a good indicator of PaCO2 and had a sensitivity of 95% in predicting hypercarbia. The authors concluded that the use of ETCO2 and SpO2 can be used safely to wean patients after cardiac surgery. This study directly relates to this capstone project that involves use of ETCO2 in post-op cardiac surgery patients to improve extubation times. This study helps validate the implementation of ETCO2 into current practice as an acceptable means of evaluating readiness for extubation.

Rasera, Gewehr, and Domingues (2015) performed a study to evaluate the use of capnography to wean mechanical ventilation and use it as a predictor for successful extubation in pediatric patient’s post-cardiac surgery. The authors looked at ETCO2, PaCO2, and capnography prior to extubation. The authors concluded that the use of ETCO2 helped successfully predict extubation criteria in 71.9% of the patients. They were also able to predict those who would fail extubation within 48hrs. The results showed that the use of ETCO2 monitoring can help differentiate extubation criteria and was predictive in patients who required return to mechanical ventilation prior to extubation and avoidance of a failed extubation. Although this study examined pediatric patients, the patients were post-cardiac surgery patients, and this data can be extrapolated to the use in the adult population to meet extubation criteria. This study directly
supports the need to implement ETCO2 in the adult cardiac surgery population to aid in identifying appropriate extubation criteria and use as surrogate to ABG analysis.

It can be postulated that the lack of ETCO2 monitoring in critical care medicine, especially for the purposes of mechanical ventilation weaning guidance for extubation is related to lack of knowledge, comfort, and experience with ETCO2 monitoring. A mixed-methods analysis was done by Langhan, Kurtz, Schaeffer, Asnes, and Riera (2014) to further explore the reasons that capnography was not being utilized in more areas of medicine. The authors conducted semi-structured interviews with medical staff from the emergency department and intensive care units. The authors interviewed 19 individual providers and discovered several themes when looking for barriers and facilitators to capnography use. The themes that were discovered were: variability in use of capnography among acute care units, availability and accessibility of capnography equipment, the evidence behind capnography use, the impact of capnography on patient care, personal experiences impacting use of capnography, and variable knowledge about capnography (Langhan, Kurtz, Schaeffer, Asnes and Riera, 2014). It was the authors intention that if barriers were identified then the next step would be to try and resolve them with the hopes of improving use of capnography in more clinical areas. This article directly correlates with the purpose of this capstone project. Several of the barriers identified in this study will be resolved in the current research study such as improving knowledge about capnography, identifying personal experiences, presenting current evidence of ETCO2 monitoring, and discussing various clinical areas in which ETCO2 monitoring has been used successfully.

Current practice in many Cardiac ICU’s is the use of routine invasive measurement of PaCO2; this process although a standard, comes at increasing cost and time. A study by Rousselon et al. (2011) wanted to compare PaCO2 with ETCO2 in the post-operative setting for
patients during mechanical ventilation who underwent cardiac surgery. The authors of this study looked at 20 patients and used a prospective, observational design. They measured ABG’s simultaneously to ETCO2 for both intubated patients and extubated patients. They author’s concluded a significantly larger gradient between PaCO2 and ETCO2 in the extubated group compared to the intubated group. This study helps support the accuracy and reliability of using ETCO2 as a surrogate to PaCO2 for intubated patients post cardiac surgery who require weaning and evaluation for extubation.

To conclude, the review of literature consistently showed limited research in the use of ETCO2 monitoring in the intensive care unit, and even less information in regards to adult cardiac surgery patients. However, the information that was discovered all demonstrated that ETCO2 monitoring is an acceptable surrogate for PaCO2. The review of literature also demonstrated a significant gap in knowledge for critical care providers with the use of ETCO2 monitoring to guide extubation criteria. Furthermore, the results of the literature review also demonstrated an overwhelming agreement that it was time that ETCO2 monitoring became part of current guidelines for ventilator management and use in the intensive care unit. All of this information helps support the need to implement the current proposed capstone project to enhance provider knowledge and comfort of ETCO2 monitoring.

Methodology

The capstone project took place at Strong Memorial Hospital. A convenience sample was used to recruit members of the CVICU team. The members of the CVICU team consisted of fifteen providers which included one medical doctor, four physician assistants, and ten nurse practitioners. This capstone project utilized a quasi-experimental pretest-posttest design utilizing a test of knowledge and survey on comfort of use; both of which were created uniquely for the
purposes of this capstone project, based on the researcher’s clinical expertise with ETCO2 monitoring, various anesthesia texts, and the literature review. The validity of both the test of knowledge and survey on comfort of use was tested by having multiple supervisory members at Strong Memorial Hospital review each and provide feedback. Further validation was achieved by several CRNA’s in practice as well as CRNA faculty at UB.

The test of knowledge and comfort took place on Day 0. The test of knowledge pre-test was developed from the readings of Duke & Keech, 2016 (appendix A) to gauge the participant’s knowledge of ETCO2. The survey on comfort of use also took place on Day 0. This survey was created through extrapolation of the barriers identified through the literature review as well as readings from Duke & Keech, 2016 (appendix B); it consisted of a Likert scale, scored from 0-4. The purpose of the survey was to examine the participant’s experiences, comfort level, and current use of ETCO2. The results of each pre-test were examined and scored by the researcher. The researcher then returned 30 days later to give the participants an education intervention (appendix C). At the conclusion of the education intervention, the participants were given their repeat post-test to examine knowledge and a repeat post survey to examine comfort and use of ETCO2. A comparative analysis was done on the participant’s pretest and posttest scores.

Data Analysis

There were two data endpoints that were analyzed for this project; knowledge and comfort with ETCO2 monitoring. The test of knowledge was analyzed using descriptive statistics. Statistical analysis was performed using SPSS v24 to perform a paired T-test of the participant’s pre-test and post-test scores. The survey identifying provider comfort with ETCO2 was measured using a Likert scale; the categories ranged from zero to four; zero being non-applicable and four being always, with a total score of 40. A lower score corresponded to a
lower comfort level and a higher score correlated with a higher comfort level using ETCO2. Results of the survey were also compared using a paired T-test and analyzed using SPSS software v24.

**Results**

The results of the study were overwhelming significant (appendix E); all participants showed significant improvement in both knowledge of ETCO2 as well as their comfort of use. Of the fifteen participants the mean score of the pre-test of knowledge was 52.0%. After the participants received the educational intervention their post-test of knowledge score improved to 92.88%. The participant’s improvement showed an overall increase of 40.88% with a statistical significance of <.004. The analysis of the participants scores shows that this educational intervention will be successful or show significant improvement in knowledge >98.7% of the time. The results of the pre-test survey showed that on average the participants were only 44.83% comfortable with the use of ETCO2. After the education intervention their comfort with use improved to 78.0%. The participant’s improvement showed an overall increase of 33.17%, which correlated with a statistical significance of <.003. The analysis of the participants scores showed that the education intervention will be successful or show significant improvement in comfort of use > 99.1% of the time.

**Discussion**

The objective of this capstone project was met at the conclusion of its implementation. All providers showed improvement in knowledge and comfort ETCO2 monitoring after they received an education intervention. The test of knowledge incorporated all key elements required to have a solid foundation to using ETCO2. These key elements included basic physiology of ventilation, physiological dead space, as well as graphic representation of common ETCO2 tracings that will be encountered. The participants all scored quite low initially, which was
anticipated based on the lack of familiarity with ETCO2, both on this particular unit and in the literature. The improvement in their knowledge provided strong evidence that an education intervention will improve the provider’s knowledge of ETCO2 to allow them to use it properly and effectively. Improvement in knowledge is not always enough to create change, therefore the survey on comfort of use was used to increase the validity and ensure change would develop from this capstone project. The data from the Likert showed significant statistical significance in regards to improvement in comfort of use with ETCO2. All questions from the likert scale were written in the same direction, that is they were written and designed for the participant to answer a lower score for each of the 10 questions should they feel uncomfortable with the use of ETCO2 and a higher score should their comfort improvement post-education intervention. This design allowed for analysis of the data using descriptive statistics and a paired T-test. The scoring of the likert scale allowed for easy interpretation based on a percent of overall comfort. Not only did the providers knowledge increase, their comfort with the use of ETCO2 also increased. This combination will help solidify their change in practice and move towards implementing ETCO2 as a surrogate to help wean mechanical ventilation in fast track cardiac surgery patients.

**Recommendations/Future Research**

This study has shown the ability to improve CVICU provider’s knowledge and comfort with the use of ETCO2 monitoring to help guide extubation criteria in post-operative CABG patients. This study was initially implemented to identify the gap in knowledge and correct that through the use of an education intervention. Future studies should look at extubation times after ETCO2 has been implemented as a standard. This data will help further strengthen its use as a standard of care in weaning mechanical ventilation in fast track cardiac surgery patients. Additionally, this study and education intervention should be implemented in all intensive care
units and be given to their providers to help improve their knowledge and comfort of use to enhance the use of ETCO2. This will help increase its use in all areas of critical care medicine. A cost analysis can also be added to this research to help justify the use of ETCO2 monitoring to replace or decrease arterial blood gas analysis. The research is lacking tremendously with this non-invasive tool and there are countless avenues in which future research can be conducted.

**Strength and Limitations**

The limitations of the study begin the use of a small sample size. Although fifteen participants were enough to use a paired T-test, a larger sample would have provided more data and perhaps allowed for a greater generalizability of the results. Another limitation was that all participants were recruited from a single intensive care unit with a very specific population of focus. This may not have a significant impact since most intensive care units are not using ETCO2, however, this is left for speculation as other intensive care units and their providers were not included.

The strengths of this study lie in its purpose; it addresses both a clinical need and a gap in the literature. The design and methods of the project are evidence-based. The results were overwhelming positive showing tremendous improvement in provider knowledge as well as comfort. This education intervention can easily be used to provide education to other ICU providers and its improved use can readily assimilate into other ICU’s and potentially become a standard of care.

**Ethical Issues**

Since the study’s data collection took place at the researcher’s place of employment and part of the researcher’s team; there are no ethical issues associated with the data collection. All participants were fully informed about the study and all participants signed their consents to take
place in the study. This study sought simply to gain consent, evaluate provider’s current knowledge and comfort with ETCO2 monitoring, provide an education intervention and re-evaluate their knowledge and comfort. The ethical issues that surround the study are maintaining anonymity and access to information. In regards to maintaining anonymity all participants were evaluated individually and all identifying information was coded to protect their identity. In regards to access of information, all pieces of data were stored in a secured folder inside a locked drawer in the researcher’s office.
References


doi:10.1016/j.annfar.2010.11.008

Appendix A
Knowledge Test on ETCO2 monitoring

1. Monitoring ETCO2 with capnography is useful in detecting which of the following (Select all that apply)?
   a. Ventilation
   b. Cardiac Output
   c. Ventilator Function
   d. All the above

2. What is the approximate difference in mmHg between ETCO2 to PaCO2, and which is higher?
   a. PaCO2 > ETCO2; 15mmHg
   b. ETCO2>PaCO2; 5 mmHg
   c. PaCO2>ETCO2; 5 mmHg
   d. ETCO2>PaCO2; 15 mmHg

3. What affect does an increase in dead space have on gradient between ETCO2 and PaCO2?
   a. Increases; PaCO2>ETCO2
   b. Increases; ETCO2>PaCO2
   c. Decreases; PaCO2>ETCO2
   d. Decreases; ETCO2>PaCO2

4. What process might lead to a decrease in ETCO2?
   a. Pulmonary Embolism
   b. Hypertension
   c. Increased Cardiac Output
   d. Hypoventilation

5. What process may increase ETCO2?
   a. Decreased Cardiac Output
   b. Hyper metabolic events
   c. Hyperventilation
   d. Increased physiologic dead space

6. What equation can be used to help calculate physiologic dead space in a patient in which ETCO2 monitoring is being implemented
   a. Bohr
   b. Haldane
   c. Bernoulli
   d. Hagen Poiseuille
Use the capnography waveform below to answer questions 6-9.

7. At which point do you measure ETCO2?
   a. A-B
   b. B-C
   c. C-D
   d. D-E

8. Inspiration occurs between what two points?
   a. A-B
   b. B-C
   c. C-D
   d. D-E

9. Which points accurately depict where there is a mixing of dead space sampling and alveolar sampling?
   a. A-B
   b. B-C
   c. C-D
   d. D-E

10. Which points accurately depict where gas sampled is strictly dead space?
    a. A-B
    b. B-C
    c. C-D
    d. D-E

11. Based on the diagram below, what may be happening with the patient?
    a. Patient is beginning to breathing on their own
    b. The gas sampling port is filled with excess moisture
    c. The gas sampling port is partially discontented
    d. The patient is showing early signs of hypoventilation
12. The diagram below is representative of what patient condition

![Diagram]

a. Bronchoconstriction  
b. Hyperventilation  
c. Hypoventilation  
d. Increasing Cardiac Output

13. The diagram below is best representative of which of the following conditions?

![Diagram]

a. Hyperventilation  
b. Increased Cardiac Output  
c. Hypoventilation  
d. Hyperthermia

14. The diagram below is best representative of which of the following conditions?

![Diagram]

a. Hyperventilation  
b. Decreased Cardiac output  
c. Hypothermia  
d. Hypoventilation
15. The diagram below is best representative of which of the following conditions?

![CO2 WAVEFORM]

a. Cardiac Arrest  
b. Hypoventilation  
c. Right Mainstem Intubation  
d. High Peak Airway Pressures
Appendix B

Survey for Comfort and Use

<table>
<thead>
<tr>
<th>Questions</th>
<th>N/A (0)</th>
<th>Never (1)</th>
<th>rarely (2)</th>
<th>Often (3)</th>
<th>Always (4)</th>
</tr>
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<tbody>
<tr>
<td>1. How regularly do you use ETCO2 monitoring in the ICU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. I feel I can regularly use ETCO2 monitoring to make clinical decisions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. I feel comfortable with the use of ETCO2 monitoring in the ICU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. I feel comfortable reading Capnography</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. I feel comfortable interpreting ETCO2 to make clinical decisions</td>
<td></td>
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<td></td>
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<tr>
<td>6. I feel comfortable managing patients on the ventilator using ETCO2 monitoring</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>7. I feel comfortable ordering ETCO2 monitoring</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. I feel comfortable with variations in ETCO2 with various co-morbidities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. I feel comfortable using ETCO2 instead of ABG analysis to guide extubation criteria</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. I feel ETCO2 can be used as a surrogate to guide extubation criteria in my practice</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Definition of Terms

- Capnometry Vs. Capnography
  
  - Capnometry: Numeric measurement and display of the level of CO2
  
  - Capnography: Expired CO2 level is graphically displayed as a function of time and concentration
    - Capnography is more useful since the graphic representation provides more information about various physiological changes that could be taking place.
Methods of Gas Sampling

- Side stream devices aspirate gas: Usually 50-250ml/min at the Y-piece of the circuit.
- Gas is transported via small bore tubing to gas analyzer
- Nasal Cannulas can also be used to sample Gas
  - Limitations: room air entrainment and dilution
  - Therefore Y-piece provides better qualitative and quantitative measurement than nasal cannula; something to consider if using in extubated patients for continued follow up.
- Further Issues with gas sampling:
  - Delay until results are displayed and possible clogging of tubing with condensed water vapor or mucus (This is issue RT has with its use)

Importance of Measuring CO2

- IN OR:
  - Reducing anesthesia related mortality and morbidity
  - Other than bronchoscopy, ETCO2 is best method of verifying ETT placement
- OR and ICU
  - Can verify ETT placement
  - More importantly provides information about important physiologic factors such as:
    - Ventilation
    - Cardiac Output
    - Metabolic Activity
    - Ventilator Function
  - Predict outcome of resuscitation; ETCO2 <10mmHg after 20 minutes of ACLS=100% mortality

Capnographic Waveform

- Four Distinct Phases
- A-B:
  - Initial stage of exhalation; dead space gas, free of CO2
- B-C
  - Mixing of alveolar gas with dead space gas; CO2 level abruptly rises
- C-D
  - Alveolar plateau; gas sampled is essentially alveolar
- D-E
  - Point D is maximal CO2 level; known as ETCO2
  - Fresh gas entrained on inspiration and waveform returns to 0
Elevation of Baseline of Capnogram

- High respiratory rates
- If elevated above 2mmHg; the patient is receiving CO2 during inspiration (Rebreathing)
  - Causes of rebreathing:
    - Exhausted CO2 absorber (OR problem)
    - Channeling of gas within CO2 absorber (OR Problem)
    - Incompetent unidirectional inspiratory or expiratory valve in circle systems
    - Accidental CO2 administration
    - Bicarbonate Administration
    - Tourniquet release
    - Inadequate fresh gas flow
    - Sepsis and other hypermetabolic event (Fever, MH)

Correlation of ETCO2 with PaCO2

- CO2 is easily diffusible (20x more than oxygen; O2 coefficient .0031, CO2 coefficient .067)
  - ETCO2 should provide an estimate of alveolar CO2 partial pressures and arterial CO2 partial pressures
  - Alveolar CO2 pressure and PaCO2 normally differ by about 5 mmHg (2-10mmHg). Difference caused by alveolar dead space (ventilation without perfusion) "PaCO2 = ETCO2 by about 5mmHg"
  - Increased dead space ventilation will result in decreasing correlation in ETCO2 and PaCO2; with ETCO2 being lower.
  - If increased dead space suspected: compare ETCO2 and PaCO2 with ABG analysis
  - Shunt has minimal effect on arterial-alveolar CO2 gradients

CO2 and Esophageal Intubation

- Carbonated beverages or medications (Alka-Seltzer) return CO2 after esophageal intubation
- Normal waveform and levels would not be expected and CO2 would exhaust quickly
- Some CO2 can be present if mask ventilation is suboptimal
  - Bottom Line:
    - Always check ETCO2 after intubation
    - Immediately assess for bilateral lung sounds and visible chest rise
    - Misting in tube alone can be misleading
Sudden Loss of Capnographic Waveform

- Esophageal Intubation
- Ventilator disconnection or malfunction
- Capnographic disconnection or malfunction
- Obstructed ETT
- Catastrophic physiologic disturbances such as cardiac arrest or PE

Decreasing ETCO2

- Rapid Decrease:
  - Hypotension
  - Hypovolemia
  - Decreased CO
  - Lesser degree of PE
  - Dislodgement of a correctly placed ETT
- Less Dramatic Decrease
  - Hypoventilation
  - Hypothermia
  - Increasing Dead Space
  - Decreased metabolic activity
  - Partial Airway obstruction
  - Incomplete exhaled gas sampling
  - Airway leaks
  - Partial circuit disconnect

Increasing ETCO2

- Hypoventilation
- Increased Body Temperature
- Increased Metabolic acidity (Fever, sepsis, MH)
- Partial airway obstruction
- Bronchial Intubation
- Rebreathing
- Faulty ventilator
- Intravenous bicarb administration, release of tourniquet or vascular cross clamps
Change in Usual Configuration

- Asthma and COPD can cause a delayed upslope and steep alveolar plateau
- This type of upsloping would be seen with dynamic compliance changes without a change in static, implying airway resistance problem
  - Can check plateau vs peak airway pressures
  - Dynamic Compliance:
    - $V_t (P_{IP} - P_{PEEP})$
  - Static Compliance:
    - $V_t (Plat - P_{PEEP})$
  - The normal gradient is approximately 10 cm H2O.
  - Normal Compliance: 60 to 100 ml/cm H2O per second.

Change in Usual Configuration

- Patient beginning to make spontaneous respiratory efforts and inhales before next mechanical inspiration
- Characteristic Cleft in the alveolar plateau is useful clinical sign

Key Points

- Short of visualizing with bronchoscopy, CO2 detection is the best method of verifying ETT location
- In the absence of V/Q abnormalities, ETCO2 roughly approximates PaCO2
- Analysis of the capnographic waveform provides supportive evidence for numerous clinical conditions, including decreasing cardiac output; altered metabolic activity; acute and chronic pulmonary disease; and ventilator, circuit, and ETT malfunction
- Can be used as a surrogate to PaCO2 for fast track CT surgery patients to quickly wean the ventilator and improve extubation criteria
- Ultimate Goal= Decrease time to extubation
References

Appendix D

University at Buffalo Institutional Review Board (UBIRB)
Office of Research Compliance | Clinical and Translational Research Center Room 5018
875 Ellicott St. | Buffalo, NY 14203
UB Federalwide Assurance ID#: FWA00008824

Adult Consent to Participate in a Research Study

**Title of research study:** Evaluation of an Education Intervention on ETCO2 monitoring to Enhance Provider Knowledge and Understanding of ETCO2 Monitoring to Guide Extubation Criteria and Ultimately Improve Extubation Times in Post-Operative Coronary Artery Bypass Patients

**Version Date:** 9/5/18

**Investigator:** Christopher Bona

**Why am I being invited to take part in a research study?**
You are being invited to take part in a research study because you are providers who work with post-operative cardiac surgery patients.

**What should I know about a research study?**
- Someone will explain this research study to you.
- Whether or not you take part is up to you.
- You can choose not to take part.
- You can agree to take part and later change your mind.
- Your decision will not be held against you.
- You can ask all the questions you want before you decide.

**Who can I talk to?**
If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team at cpbona@buffalo.edu or ksfau@buffalo.edu. You may also contact the research participant advocate at 716-888-4845 or researchadvocate@buffalo.edu.

This research has been reviewed and approved by an Institutional Review Board (“IRB”). You may talk to them at (716) 888-4888 or email ub-irb@buffalo.edu if:
- You have questions about your rights as a participant in this research
- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
• You want to get information or provide input about this research.

**Why is this research being done?**
• To create an education intervention to improve cardiovascular intensive care provider’s knowledge and comfort with use of end tidal carbon dioxide monitoring to guide extubation criteria in post-op coronary artery bypass patients.

**How long will the research last?**
• We expect that you will be in this research study for 3 months

**How many people will be studied?**
• 15

**What happens if I say yes, I want to be in this research?**
• If you agree to participate in this study, the researcher will be giving you a test of knowledge and a survey on comfort of use of end tidal carbon dioxide monitoring. The test of knowledge consists of fifteen questions; all multiple choice. The survey of comfort of use will contain 10 questions that will be graded on a Likert scale. Each participant will take both; the data will then be analyzed to create an education intervention. The researcher will return to give the education intervention, which will take approximately twenty minutes. At the conclusion of the intervention all participants will retake the test of knowledge and comfort of use survey for comparative analysis.

**What are my responsibilities if I take part in this research?**
• Your responsibilities will be to take both the pretest and posttest of knowledge and survey of comfort of use. You will also be a part of the education intervention given by the researcher in the form of a power point lecture

**What happens if I do not want to be in this research?**
• Your participation in this research study is voluntary. You may choose not to enroll in this study.
• There are no alternatives to participating in this study; if you choose to not be a part of the study, you will have nothing to do with it moving forward.

**What happens if I say yes, but I change my mind later?**
• You can leave the research at any time it will not be held against you.

• There are no adverse consequences to withdrawing from the research study
• Data that has been collected to the point of withdrawal will be destroyed and removed from the study results. Your reasons for withdrawal do not need to be explained

**Is there any way being in this study could be bad for me?**
• There are no known risks associated with this study
**Will being in this study help me in any way?**

- Being a provider in critical care requires constant learning through evidence based practices. Being a part of this study will help enhance your current knowledge base and help you improve your management of patients recovering post-operatively from cardiac surgery who require liberation from the ventilator.

**What happens to the information collected for the research?**

Efforts will be made to limit the use and disclosure of your personal information, including research study and medical or education records, to people who have a need to review this information. We cannot promise complete secrecy. Organizations that may inspect and copy your information include the IRB and other representatives of this organization.

**Can I be removed from the research without my OK?**

- No, you will not be removed without your direct consent to do so.

---

**Signature Block for Capable Adult**

Your signature documents your permission to take part in this research. By signing this form you are not waiving any of your legal rights, including the right to seek compensation for injury related to negligence or misconduct of those involved in the research.

_________________________________________  ______________________________
Signature of subject  Date

_________________________________________
Printed name of subject

_________________________________________  ______________________________
Signature of person obtaining consent  Date

_________________________________________
Printed name of person obtaining consent
# Appendix E

## Table 1. Mean Scores

<table>
<thead>
<tr>
<th>Code</th>
<th>Pre-Test Of Knowledge</th>
<th>Post-Test of Knowledge</th>
<th>Pre-Test Survey</th>
<th>Post-Test Survey</th>
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<td>6/15: 40%</td>
<td>14/15: 93.3%</td>
<td>16/40: 40%</td>
<td>32/40: 80%</td>
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<tr>
<td>2</td>
<td>7/15: 46.6%</td>
<td>15/15: 100%</td>
<td>13/40: 32.5%</td>
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<td>3</td>
<td>9/15: 60%</td>
<td>15/15: 100%</td>
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<td>33/40: 82.5%</td>
</tr>
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<tr>
<td>5</td>
<td>9/15: 60%</td>
<td>15/15: 100%</td>
<td>11/40: 27.5%</td>
<td>35/40: 87.5%</td>
</tr>
<tr>
<td>6</td>
<td>9/15: 60%</td>
<td>14/15: 93.3%</td>
<td>22/40: 55%</td>
<td>29/40: 72.5%</td>
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<td>37/40: 92.5%</td>
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<td>14/15: 93.3%</td>
<td>14/40: 35%</td>
<td>33/40: 82.5%</td>
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<tr>
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<td>6/15: 40%</td>
<td>12/15: 80%</td>
<td>11/40: 27.5%</td>
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<td>12/15: 80%</td>
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<td>28/40: 70%</td>
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<td>20/40: 50%</td>
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<td>19/40: 47.5%</td>
<td>32/40: 80%</td>
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<tr>
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<td>14/15: 93.3%</td>
<td>16/40: 40%</td>
<td>33/40: 82.5%</td>
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<td>15/15: 100%</td>
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Table 2. Paired Samples Statistics

<table>
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<tr>
<th>Pair</th>
<th>Test Description</th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
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<tr>
<td>Pair 1</td>
<td>Pre-Test of Knowledge</td>
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<td>15.57%</td>
<td>4.02%</td>
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<td>Pair 1</td>
<td>Post-Test of Knowledge</td>
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<td>2.00%</td>
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<td>Pair 2</td>
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<td>Pair 2</td>
<td>Post-Test Survey</td>
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Table 3. Paired Samples Correlations

<table>
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<th>Pair</th>
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<th>N</th>
<th>Correlation</th>
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<td>Pair 1</td>
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<td>Pair 2</td>
<td>Pre-Test Survey &amp; Post-Test Survey</td>
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<td>.991</td>
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IRB Approval Form

September 7, 2018

Dear CHRISTOPHER BONA:

On 9/7/2018, the IRB reviewed the following submission:

<table>
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<th>Initial Study</th>
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<td>Title of Study:</td>
<td>Evaluation of an Education Intervention on ETCO2</td>
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<td>monitoring to Enhance Provider Knowledge and</td>
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<td>Criteria and Ultimately Improve Extubation Times in Post-</td>
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<td>Operative Coronary Artery Bypass Patients</td>
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<td>Investigator:</td>
<td>CHRISTOPHER BONA</td>
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<td>Documents Reviewed:</td>
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<td>Protocol;</td>
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<td>Protocol</td>
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The IRB approved the study from 9/7/2018 to 9/6/2019 inclusive. The Initial study materials for the project referenced above were reviewed and approved by the SUNY University at Buffalo IRB (UBIRB) by Non-Committee Review. The IRB has determined that the study is no greater than minimal risk. Before 9/6/2019 or within 30 days of study closure, whichever is earlier, you are to submit a continuing review application with required explanations. In order to avoid a lapse in IRB approval, it is recommended that you submit your continuing review at least 30 days for an expedited study and at least 45-60 days for a full board study, prior to the approval end date of the study. You can submit a continuing review application by navigating to the active study in Click IRB and selecting ‘Create Modification / CR’. Studies cannot be conducted beyond the expiration date without re-approval by the UBIRB.

In conducting this study, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system.

UBIRB approval is given with the understanding that the most recently approved procedures will be followed and the most recently approved consent documents will be used. If modifications are needed, those changes may not be initiated until such modifications have been submitted to the UBIRB for review and have been granted approval.

As principal investigator for this study involving human participants, you have responsibilities to the SUNY University at Buffalo IRB (UBIRB) as follows:
1. Ensuring that no subjects are enrolled prior to the IRB approval date.

2. Ensuring that the study is not conducted beyond the expiration date without re-approval by the UBIRB.

3. Ensuring that the UBIRB is notified of:
   - All reportable information in accordance with the New Information SOP (HRP-024).
   - Project closure/completion by submitting a Continuing Review/Modification submission.

4. Ensuring that the protocol is followed as approved by UBIRB unless a protocol amendment is prospectively approved.

5. Ensuring that changes in research procedures, recruitment or consent processes are not initiated without prior UBIRB review and approval, except where necessary to eliminate apparent immediate hazards to subjects.

6. Ensuring that the study is conducted in compliance with all UBIRB decisions, conditions, and requirements.

7. Bearing responsibility for all actions of the staff and sub-investigators with regard to the protocol.

8. Bearing responsibility for securing any other required approvals before research begins.

If you have any questions, please contact the UBIRB at 716-888-4888 or ub-irb@buffalo.edu. Please include the project title and number in all correspondence with the UBIRB.
EDUCATION INTERVENTION ON ETCO2 MONITORING
Christopher Bona, MS, RN, NP-C, CCRN, CSC, CMC, SRNA

Introduction
- ETCO2 provides information about physiologic factors including ventilation, cardiac output, metabolic activity, and proper ventilator function
- Used mainly in CRP, but limited use and research in critical care. Mainly used in codes and neuro-surgical ICU
- Currently, there is a gap in knowledge and literature on ETCO2 and its application in CVICU’s and post-op CABG patients for ventilator management

Research Question:
- Will provider education on ETCO2 monitoring enhance provider understanding and application of ETCO2 monitoring to guide extubation criteria and ultimately improve extubation times in post-op coronary artery bypass patients

Objectives:
- Show an improvement in provider knowledge
- Show an improvement in provider comfort with ETCO2 monitoring

Methods
- Project took place at Strong Memorial Hospital
- 15 providers from the CVICU team took part in this project
- Utilized a quasi-experimental pretest-posttest design
- Participants received initial test and survey on Day 0
- An education intervention was given on Day 30, with a repeat of both the test of knowledge and survey

Data Analysis
- Two data endpoints were analyzed
  - Provider knowledge
  - Provider comfort with ETCO2 monitoring
- Test of knowledge and survey were both analyzed using SPSS v23 to perform a paired t-test of the participants pre-test and post-test scores
- Survey consisted of a Likert scale: Scored 0-4. There were ten questions for a total score of 40.
  - The higher the score the greater the participants comfort
  - The lower the score the lower the participants comfort
- The test of knowledge consisted of 15 questions. Correct consisted of:
  - Basic physiology of ventilation
  - Physiological dead space
  - Graphic representation of common ETCO2 tracings

Results
- Table 1: Comparative Analysis
- Table 2: Paired Samples Statistics
- Table 3: Paired Samples Correlation

Conclusion
- All providers showed a significant improvement in knowledge and comfort with ETCO2 monitoring post education intervention
- The improvement in all the participants scores provides strong evidence that an education intervention will greatly increase knowledge and comfort with ETCO2 monitoring
- This increase in knowledge and comfort will aid in increasing its use to reduce mechanical ventilation in post-op CABG patients

Future Research
- Future research should look at extubation times following long term implementation of ETCO2 monitoring in the CVICU at SBH
- Follow up on retained knowledge and comfort with ETCO2 monitoring with the same provider group
- ETCO2 education intervention can be given to other ICU providers to enhance its use throughout all intensive care units

References
Available upon request