IMPROVING THE EFFECTIVE USE OF END-TIDAL CARBON DIOXIDE MONITORING POSTOPERATIVELY THROUGH NURSING EDUCATION

by

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As members of the DNP Project Committee, we certify that we have read the DNP project prepared by Rachel Elizabeth Ramirez, titled Improving the Effective Use of End-Tidal Carbon Dioxide Monitoring Postoperatively Through Nursing Education and recommend that it be accepted as fulfilling the DNP project requirement for the Degree of Doctor of Nursing Practice.

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Final approval and acceptance of this DNP project is contingent upon the candidate's submission of the final copies of the DNP project to the Graduate College.

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DEDICATION

This project is dedicated to my incredible family, without whom I would never have been able to complete this project or doctoral degree.

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ABSTRACT

Background: Postoperative patients in the Post Anesthesia Care Unit (PACU) are recovering from procedures where they may receive anesthesia, sedatives, and analgesics that place them at a high risk for respiratory depression and associated complications including ICU admissions, brain damage, and even death. To prevent these complications, postoperative patients are closely monitored but there are limitations in current monitoring techniques' ability to detect respiratory depression. Capnography, or End Tidal Carbon Dioxide ($ETCO_2$) monitoring is the measurement of the partial pressure of Carbon Dioxide (CO_2) at the end of an exhaled breath. $ETCO_2$ monitoring is a continuous way to accurately measure respiratory rate and CO_2 levels to provide safe monitoring of ventilatory status in extubated postoperative patients.

Objective: The purpose of this project was to provide evidenced-based education to the PACU nursing staff at Northwest Medical Center on $ETCO_2$ monitoring in order to increase nursing knowledge, confidence, and ability to utilize $ETCO_2$ monitoring effectively in the postoperative setting.

Design: This was a quality improvement project that utilized a pre-test/post-test design to measure the benefit of an evidenced-based education program for PACU nursing staff on $ETCO_2$ monitoring.

Setting: This project was implemented in the PACU at Northwest Medical Center in Tucson, AZ.

Participants: The participants of this project were Registered Nurses (RN) who work in PACU either full time or part time, with a total of 20 nurses that fit this criterion.

Measurements: Data collection for this project was done through pre-test and post-tests, both with the same 20 questions, 15 of which were multiple choice questions based on content and 5 of

which were a Likert scale evaluating nursing confidence and likelihood of changing future practice. A paired T-test was used on content questions and Wilcoxon Signed Rank Test on Likert scale questions to determine statistical significance of the difference scores before and after receiving education about End Tidal CO_2 monitoring.

Results: Eighteen RNs attended the educational presentation and completed pre-and post-tests. The mean score and standard deviation on the pre-education tests was 6.67 ± 2.4 while post-test mean score was 14.28 ± 0.75, with a paired t test showing significant improvement between scores ($p < 0.0001$). The Likert scale questions evaluating nursing confidence and likelihood to initiate $ETCO_2$ monitoring in the next month all showed a significant improvement in scores ($p<0.05$, Wilcoxon Signed Rank Test).

Conclusion: In this quality improvement project, we demonstrate that an $ETCO_2$ education session provided to nurses improved knowledge and intention to implement knowledge in the PACU at Northwest Medical Center (Tucson, AZ). This project met its goal of providing evidenced-based education on $ETCO_2$ monitoring in order to increase nursing knowledge, confidence, and ability to utilize $ETCO_2$ monitoring effectively.

INTRODUCTION

Background Knowledge

Postoperative patients in the Post Anesthesia Care Unit (PACU) are recovering from surgeries or procedures where they receive various amounts of anesthesia, sedatives, and analgesics. Opioid analgesics are frequently given to postoperative patients in this setting for pain control but opioids have a significant risk of causing respiratory depression, especially when combined with general anesthesia (Joint Commission, 2012). Respiratory depression is defined as respirations that have a rate below 10 breaths per minute or respirations that fail to provide full ventilation and perfusion of the lungs (Gupta et al., 2018). Respiratory depression can lead to numerous complications including respiratory failure, reintubation, carbon dioxide (CO_2) narcosis, intensive care unit (ICU) admissions, brain damage and even death (Lee et al., 2015; Latham, Bird, & Burke, 2016).

To prevent these complications, postoperative patients in the PACU have vital signs monitored closely including heart rate with continuous electrocardiogram (ECG), continuous pulse oximetry, blood pressure, and respiratory rate. However, there are limitations to this monitoring. Respiratory rate is monitored through electrical impedance that uses ECG monitoring leads on the chest to detect movement, but chest wall movement still occurs with airway obstruction and hypoventilation (Latham, Bird, & Burke, 2016). Body habitus, blankets, lead placement and patient position or motion could all affect respiratory rate detection and accuracy as well. This means that respiratory depression or even apnea could occur without traditional respiratory rate monitoring detecting it. Additionally, while transcutaneous pulse oximetry indirectly detects oxygen levels in the blood and is a routine and reliable measure of oxygenation, decreased oxygen saturation is a late sign of hypoventilation, especially in the presence of supplemental oxygen, and is not a measure of ventilation (Huttman et al., 2014; Lam et al., 2017).

The measurement of expired carbon dioxide (CO_2) is called capnometry (Siobal, 2016). End tidal CO_2 ($ETCO_2$) is the partial pressure of CO_2 at the end of an exhaled breath and is measured noninvasively through a nasal cannula or specialized sensor (Huttman et al., 2014). A waveform image of each exhaled breath representing its CO_2 concentration is produced on the monitor along with the numeric values detected, that is called capnography (Huttman et al., 2014). $ETCO_2$ monitoring, or capnography, is a continuous and noninvasive way to accurately measure respiratory rate and CO_2 levels to provide safe monitoring of ventilatory status in extubated postoperative patients (Huttman et al., 2014; Siobal, 2016). Normal $ETCO_2$ values range from 35-45 mmHg (DiCorpo et al., 2015). Values <35 mmHg are generally considered diagnostic of hyperventilation or hypocarbia whereas values >45 mmHg indicate hypoventilation or hypercarbia (DiCorpo et al., 2015). The waveform tracing for capnography also provides useful information on patterns of breathing including not only hypoventilation and apnea, but also bronchospasms seen in patients with asthma or COPD (Huttman et al., 2014; DiCorpo et al., 2015). Multiple studies have demonstrated that $ETCO_2$ monitoring is superior to pulse oximetry and respiratory rate monitoring in detecting respiratory depression (Kopka et al., 2007; Lam et al., 2017; Latham, Bird, & Burke, 2016). Combined data from multiple capnography studies showed that continuous $ETCO_2$ compared to continuous pulse oximetry identified 8.6% more respiratory depression events and the odds of recognizing respiratory depression was 5.8 times higher in the capnography groups (Lam et al., 2017). $ETCO_2$ monitoring is standard practice in most hospitals for intubated patients in the operating room and ICU settings in order to monitor ventilation status, but it is more recently been recognized as a beneficial monitoring technique in non-intubated patients in order to improve patient safety and detect respiratory depression (Kodali, 2014; Restrepo et al., 2014).

Significance

The Anesthesia Patient Safety Foundation, The Joint Commission, The Institute for Safe Medication Practices, The American Society for Pain Management Nursing, and the American Society of Perianesthesia Nursing have all recommended the use of capnography to some extent for postoperative patients receiving opioids (Jarzyna et al., 2011; ASPAN, 2014; Joint Commission, 2012; Weinger, 2008). The Anesthesia Patient Safety Foundation (APSF) recommends that health care providers have “zero tolerance” for opioid induced respiratory depression (OIRD) in the postoperative period because “these events should be completely preventable” with proper monitoring including continuous capnography (Weinger, 2008, p. 66). The American Society for Pain Management Nursing (ASPMN) and the American Society of Perianesthesia Nursing (ASPAN) have both issued recommendations that include evaluating patients at high risk for respiratory depression and utilizing capnography for these high-risk patients in the PACU to improve safety (Jarzyna et al., 2011; ASPAN, 2014). The Joint Commission’s 2012 sentinel alert on safely using opioids does recommend identifying patients at high risk for OIRD, but they recommend using capnography to better detect OIRD in all patients receiving opioids. Closer monitoring should be utilized for patients who have received general anesthesia in addition to opioids, such as the majority of patients in the PACU (Joint Commission, 2012). The Joint Commission warns providers “not to rely on pulse oximetry alone because pulse oximetry can suggest adequate oxygen saturation in patients who are actively experiencing respiratory depression, especially when supplemental oxygen is being used – thus the value of using capnography to monitor ventilation" (Joint Commission, 2012, p. 3).

In the Joint Commission's database from 2004-2011, they found that in opioid related adverse events 29% were related to improper monitoring. In a review of the Anesthesia Closed Claims Project database of 357 claims, it was found that 92 of these claims were possible, probable, or definite postoperative respiratory depression incidents of which 77% resulted in severe brain damage or death and 97% were judged as preventable with better monitoring and response (Lee et al., 2015). The 8th Annual Health Grades Patient Safety in American Hospitals Study reported 79,670 potentially preventable deaths over a 3-year period in the United States and stated that one in ten monitored events was related to OIRD (Restrepo et al., 2014). The average healthcare cost per OIRD event was $53,500 (Restrepo et al., 2014). Thus, potentially costing the American healthcare industry over 400 million dollars during this time period.

While $ETCO_2$ monitoring may not be necessary for all patients undergoing surgery, certain populations including those with Obstructive Sleep Apnea (OSA), Chronic Obstructive Pulmonary Disease (COPD), and those on narcotic patient-controlled analgesics (PCAs) among others are at a significantly higher risk for postoperative respiratory depression and resultant CO_2 retention (Joint Commission, 2012; Gupta et al., 2018; Jarzyna et al., 2011; ASPAN, 2014). All healthcare providers, including physicians, nurses, or nurse practitioners who care for these patients in the perioperative period have the ability to initiate $ETCO_2$ monitoring when they identify which patients are known to be at a higher risk. Report among care providers is given multiple times throughout the perioperative process where past medical history and medications given are communicated and high-risk patients could be identified as such. Since hospitals and providers have been found liable for incidents of respiratory depression where better monitoring could have prevented serious adverse events, the use of capnography monitoring, which is supported by evidence-based research and expert opinion, can benefit not only patients but providers as well.

Local Problem and Setting

The site of this project is the Post Anesthesia Care Unit (PACU) at Northwest Medical Center (NMC) in Tucson, Arizona. This PACU recovers both inpatient and outpatient surgeries ranging from noninvasive procedures such as lithotripsies to ICU patients undergoing craniotomies, thoracotomies, and abdominal surgeries among others. The PACU has 24 beds, 2 of which are isolation rooms and not routinely utilized. The Registered Nurse (RN) staffing ratio is typically 2 patients:1 nurse for routine postoperative patients, 1 patient:1 nurse for ICU patients and pediatrics, and 3 patients:1 nurse or 4 patients:1 nurse for Phase II patients. Phase II patients are lower acuity patients that have generally recovered from anesthesia, with stable airways and vital signs, who are just waiting for discharge or an inpatient bed. The unit has between 0-20 pediatric patients per month and all PACU nurses must be Pediatric Advanced Life Support Certified (PALS). The vast majority of patients are adults 20 years or older and all RNs also have Advanced Cardiac Life Support (ACLS) certification. The PACU receives patients predominantly directly from the Operating Room (OR), but also recovers patients that receive general anesthesia from other hospital departments such as the Cardiac Catheterization Lab, Endoscopy, and Interventional Radiology.

Currently in the PACU, patients recovering from all types of anesthesia are monitored with a three-lead continuous ECG that also measures respiratory rate, continuous pulse oximetry, and blood pressure readings every 15 minutes. The cardiac monitors in every patient bay that are utilized for this routine monitoring are currently equipped with modules for monitoring $ETCO_2$. These modules have the adaptor for an $ETCO_2$ monitoring line and the necessary capnography nasal cannulas and monitoring lines are routinely stocked and available in the supply room in the PACU. However, $ETCO_2$ monitoring is almost never utilized by nursing staff. From informal interviews, most of the nurses on the unit stated they have never used $ETCO_2$ monitoring, don't know how to use it, and have only ever seen in used by the RN unit manager. It is unclear the exact number of respiratory depression incidents that have occurred in this unit since this data has not been tracked. Although there is no clear data for this unit, there have been two incidents in the 3 months preceding the initiation of this project that involved respiratory failure in postoperative patients in the PACU. One incident involved an older female with COPD who had altered mental status followed by respiratory distress, was placed on BIPAP, found to have significantly elevated CO_2 levels on arterial blood gas (ABG), and was admitted to ICU even though she was originally scheduled to be an outpatient. The second incident involved a middle-aged patient receiving IV opioids and experiencing respiratory failure who required intubation and ICU admission. It is impossible to say if $ETCO_2$ monitoring would have prevented either incident but it would have at least given nurses and providers earlier notice of elevated $ETCO_2$ and respiratory depression not detected by pulse oximetry alone. Regardless of past incidents of respiratory depression, current nursing practice at this site is not in compliance with current recommendations for best practice regarding monitoring high risk patients to prevent future cases of respiratory depression.

Purpose

The purpose of this quality improvement project is to provide evidenced-based education to the PACU nursing staff at Northwest Medical Center on $ETCO_2$ monitoring in order to increase nursing knowledge, confidence, and ability to utilize $ETCO_2$ monitoring effectively in the postoperative setting. The intervention is an evidenced based educational session developed to cover the importance of and essentials for utilizing $ETCO_2$ monitoring effectively for high risk postoperative patients. The objective is to increase PACU nurses' knowledge of $ETCO_2$ monitoring by 50% from the pre-test to the post-test after the education session. Content of the education will cover the rationale for $ETCO_2$ monitoring, essential aspects of $ETCO_2$ monitoring including waveform interpretation, identification of high-risk patients, as well as a practical demonstration of how to initiate monitoring with the available bedside equipment.

Stakeholders

The Perioperative RN Manager at NMC strongly supports the use of $ETCO_2$ monitoring for high-risk patients. She has an ICU background and has experience utilizing $ETCO_2$ monitoring on her patients in both the ICU and the PACU. As a new manager for this department, she is committed to increasing RN education and implementing technology into practice that is in line with current evidence to improve the safety and quality of patient care in her units. As manager she recognizes the current gap in education regarding initiation and management of $ETCO_2$ monitoring in the PACU RN staff. She supports this education project and is willing to help as needed to ensure its success.

In addition to the RN manager, other stakeholders involved in the project include the PACU RN staff, the director of perioperative services, and anesthesiologists. The bedside RNs are the focus of the project and their baseline knowledge of the subject will be assessed before the education is provided. The director of perioperative services is over the Perioperative RN manager and a direct link to hospital administration. She has approved this project and is a valuable stakeholder to move the project forward and assist with getting administration and IRB approval. Finally, anesthesiologists are also stakeholders because they can advise and partner with RNs in identifying which of their patients have risk factors for developing respiratory depression and could therefore benefit from $ETCO_2$ monitoring.

Study Questions

This DNP project intended to answer the following questions:

1. Does evidenced based education improve PACU nurses' ability to identify patients that are high risk for respiratory depression in the postoperative period?
2. Does evidenced based education improve PACU nurses' knowledge of how to effectively utilize $ETCO_2$ monitoring for postoperative patients?
3. Does evidenced based education increase the intent to utilize $ETCO_2$ monitoring for postoperative patients?
4. Does evidenced based education increase PACU nurses' confidence in their ability to effectively utilize $ETCO_2$ monitoring?

Theoretical Framework

Social Learning Theory

Since the purpose of this project is centered on providing evidenced based education for the PACU nursing staff, the theory that will be the most useful in guiding the project's development is the Social Learning Theory. The Social Learning Theory (SLT), also known as Social Cognitive Theory, was primarily developed by Albert Bandura as the integration of behavioral and cognitive theories of learning in order to have a more comprehensive theory of how learning occurs in everyday situations (Aliakbari et al., 2015). A central aspect of this theory is the focus on the internal aspects of the learner rather than external aspects alone such as educational material (Aliakbari et al., 2015). According to SLT, cognitive learning is an active process, largely directed by the individual yet it is also highly influenced by the social environment in which it occurs (Bahn, 2001). Most human behavior is learned observationally through modeling, observing others to develop a new idea of how to perform a certain behavior (Rosenstock, Stecher, & Becker, 1988). Observational learning is not just simple imitation but involves cognitive processes that play a large role in whether individuals will accept and perform the actions they are shown (Bahn, 2001). Considering this, the SLT is well suited as a framework for teaching nursing staff in a group environment (Aliakbari et al., 2015). SLT identifies four processes: attention, retention, motor reproduction, and motivation that will determine if an observed behavior will be performed (Bandura, 1986). See Figure 1.

Theoretical Concepts

Attention. The first concept in SLT is attention, or the extent to which the behavior is noticed (Bandura, 1986). Nurses are exposed to new information on a daily basis, so the extent that a topic can grab their attention and be noteworthy will affect whether they will be influenced into imitating and incorporating it into practice (Bahn, 2001). The presentation was given in a quiet, relaxed environment with distractions limited so nurses could focus on the material. Having a presentation that is supported by management, with food available, a peer presenting that they know and respect, and content that sparks interest in $ETCO_2$ monitoring helped capture the attention of nursing staff (Aliakbari et al., 2015). Since there has not been a quality improvement project in this unit in the last few years, the novelty of the project and knowledge that it was helping a co-worker was very helpful in grabbing the attention of the unit and sparking interest.

Retention. The next concept is retention, or how well the behavior/content is remembered (Bandura, 1986). Just because something grabs the individual’s attention does not mean it will have a long-lasting impact. Retention can be increased by repeated exposure to the most important concepts and, more importantly, by rehearsal that connects the concepts to the observers' perception of its functional value or usefulness (Bahn, 2001). So, in the case of $ETCO_2$ education, important concepts were covered initially in the presentation, again in the summary, addressed on both tests and stated in the educational handout. While foundational knowledge is important, content was directed at everyday application in clinical practice in PACU so that nurses see how this tool can impact their everyday life in caring for their patients. Every effort was made to ensure important information for $ETCO_2$ monitoring is emphasized clearly and not overshadowed with superfluous or confusing information in order to increase nurse retention of the prioritized message (Bahn, 2001).

Motor reproduction. The next concept is motor reproduction or the ability to perform the behavior that was just presented (Bandura, 1986). The behavior may have grabbed their attention and they may even retain important information about it, but unless they are able to actually perform the behavior then it is unlikely it will be imitated (Bahn, 2001). Understanding this, the $ETCO_2$ education included a section where RNs practiced applying the important information. This entailed a demonstration followed by an actual practice session where nurses physically worked with all of the components of $ETCO_2$ monitoring. This included having actual monitors and attaching the specialized $ETCO_2$ nasal cannula to the monitor, activating the $ETCO_2$ monitoring, and adjusting settings such as alarm limits.

Motivation. The final concept is motivation or the will to perform the behavior (Bandura, 1986). The perceived rewards and punishments associated with the behavior will influence whether it is worth imitating the new behavior (Bahn, 2001). Incentives can be external, such as physical rewards or praise, vicarious which is seeing success and failures of others, or self-produced where their new ability gives them a sense of pride and self-satisfaction (Bahn, 2001). When trying to motivate nurses about implementing $ETCO_2$ monitoring the goal was to incorporate multiple types of incentives from praise from management, seeing influential nurses perform the behavior, and appealing to their pride in excellent nursing care and protecting their patients. Education included consequences of hypoventilation and respiratory depression so that nurses can see the real benefits of $ETCO_2$ and how it can help them protect the patients that they care for. Personal satisfaction from providing safe, quality care that protects patients from harm can be a strong motivating factor, especially for nurses.

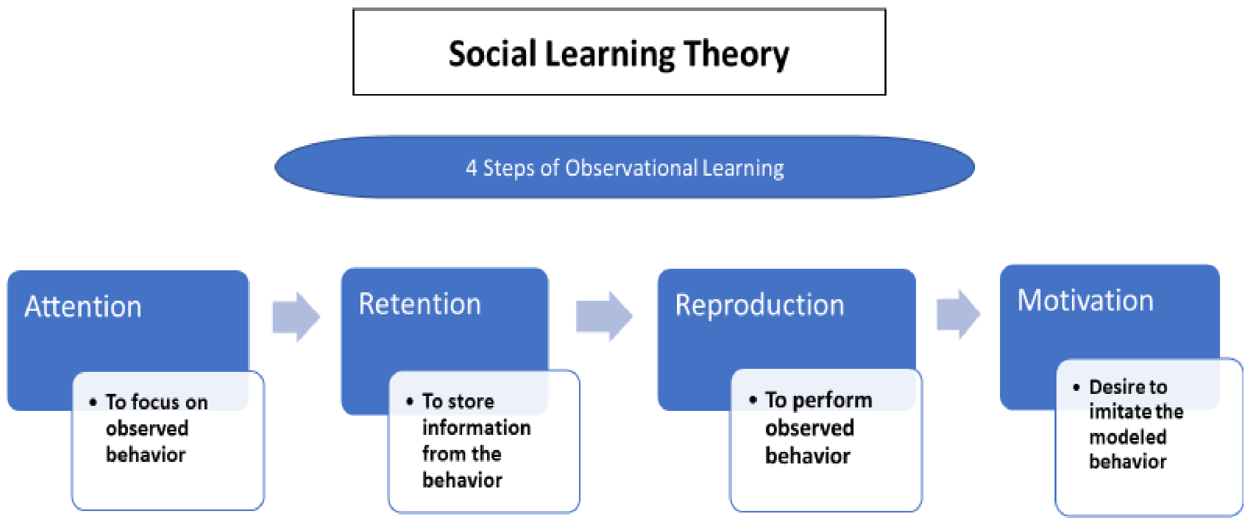


FIGURE 1. Social learning theory. (Figure derived from content in Bahn, 2001)

Understanding the role that the social environment and cognitive processes play in the act of learning a new behavior will impact how the intervention of this project should be constructed. The concepts in SLT are incorporated into the proposed $ETCO_2$ education program in order to increase the likelihood for the education to be effective and long-lasting in this environment.

Synthesis of Evidence

A literature search was conducted to find evidence to support this project's purpose of increasing RN knowledge of $ETCO_2$ monitoring in the PACU in order to increase the safety of patients at high risk for respiratory depression. Multiple searches were conducted using PubMed and Cumulative Index of Nursing and Allied Health Literature (CINAHL) using the following keywords: capnography, End-tidal CO_2, postoperative, non-intubated, PACU, and respiratory depression. Filters applied to search results included: published within the last ten years, English language, peer-reviewed, full-text and human species. These searches combined yielded a total of 106 results. Articles were excluded if they did not closely relate to this project's purpose statement. Articles were included if they were primary sources of evidence, meta-analyses or systematic reviews. Ten articles fit the necessary criteria and are included in this literature review (Appendix A).

The first four of the included articles are research studies comparing the effectiveness of $ETCO_2$ monitoring in detecting hypoventilation and respiratory depression. Lam et al. (2016) is a meta-analysis that included nine studies the authors determined to be high quality studies of postoperative patients and concluded that capnography provides an early warning of RD before oxygen desaturation, especially when supplemental oxygen is administered. Three research articles looked at patients receiving conscious sedation for procedures, and one of the studies specifically addressed pediatric postoperative patients in the PACU, but all of them had the same conclusion that capnography detected RD better than continuous pulse oximetry (Langham et al., 2016; Waugh et al., 2011; Saunders et al., 2017). This demonstrates that $ETCO_2$ monitoring is effective in detecting hypoventilation in patients who have received opioids and sedation, and is more effective than pulse oximetry alone in patients of all ages. A randomized controlled trial by Arakawa et al (2013) also looked at pulse oximetry during sedated procedures but specifically addressed the effect of supplemental oxygen finding that oxygen masks alveolar hypoventilation from detection by pulse oximetry but is still detected by $ETCO_2$. This is important as almost all patients in PACU are on supplemental oxygen and currently only being monitored by pulse oximetry that would not detect this hypoventilation.

In a study by Kasuya et al (2009), the authors assessed the accuracy of $ETCO_2$ monitoring compared to arterial CO_2 measurements and found that in non-obese, obese without

OSA, and obese with OSA, $ETCO_2$ with capnometer was within 3-4 points of arterial CO_2 levels. This demonstrates that $ETCO_2$ monitoring is accurate and reflective of arterial CO_2 levels even in patients who are obese and experience hypoventilation and apnea. In combination with the previous articles this shows that $ETCO_2$ monitoring is an accurate form of monitoring with clear superiority over continuous pulse oximetry alone.

Two articles analyzed specific risk factors for respiratory depression in the postoperative period (Lee et al., 2015; Gupta et al., 2018). Lee et al looked at previous closed claims of respiratory depression incidents and found that contributory factors included orders from multiple providers, PCA use, especially continuous infusions, obesity, OSA, timeframe within 24 of surgery/anesthesia, and concurrent administration of non-opioid sedating medication with opioids. Gupta et al (2018) was a systematic review that looked at 13 articles including 871,912 adult patients undergoing surgery and found that risk factors for OIRD included elderly (>65 years), females, OSA, COPD, cardiac disease, diabetes mellitus, hypertension, neurologic disease, renal disease, obesity, 2 or more comorbidities, opioid dependence, use of PCAs, different routes of administration of opioids, and concomitant administration of sedatives. Both studies concluded that in incidents of respiratory depression the patients were inadequately monitored (Lee et al., 2015; Gupta et al., 2018). These articles' conclusions on risk factors for respiratory depression are affirmed by numerous consensus groups including The Joint Commission and are summarized in Appendix B.

Finally, two quality improvement projects were included that detail the implementation of $ETCO_2$ monitoring in order to reduce OIRD (Carlisle, 2015; Milligan et al., 2018). Both studies analyzed risk factors for OIRD which were the same as previous studies mentioned above with the addition of specific comorbidities including asthma and heart failure (Carlisle, 2015; Milligan et al., 2018). Carlisle (2015) did a hospital wide implementation of $ETCO_2$ monitoring and after twelve months there was 2.56 times more patients at high risk for OIRD being monitored with capnography than at baseline. Both QI projects analyzed research in support of $ETCO_2$ monitoring, found that nursing education is a vital component of a successful implementation, and showed a negative trend in rates of respiratory depression events compared to pre-implementation of $ETCO_2$ monitoring.

Appraisal of Evidence

These articles provide strong evidence through meta-analyses, systematic reviews, and randomized controlled trials that capnography in non-intubated patients provides superior detection of respiratory depression over pulse oximetry monitoring alone. While some of the research articles evaluating capnography were not focused specifically on PACU patients, they were relevant to patients receiving various levels of sedation and anesthesia that were at risk for respiratory depression. This population is similar to patients in the PACU, many of whom arrive unresponsive with temporary airways still in place, others who receive conscious sedation for procedures performed in PACU, and the majority of all patients that will continue to receive various amounts of benzodiazepines and intravenous (IV) opioids during their PACU stay. The studies evaluating the superiority of $ETCO_2$ to continuous pulse oximetry (CPOX) include three separate meta analyses which provides a higher level of evidence and all come to the same conclusion that $ETCO_2$ monitoring detects hypoventilation and respiratory depression better than CPOX. The quality improvement projects have large, generalizable populations as they take place at multiple acute care hospitals in multiple states. As a result, these projects were able to demonstrate improvements after implementation of $ETCO_2$ monitoring in addition to valuable procedural and sociological information about the implementation process itself. The systematic reviews incorporate multiple high-quality studies and provide valuable information on high-risk patients thus confirming expert recommendations. Overall, this collection of evidence provides support for this project and educating PACU RNs about implementing $ETCO_2$ monitoring for high-risk patients in order to increase patient safety in the PACU setting.

METHODS

Design

This is a quality improvement project that utilized a pre-test/post-test design to measure the benefit of an evidenced-based education program for PACU nursing staff on $ETCO_2$ monitoring. Participants were given a short test prior to an education and practice session on multiple aspects of $ETCO_2$ monitoring (Appendix F), and then given the same test after the session to evaluate for improvement (Appendix G). The tests were anonymous, voluntary, and the pre-test and post-tests had matching randomized identification numbers for data analysis. To increase participation, refreshments were provided for all who attend the education session.

Setting and Participants

This quality improvement project took place in the PACU at Northwest Medical Center in Tucson, Arizona. The participants were Registered Nurses who work in PACU either full time or part time. Currently, there are 20 bedside nurses that fit this criterion. The education session itself took place divided between the staff lounge, where there was seating available for the education presentation, and then an isolation patient room next to the lounge where there was working bedside equipment available for the demonstration and practice portion. Flyers were placed around the unit two weeks prior to the education sessions to help inform staff of the available sessions (Appendix J). The plan was for the education sessions to take place on two separate days with two different times available each day to accommodate different work schedules and shift hours. Refreshments were provided as advertised on the flyers, including donuts, candy, a platter or cheese and crackers, and a vegetable tray along with drinks including soda, coffee and iced tea to help increase nurse attendance.

Intervention

The intervention for this project was an educational presentation on $ETCO_2$ monitoring. After obtaining IRB (Appendix K) and site approval for this project (Appendix I), the implementation of the intervention was scheduled for October 2-3, 2019. The intervention included an oral presentation, accompanying handout, demonstration of the technique for initiating $ETCO_2$ monitoring along with a practice session for participants with the current unit equipment. Time was allotted for a question and answer session at the end of each presentation and demonstration, as well as additional time for any nurse who wanted further practice with setting up the monitoring equipment. Each education session lasted a total of 30 min. At the beginning of each session, participants were handed a packet (described below). The oral presentation outline (Appendix D) included content on the purpose of $ETCO_2$ monitoring, the problems with current pulse oximetry and respiratory monitoring, the national organizations recommending $ETCO_2$ monitoring, brief overview of research comparing pulse oximetry to $ETCO_2$ monitoring, identification of patients at high risk for respiratory depression that could benefit from $ETCO_2$ monitoring, and how to interpret $ETCO_2$ numeric and waveform values. The content of the education session was reviewed by Dr. Heather Carlisle and Dr. Zawilski to ensure accuracy and appropriateness for the project's stated purpose (Appendix E). Dr. Carlisle is a professor in the DNP program at the University of Arizona who completed her own DNP project, and has published multiple papers, on the subject of $ETCO_2$ monitoring. Dr. Zawilki is a practicing anesthesiologist at Northwest Medical Center. They are both experts in the field of capnography and qualified to approve the content of the education session.

Data Collection

The participants were given a stapled collection of six papers when they arrived for the education session. The first paper was the IRB disclosure form (Appendix H) that introduced and explained the project, that it is voluntary and anonymous, and other pertinent information related to IRB and their participation. The second paper was the pre-test consisting of 20 questions, 15 of which tested nurses' knowledge of $ETCO_2$ monitoring and related topics and five of which were related to intent to change practice and nurse confidence level in utilizing $ETCO_2$ monitoring (Appendix F). The participants were asked to fill out the pre-test upon arrival while enjoying refreshments and then turn in their answer sheet prior to the education session. The third paper was blank and used to separate the pre-test from the handout with the $ETCO_2$ monitoring information that the pre-test questions could be answered with. The next paper was another blank to separate the educational handout from the final form, the post-test. The intent was to increase participants following the instructions of taking the post-test without looking at the educational handout. The post-test had the same questions as the pre-test, presented in a different order (Appendix G). The pre-test and post-test in the same stapled collection of papers had matching three-digit randomized identification numbers at the bottom so the results could be compared while preserving anonymity for participants. After the demonstration and practice session with the $ETCO_2$ monitoring equipment, as well as time for answering questions, participants were asked to complete the post-test and turn in the answer sheet when finished. A sealed box with a slit in the top was placed in the staff lounge where the presentations were held and was available for 72 hours following the presentations for participants to turn in completed tests anonymously and securely. Food was used as an incentive to complete the surveys as directed but all submissions were anonymous as the presenter did not monitor who submitted tests to the collection box.

Data Analysis

Data from the pre- and post-tests were entered into Excel and then paper surveys were shredded. The first 10 questions on the pre and post-test are related to $ETCO_2$ monitoring knowledge and are multiple choice with four answers, only one of which is correct. The last five questions on the tests are based on a Likert scale and related to intent to change practice and nurse confidence levels in effectively utilizing $ETCO_2$ monitoring. The Likert scale questions asked participants “For each of the following questions please circle the response that best reflects your attitude toward each statement” and gave the options of 1. Strongly Disagree, 2. Disagree, 3. Neither agree or disagree, 4. Agree, or 5. Strongly Agree. Using the online Graphpad calculator, a paired t-test was performed on the mean scores from the multiple-choice content questions to compare $ETCO_2$ knowledge before and after the intervention to evaluate for significance. For the Likert scale questions, a Wilcoxon Signed Rank test was performed on each question’s scores individually to determine significance. Descriptive statistics were performed to analyze both the multiple-choice questions evaluating content and the Likert scale questions evaluating nursing confidence and practice change to evaluate for improvement in the different areas as a result of the education provided.

Ethical Considerations

The ethical principles of respect for persons, beneficence, and justice have been considered throughout the development and implementation of this project (Polit & Beck, 2012). Since this is a quality improvement project to educate bedside nurses about $ETCO_2$ monitoring, there was no direct patient involvement in the program. The participants of this project were all adult PACU nurses that were able to give informed consent and do not represent vulnerable populations. The project design maximizes the benefit of improved RN education and consequently improved patient safety with no known risks posed to participants. All full-time and part-time RNs in the PACU made up the target population and participation was strictly voluntary. The first form given to participants was the disclosure form which explained the purpose of the project, time requirements, benefits, lack of any known risks, and the voluntary nature of the project including no loss of benefits or penalty for those wishing not to participate. Demographic or personal information relating to race, ethnicity, sexual orientation, gender or religion was not collected or discussed in this project, and all participants in this project were treated equally and fairly (Polit & Beck, 2012). Pre and post-tests had randomized numbers assigned to them in order to respect anonymity and privacy of the participants. There are no conflicts of interest to declare related to the proposed project. Site approval was obtained from Northwest Medical Center (Appendix I). IRB approval was received from the University of Arizona prior to the implementation of the project (Appendix K).

RESULTS

Sample

The education session was given two times on the first day as scheduled with four eligible participants at each session. On the second day of the intervention, the staff meeting that the education sessions were paired with was cancelled due to the manager being sick. To make up for this, the two education sessions that were originally planned still took place and two additional sessions were given at the beginning of the shift and around lunch time to increase opportunities for nurses to participate. The second day sessions had three, three, two, and two eligible participants at each respectively. That gave a total sample of 18 participants out of 20 possible RNs who met criteria. All of the paired pre- and post-tests were completed, with no missing or partially completely tests.

$ETCO_2$ Knowledge

The first 15 questions of the pre- and post-test are multiple choice questions evaluating knowledge of content of $ETCO_2$ monitoring and related material. A description of test scores, question by question, is summarized in Table 1. With only one correct answer for each question, tests were graded for a score out of 15 for both the pre-test and post-test. The mean score and standard deviation on the pre-education tests was 6.67 ± 2.4 (44.4%) while post-education, the mean score was 14.28 ± 0.75 (95.2%), a significant improvement ($p < 0.0001$). A paired t-test was used to test for differences between test scores. The objective of this project, to increase PACU nurses' knowledge of $ETCO_2$ monitoring using an education session, was met.

TABLE 1. *Number who missed correct answer for each question.*

Question and *Correct Answers*	Number Who Missed on Pre-Test	Number Who Missed on Post Test
Pulse oximetry is an accurate measure of: *Oxygenation*	13	1
Which patient would be the highest risk for postoperative respiratory depression: *75-year-old on a Patient Controlled Analgesic pump*	7	0
$ETCO_2$ monitoring should be initiated on: *On a patient receiving CPR*	17	0
A patient with an $ETCO_2$ reading of 49 mmHg should be assessed for: *Hypoventilation*	12	0
Which condition is most likely present if this $ETCO_2$ waveform is seen: *Chronic Obstructive Pulmonary Disease*	15	0
Respiratory depression is demonstrated by: *Respiratory rate of 9 bpm*	12	0
If you are having frequent alarms on your $ETCO_2$ monitor you should: *Check the patient and tubing*	3	0
Increased $ETCO_2$ values can be caused by: *Shivering*	14	3
Predictors of Obstructive Sleep Apnea include: *All of the above*	3	0
The reversal agent for opioid induced respiratory depression is: *Naloxone*	0	0
Effective compressions during a Code Blue are indicated by an $ETCO_2$ level of: *≥ 10 mmHg*	13	0
The Joint Commission recommends the use of $ETCO_2$ monitoring: *On all patients that are receiving opioids*	18	8
The accuracy of current respiratory rate monitoring using ECG leads is affected by: *All of the above*	2	0
$ETCO_2$ monitoring is an accurate measure of: *Ventilation, respiratory rate, & airway obstruction*	12	0
Which of the following is NOT true about $ETCO_2$ nasal cannulas?: *The nasal cannula needs to be connected to oxygen in order to monitor $ETCO_2$*	14	1

Likert Scale Questions

Likert scale questions 16-20 rated staff responses related to nursing confidence and intent to utilize $ETCO_2$ monitoring as whole numbers from 1 through 5 with strongly disagree as the low score 1 and strongly agree as the high score 5.

Nursing Confidence

Likert scale questions 16-19 evaluate nursing confidence in their ability to read and interpret $ETCO_2$ waveforms, their ability to set up and start $ETCO_2$ monitoring, their ability to identify high risk patients, and confidence that they have the skills and knowledge to utilize $ETCO_2$ monitoring effectively. In all four questions evaluating nursing confidence, there was a statistically significant improvement in scores from the pre-test to the post-test with a p value <0.05 (Wilcoxon Signed Rank Test). Results for nursing confidence questions are summarized in Table 2.

TABLE 2. *Question 16-19 results.*

	Question	**Pre-Test Score (Mean ± SD)**	**Post-Test Score (Mean ± SD)**	**P value**
Question 16	I feel confident in my ability to read and interpret $ETCO_2$ waveforms	2.38 ± 0.78	4.44 ± 0.51	<0.05
Question 17	I feel confident in my ability to set up & start $ETCO_2$ monitoring on a patient	2.22 ± 0.88	4.61 ± 0.50	<0.05
Question 18	I feel confident in my ability to identify patients at high risk of respiratory depression	2.28 ± 0.89	4.83 ± 0.38	<0.05
Question 19	I feel confident that I have the skills and knowledge to utilize $ETCO_2$ monitoring effectively when needed in my everyday practice.	2.22 ± 0.81	4.50 ± 0.51	<0.05

Likelihood to Implement $ETCO_2$ Monitoring

The final question of the test was to evaluate the likelihood of participants to initiate $ETCO_2$ monitoring for at least one patient in the next month. The mean score on the pre-test was 2.2 indicating and indicative of a low likelihood whereas following the education intervention, the score increased to 4.6, again, a statistically significant increase ($p < 0.05$). Table 3 summarizes this data.

TABLE 3. *Question 20 results.*

	Question	Pre-Test Score (Mean ± SD)	Post-Test Score (Mean ± SD)	P value
Question 20	I think it is likely given my current knowledge that I will initiate $ETCO_2$ monitoring for at least one patient in the next month.	2.22 ± 0.81	4.61 ± 0.50	<0.05

DISCUSSION

This quality improvement project met its goal of providing evidenced-based education to the PACU nursing staff at Northwest Medical Center on $ETCO_2$ monitoring in order to increase nursing knowledge, confidence, and ability to utilize $ETCO_2$ monitoring effectively in the postoperative setting. For both the multiple-choice content questions and the Likert scale questions evaluating nursing confidence and practice, there was a statistically significant difference between the pre-test and post-test scores showing the positive impact of the intervention of this project. All 18 participants showed improvement in scores between the pre-test and post-test on the content score and Likert scale.

Impact of Results

Prior to the education session delivered to PACU nurses participants missed an average of 8.4 out of 15 of the $ETCO_2$ monitoring knowledge questions. In contrast, on the post-test 17% of participants missed two questions, 39% missed one question, and 44% missed no questions at all. Out of the 10 participants who did not get a perfect score on the posttest, the most commonly missed question was Q12, which asked “The Joint Commission recommends the use of $ETCO_2$

monitoring for”. For evaluating the question of whether education improves PACU nurses’ ability to identify patients that are high risk for respiratory depression, the question that asked nurses to select the patient at highest risk for respiratory depression was missed by 50% of participants on the pre-test while 0% missed it on the posttest. Additionally, question 18 that asked participants to rate if they felt confident in their ability to identify patients at high risk for respiratory depression had a mean score on the pre-test of 3.2 or Neither Agree or Disagree, but on the post-test, the mean score was 4.8 or Agree-Strongly Agree. Finally, the last question relating to whether nurses will initiate $ETCO_2$ monitoring changed from an average score of Disagree on the pre-test to an average score of Agree-Strongly Agree on the post-test, showing a statistically significant and clinically significant intent to change nursing practice on this unit. These results show that the identified study questions were answered through this project. The results also demonstrate that this educational intervention had a positive impact on the practice in this unit where RNs have obtained knowledge, confidence, and affirmed that they are likely to initiate $ETCO_2$ monitoring which was never previously used on this unit.

Sustainability

In order to increase the chance that impact to practice on this unit, as a result of this quality improvement project, is lasting, measures were taken to increase the sustainability of the intervention. The first measure was that the education session outline and the 15-question multiple-choice test have been included in new RN orientation so that all new perioperative nurses will have to read the material and take the test as part of their training. The section of the education outline that deals with demonstration notes that preceptors are responsible for reviewing and practicing initiating the $ETCO_2$ monitoring with new RNs using the bedside equipment. Next, for established RNs on the unit, $ETCO_2$ monitoring has been added to the annual skills review for the unit. The RNs will have to read the material that does not include demonstration, take the 15-question test, and then will be required to demonstrate initiating $ETCO_2$ monitoring correctly to the designated staff member. This will promote RN retention by requiring them to practice and maintain their knowledge and skills at least annually. To encourage day-to-day use of this new skill, a laminated color copy of the educational handout was placed at the charge desk where daily huddles take place. Additionally, a sign was placed in the PACU storage room over the bin with the $ETCO_2$ nasal cannulas so that RNs can find them more easily and be reminded that they are available for use whenever needed. A final measure to promote sustainability is a new PACU unit policy that was written to include organizational recommendations for when to initiate $ETCO_2$ monitoring, what patients are included as high risk for respiratory depression, what information needs to be charted by RNs, and specifies that monitoring can be initiated either by a physician order or by bedside RNs. This policy is currently being reviewed and will take several months to go through Northwest Medical Center’s approval process, which is why administration did not want an unapproved version included in this project. However, the approval process has been started in collaboration with the Perioperative Director and will be an important aspect of increasing the effective use of $ETCO_2$ monitoring in the PACU.

Theoretical Framework

Throughout the development and execution of this project, the Social Learning Theory has been incorporated as much as possible in order to increase RN learning. The Social Learning Theory (SLT) attempts to find balance between focusing on the external aspects of the intervention such as the content itself, the internal aspects of the participants such as their cognitive learning process and motivation, and then the social environment in which it all takes place (Aliakbari et al., 2015). The four processes of the SLT, attention, retention, motor reproduction, and motivation, were integrated into the intervention as discussed in the Theoretical Concepts section. According to SLT, learning is an active process influenced by observing others and highly influenced by the social environment in which it occurs (Bahn, 2001). The social environment was curated by presenting the education in group settings instead of individually, letting participants practice together during the demonstration section, and having key role models in the unit utilize $ETCO_2$ monitoring after the intervention was complete.

Having the investigator, charge nurse, and nurse manager utilize $ETCO_2$ monitoring on appropriate patients and discuss this tool with anesthesiologist during report serves to capture attention and motivate other nurses on the unit to hopefully accept and emulate this new behavior (Bahn, 2001). Furthermore, the inclusion of $ETCO_2$ monitoring in new perioperative RN orientation and in the annual skills review helps maintain attention and will aim to gradually cement this new behavior into the culture of the unit. By following the concepts of SLT, it increases the likelihood that the education presented in the intervention will be effective and have a lasting impact on this unit's practice.

Strengths and Limitations

Strengths

The primary aim of this project was to educate PACU RNs about $ETCO_2$ monitoring through a quality improvement initiative. The design of this project accomplished this goal by providing a simple framework for the implementation of evidence related to the effectiveness of

$ETCO_2$ monitoring that is presented in the literature review. The stakeholders of this project, including administration, anesthesiologists, and nursing staff, were involved in planning and organizing the intervention to tailor it to this individual setting. The educational intervention was based on relevant evidence and was reviewed by experts in the field to ensure accuracy in the presented material. This project was both feasible and sustainable because the education intervention was held during regularly scheduled staff meetings and nursing shifts that maximizes attendance and avoided additional costs to the hospital. Out of the 20 eligible participants, 18 participated in this study and completed all aspects of both the pre- and the post-tests for a 100% response rate, which is significant for a quality improvement project of this size. All of these contribute to a strong quality improvement project at this specific location.

Limitations

Despite 90% participation, this was a small study carried out at a single Southern Arizona PACU. A challenge to validity comes from potential bias from participant's awareness of the project's design and potential desire to modify answers to achieve a result they believe the investigator is looking for (Polit & Beck, 2012). Another potentially significant limitation of this project was the inability to control whether participants ignored instructions and looked at the educational handout while taking the pre- or post-test. It was considered whether to give the handouts at the end of the session once the post-tests had been submitted, however it was decided that it would be more beneficial for participants to have something to follow along during the presentation and be able to take notes in order to make the handouts truly useful for a future reference. Additionally, since participants were allowed to turn in tests anonymously at their own timing throughout the two days, there would be no way to give them the handout after completion of the post-test without participants having to admit to the presenter directly whether or not they completed the tests. Personal information about the participants was not collected so there is no way to analyze confounding variables such as level of education, years of experience, experience in critical care specialties or other relevant variables.

Dissemination and Implications for Future Practice

The results of this project will be presented to both the stakeholders and all of the nursing staff in the PACU at Northwest Medical Center. By sharing the results of the project with the nursing staff it is the aim to increase discussion of the topic and serve as an additional reminder of their ability to utilize $ETCO_2$ monitoring in their everyday practice. One of the important stakeholder groups are the anesthesiologists who work at Northwest Medical Center. The purpose of sharing the results with this group is to increase awareness of the PACU nurses' ability to effectively utilize this tool so that anesthesiologists can partner with nurses in identifying high risk patients that would benefit from increased monitoring to improve their safety. Finally, this project will be presented to the administration at Northwest Medical Center to show them the positive impact that it had for the PACU and that it accomplished the stated goals originally presented to them. Hopefully, showing that this project could accomplish its stated goal and improve nursing education at no cost to the hospital will encourage administrative support for further quality improvement projects.

Conclusions and Recommendations

Postoperative patients in the PACU are recovering from procedures where they may receive anesthesia, sedatives, and analgesics that place them at a high risk for respiratory depression and associated complications (Lee et al., 2015; Latham, Bird, & Burke, 2016). The previous standard of care in the PACU included patient monitoring that had significant evidenced based limitations and which were not recommended by national organizations that strive for optimal patient safety. Providing evidence-based education to PACU nurses on $ETCO_2$ monitoring increased their knowledge, confidence, ability, and intent to utilize $ETCO_2$ monitoring effectively in the postoperative setting. The study questions and objective of this project were met by a 51% increase in mean scores from the pre-test to the post-test as well as statistically significant improvement in all questions. Measures have been taken to ensure the education and impact on practice is sustainable and can lead to increased utilization $ETCO_2$ monitoring in order to improve the safety of patient care.

Recommendations for Further Research

Future research on this topic should focus more specifically on the benefit of $ETCO_2$ monitoring on adult postoperative patients in the PACU. Out of all of the literature analyzed for this project it was narrowed down to the 10 most relevant studies, and out of those 10 articles not one of them specifically addressed adults in the PACU. The majority of high-quality studies and meta-analyses addressed adults undergoing procedures with sedation. Only one study addressed patients in the PACU and it was specific to children. The metanalysis by Lam et al. (2017) included postoperative patients in several of the studies but they were on inpatient floors and not specific to PACU settings. In order for $ETCO_2$ monitoring to become the standard of care in PACU settings as it has become in Operating rooms, ICUs, and in conscious sedation procedures, future research needs to be directed to this setting to provide specific data on the impact $ETCO_2$ monitoring can make for patient safety.

Clinical Recommendations

While this intervention was successful in increased nursing knowledge and confidence in effectively utilizing $ETCO_2$ monitoring, the next step in this process would be track if $ETCO_2$ monitoring was actually being used in this PACU by physicians and nurses. Now that nurses have the skills and knowledge to use this tool, it is still unknown if they will actually change their practice and incorporate this monitoring into their daily patient care. A long-term project would be to audit patient charts to track utilization of $ETCO_2$ monitoring to see how often it is used and if the patients it was used on met criteria for being at high risk of respiratory depression. Additionally, adverse events in the PACU should be reported and tracked to determine if there were missed opportunities to prevent the situation, and ideally track to see if there is any decrease in adverse events with increased usage of $ETCO_2$ monitoring. It is the hope that this quality improvement project can be used to advance or initiate other projects in order to continually increase the safety of care provided to all patients.

APPENDIX A:

EVIDENCE APPRAISAL TABLE

Author/Title	Research Question or Project Goal	Study Design	Sample and Setting	Methods	Findings
Arakawa, H., Kaise, M., Sumiyama, K., Saito, S., Suzuki, T., & Tajiri, H. (2013). Does pulse oximetry accurately monitor a patient's ventilation during sedated endoscopy under oxygen supplementation? Singapore Medical Journal, 54(4) 212-215	The aim of this study was to measure the masking effect of oxygen supplementation in pulse oximetry (SpO2) when alveolar hypoventilation develops during sedated endoscopy.	RCT	A total of 70 patients undergoing sedated diagnostic colonoscopy	Patients were randomly divided between oxygen supplementation and room air. SpO2 and $ETCO_2$ were measured by non-intubated capnography during the procedure for all the patients	The study showed that the rise of $ETCO_2$ caused by alveolar hypoventilation after sedation was the same in both groups, but O2 supplementation resulted in an overestimation of SpO2 by > 5% above the values in patients breathing room air when peak alveolar hypoventilation occurred. This demonstrates masking effect of oxygen and inadequacy of SpO2 alone in monitoring alveolar ventilation
Carlisle, H. (2015). Promoting the Use of Capnography in Acute Care Settings: An Evidence-Based Practice Project. Journal of PeriAnesthesia Nursing, Vol 30(3), 201-208.	The goal of this evidence-based practice project was to promote the standardized use of capnography to reduce the incidence of OIRD.	Quality Improvement Project	489-bed, magnet-designated, trauma center	The project included an updated nursing protocol, an electronic order trigger, improved access to capnography monitors, and staff education about OIRD risk assessment and the use of capnography.	At the end of 1 year, there were slightly fewer cases of OIRD than pre-intervention, 4.9 cases compared to 4.8 cases per 10,000 patient-days, and there were 2.56 times more patients at high risk for OIRD being monitored with capnography than at baseline

Author/Title	Research Question or Project Goal	Study Design	Sample and Setting	Methods	Findings
Gupta, K., Prasad, A., Nagappa, M., Wong, J., Abrahamyan, L., & Chung, F. (2018). Risk factors for opioid-induced respiratory depression and failure to rescue: a review. *Current Opinion Anesthesiology*, *31*(1), 109-119.	What are risk factors for opioid induced respiratory depression in the postoperative period?	Systematic review	Total of 871,912 adult patients undergoing surgery	Literature database search from 2005-2016. 13 articles were evaluated	Elderly, females, OSA, COPD, cardiac disease, diabetes mellitus, hypertension, neurologic disease, renal disease, obesity, 2 or more comorbidities, opioid dependence, use of PCAs, different routes of administration of opioids, and concomitant administration of sedatives are significant risk factors for postoperative OIRD. The majority of patients with OIRD are deeply sedated and inadequately monitored.
Kasuya, Y., Akca, O., Sessler, D. I., Ozaki, M., & Komatsu, R. (2009). Accuracy of postoperative end-tidal PCO_2 measurements with mainstream and sidestream capnography in nonobese patients and in obese patients with and without obstructive sleep apnea. Anesthesiology, 111(3), 609-615.	Are mainstream capnometer or sidestream capnometer with or without an oral guide accurate in spontaneously breathing non-obese patients, obese patients with OSA, and without OSA during recovery from general anesthesia?	RCT	60 patients: 20 non-obese without OSA, 20 were obese without OSA, 20 obese with OSA	$ETCO_2$ was measured using three capnometer combinations with oxygen at 4 l/min. Arterial carbon dioxide partial pressure was determined simultaneously. The major outcome was the arterial to $ETCO_2$ partial pressure difference with each combination.	The mainstream capnometer is the most accurate and the difference in $ETCO_2$ from arterial CO_2 was 3.0 in non-obese, 3.9 in obese non-OSA, and 4.0 in obese OSA patients ($p<0.05$). The least accurate capnometer was the sidestream capnometer without oral guide where the difference in $ETCO_2$ from arterial CO_2 was

Author/Title	Research Question or Project Goal	Study Design	Sample and Setting	Methods	Findings
					7.1 in non-obese, 8.1 in obese non-OSA, and 8.3 in obese OSA patients ($p<0.05$).
Lam, T., Nagappa, M., Wong, J., Singh, M., Wong, D., & Chung, F. (2017). Continuous pulse oximetry and capnography monitoring for postoperative respiratory depression and adverse events: A systematic review and meta-analysis. *Anesthesia-Analgesia, 125*(6), 2019-2029.	Is continuous capnography more effective than continuous pulse oximetry (CPOX) in detecting Postoperative respiratory depression (PORD) and preventing postoperative adverse events in the surgical ward?	A Systematic Review and Meta-analysis	Studies included a total of over 5000 participants on inpatient postoperative units	Literature database search between 1946 and 2017. 9 studies were included examining CPOX and continuous capnography	Pooled data from the capnography studies showed that continuous capnography group identified 8.6% more PORD events versus CPOX group (CO_2 group: 11.5% vs 2.8%; $P < .00001$). The odds of recognizing PORD was almost 6 times higher in the capnography versus the pulse oximetry group (odds ratio: 5.83, 95% confidence interval, 3.54–9.63; $P < .00001$). No studies examined the impact of continuous capnography on reducing rescue team activation, ICU transfers, or mortality.
Langhan, M. L., Li, F. Y., & Lichtor, J. L. (2016). Respiratory depression detected by capnography among children in the postanesthesia care unit:	To determine the frequency of hypoventilation and apnea as detected by capnography compared to CPOX among children in the PACU.	Cross-sectional study	194 children, age 1–17 years, in the PACU of an urban tertiary care hospital.	Staff was blinded to the capnography monitor & routine care was provided with CPOX. The frequency of hypoventilation and apnea as measured by	Capnography detected hypoventilation/apnea in 45.5% of patients whereas Oxygen desaturations occurred in only 19%. Narcotics made patients more

Author/Title	Research Question or Project Goal	Study Design	Sample and Setting	Methods	Findings
a cross-sectional study. Pediatric Anesthesia 26 (1), 1010–1017.				capnography was compared to CPOX monitoring	likely to experience hypoventilation (OR 2.3) and apnea (OR 2.7), and Hypoventilation was seen more often among children who received supplemental oxygen (OR 3.1).
Lee, L. A., Caplan, R. A., Stephens, L. S., Posner, K. L., Terman, G. W., Voepel, T… Domino, K. B. (2015). Postoperative opioid induced respiratory depression: a closed claims analysis. *Anesthesiology*, *122(*1), 659–665.	Review of anesthesia closed malpractice claims associated with respiratory depression (RD) to determine whether patterns of injuries could guide preventative strategies.	Claims review & analysis	92 patients, aged 50 +/- 17.7	Out of 357 acute pain claims in Anesthesia Closed Claims Database from 1990-2009, 92 claims were found found to have possible, probable or definite RD.	Of the 92 claims, 77% resulted in severe brain damage or death. The vast majority of RD events (88%) occurred within 24 h of surgery, and 97% were judged as preventable with better monitoring and response. Contributing/potentially actionable factors included multiple prescribers (33%), concurrent administration of nonopioid sedating medications (34%), and inadequate nursing assessments or response (31%).
Milligan, P. E., Zhang, Y. & Graver, S. (2018). Continuous Bedside Capnography	The aim of this QI project was to expand the use of continuous capnography monitoring	Quality Improvement Project	Healthcare system in including 15 acute care hospitals, utilized in all areas of hospital where	Review of all incidents involving respiratory depression and/or naloxone	High risk patients were identified as: advanced age, obesity, low body weight, OSA, COPD,

Author/Title	Research Question or Project Goal	Study Design	Sample and Setting	Methods	Findings
Monitoring of High-Risk Patients Receiving Opioids. Biomedical Instrumentation & Technology, 28(1), 208-217.	to at risk patients to decrease OIRD.		patients meet criteria	administration. Developed protocol identifying high risk patients, policy for $ETCO_2$ use, and RN education program	PCAs, asthma, use of other sedatives, postoperative patients, and those on high dose opioids. Nursing education included vendor materials, training sessions, and custom teaching materials. The number of events resulting in patient harm was reduced from 21 to 14 (33%) during the 5 quarters after implementation compared to the 5 before.
Saunders, R., Struys, M., Pollock, R. F., Mestek, M., & Lightdale, J. R. (2017). Patient safety during procedural sedation using capnography monitoring: a systematic review and meta-analysis. *BMJ Open, 7*(1). doi:10.1136/bmjopen-2016-013402	Does capnography monitoring compared to visual assessment and pulse oximetry monitoring alone improve patient safety?	Systematic review and meta-analysis	Total of 5,475 adult patients receiving sedation and analgesia for procedures in various hospital settings	Literature database search from 2000-2016. 13 articles of RCTs were evaluated	Addition of capnography to visual assessment and pulse oximetry was associated with a significant reduction in mild (risk ratio (RR) 0.77, 95% CI 0.67 to 0.89) and severe (RR 0.59, 95% CI 0.43 to 0.81) desaturation, as well as in the use of assisted ventilation (OR 0.47, 95% CI 0.23 to 0.95).

Author/Title	Research Question or Project Goal	Study Design	Sample and Setting	Methods	Findings
Waugh, J. B., Chad, A., Epps, A., & Khodneva, Y. (2011). Capnography enhances surveillance of respiratory events during procedural sedation: a meta-analysis. Journal of Clinical Anesthesia, 23(1), 189–196.	Does capnography, in addition to standard monitoring, identify more respiratory complications than standard monitoring alone?	Meta- analysis	Total of 664 adult patients receiving sedation and analgesia for procedures in various hospital settings	Literature database search from 1995-2009. Five studies were evaluated	Analysis showed that during procedural sedation and analgesia, cases of respiratory depression were 17.6 times more likely to be detected if monitored by capnography than cases not monitored by capnography (95% CI, 2.5-122.1; P b 0.004).

APPENDIX B:

IDENTIFIED RISK FACTORS FOR RESPIRATORY DEPRESSION

Identified Risk Factors for Respiratory Depression

- Obesity (BMI >30)
- Age (>55 years or <17 years)
- Obstructive Sleep Apnea (diagnosed or predictors for OSA)
- Chronic Obstructive Pulmonary Disease
- Less than 24 hours after surgery with general anesthesia
- Longer length of time receiving general anesthesia during surgery (>2 hours)
- Patient Controlled Analgesic use
- Concurrent use of other sedating medications:

  benzodiazepines, antihistamines, promethazine etc.
- Renal failure (Creatinine >1.5)
- Heart failure
- Multiple comorbidities: Diabetes Mellitus, Hypertension, tobacco use etc.
- Opioid naïve
- Thoracic or other surgical incisions that may impair breathing
- ASA score >2

(Joint Commission, 2012; Gupta et al., 2018; Carlisle, 2015; ASPMN, 2011; ASPAN, 2014; Lee et al., 2015)

APPENDIX C:

$ETCO_2$ MONITORING EDUCATIONAL HANDOUT

$ETCO_2$ Monitoring Educational Handout

- End tidal CO2 is the partial pressure of CO2 at the end of an exhaled breath and is a noninvasive measure of ventilatory status.
- Normal EtCO2 values range from 35–45 mmHg.
- Values < 35 mmHg indicate hyperventilation
- Values > 45 mmHg indicate hypoventilation

<u>Key Points to Remember!</u>

- Not all patients require ETCO2 monitoring
- ETCO2 monitoring does not require a physician order. Nurses can initiate monitoring.
- ETCO2 monitoring should be documented in patient’s chart along with other vital signs.
- Interpret ETCO2 values and waveforms in combination with overall patient clinical picture

	Capnography	Pulse Oximetry
Measures	Carbon dioxide exhaled in each breath	Oxygen saturation of hemoglobin in arterial blood
Provides data on	Ventilation; respiratory rate	Oxygenation; heart rate
Reflects changes	In ventilation within 10 seconds	In oxygenation within 5 minutes
Effect of oxygen	Not affected	Affected

<u>Patients at **high risk** for respiratory depression:</u>

-Obesity (BMI>30)
-OSA
-COPD
-Age (>55 and <17 years)
-ASA score >2
-Opioid naïve
-Within 24 hours of surgery
-Long surgery/anesthesia (>2 hours)
-PCA usage
-Heart or renal failure
-Multiple comorbidities
-Opioids + benzodiazepines, antihistamines, promethazine or other sedating medications

<u>Steps to setting up ETCO2 monitoring:</u>

1. Identify patients at high risk for or suspected respiratory depression.

2. Obtain ETCO2 nasal cannula

3. Slide down cover and gently screw nasal cannula adaptor to bedside monitor outlet as shown to the right

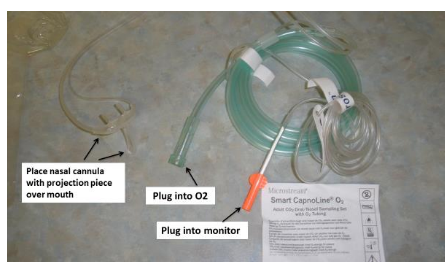
4. Activate ETCO2 monitoring if it does not automatically appear on screen (Same as for activating arterial line monitoring).

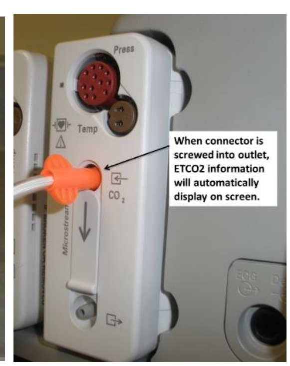
5. Place nasal cannula on patient as normal with small openings in canula facing upwards and spoon piece over mouth (if present)

6. Plug in nasal cannula to O2 if needed

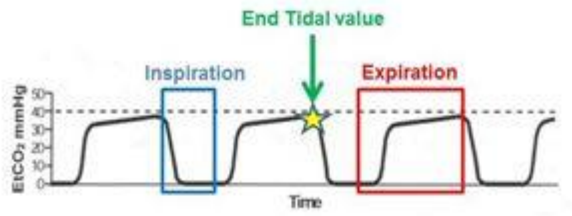
6. Ensure ETCO2 waveform displays on monitor

7. Ensure ETCO2 readings transfer to chart





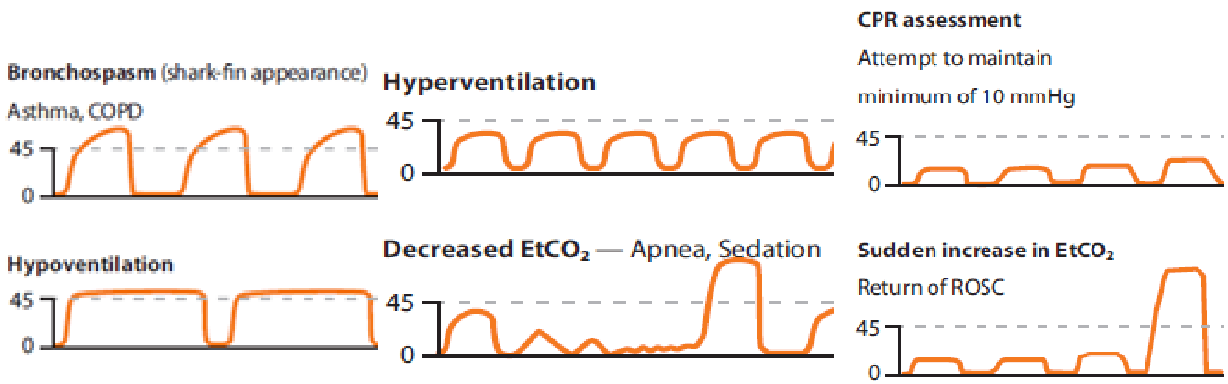
Normal Capnography Waveform



Tips for Nursing

- Always check the patient first!!
- If monitor is alarming or poor waveform, check all tubing for kinks, if ETCO2 filter is saturated, or if any part is disconnected
- Monitor for TRENDS in ETCO2
- Not accurate when patients are eating
- Re-evaluate whenever risk factors change

Abnormal capnography waveforms:



	Causes of **Increased** $ETCO_2$ values	Causes of **Decreased** $ETCO_2$ values
Respiratory	Hypoventilation, COPD, Asthma, Resolving bronchospasm	Hyperventilation, Pulmonary edema, PE, intrapulmonary shunting, bronchospasm
Metabolic/ Hemodynamic	Shivering, Malignant Hyperthermia, Severe sepsis, Increased CO (ROSC during CPR), fever, seizures	Hypothermia, metabolic acidosis, decreased CO (cardiac arrest), significant hypotension or hemmorhage
Technical	Exhausted CO_2 absorber, contamination of monitor	Blockage in tubing, disconnection

References

Carlisle, H. (2014). The case for capnography in patients receiving opioids. American Nurse Today, 9(9), 22-27.
DiCorpo, J. E., Schwester, D., Dudley, L. S., & Merlin, M. A. (2015). A wave as a window: Using waveform capnography to achieve a bigger physiological patient picture. *JEMS,* 40(11), 32-35
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APPENDIX D:

EDUCATIONAL PRESENTATION OUTLINE

Educational Presentation Outline

I. Introduction

A. Purpose: The purpose of this presentation is to educate bedside PACU RNs on $ETCO_2$ monitoring so they gain an understanding of the what $ETCO_2$ monitoring entails, the benefits of this tool, when it is appropriate to initiate this monitoring, how to actually initiate it in practice, and how to interpret the data effectively once it is initiated.

B. Background review of respiratory physiology (Siobal, 2016; Huttman et al., 2014)

i. Respiration includes both oxygenation and ventilation, two separate physiologic processes.

- Oxygenation is the process of adding oxygen to the body. Oxygen molecules from the air diffuse across pulmonary alveoli to the hemoglobin in blood and are transported to body tissues. Oxygenation is measured indirectly by transcutaneous pulse oximetry and directly by PaO2 from blood gasses.
- Ventilation is the movement of air into and out of the lungs. Gases are exchanged between the lungs and ambient air through inhaling and exhaling where CO_2 is eliminated. Ventilation is measured indirectly by exhaled CO_2, or capnography, and directly by $PaCO_2$ from blood gasses.
- CO_2 is the gas produced in the tissues as a byproduct of cellular metabolism and is transported by the bloodstream to the lungs where it removed from the body by ventilation. Cellular metabolism, perfusion, and ventilation will all affect the amount of CO_2 exhaled.

C. Review of respiratory depression and complications

i. Respiratory depression is defined as respirations that have a rate below 10 breaths per minute or respirations that fail to provide full ventilation and perfusion of the lungs (Gupta et al., 2018).

- Respiratory depression can lead to numerous complications including respiratory failure, reintubation, carbon dioxide (CO_2) narcosis, increased length of PACU and hospital stay, intensive care unit (ICU) admissions, brain damage and even death (Lee et al., 2015; Latham, Bird, & Burke, 2016).

- Respiratory depression is a known risk for all opioid administration and it becomes a much higher risk when combined with sedatives and general anesthesia.

ii. The 8th Annual Health Grades Patient Safety in American Hospitals Study reported 79,670 potentially preventable deaths over a 3-year period and stated that one in ten events was related to OIRD. The average healthcare cost per OIRD event was $53,500 (Restrepo et al., 2014).

iii. In a review of the Anesthesia Closed Claims Project database of 357 claims, it was found that 92 of these claims were possible, probable, or definite postoperative respiratory depression incidents of which 77% resulted in severe brain damage or death and 97% were judged as preventable with better monitoring and response (Lee et al., 2015).

D. What is capnography and $ETCO_2$ monitoring (Siobal, 2016; Kodali, 2014)

i. Capnography is the measurement of exhaled carbon dioxide, referred to as End Tidal CO_2 ($ETCO_2$).

- $ETCO_2$ is the partial pressure of CO_2 at the end of an exhaled breath and is measured noninvasively through a nasal cannula with a specialized sensor (Huttman et al., 2014).
- Capnography provides 3 important tools: an accurate respiratory rate, an $ETCO_2$ numeric value, and a waveform tracing for each breath
- Capnography is an accurate measure of ventilation.

II. Why should we use $ETCO_2$ monitoring?

A. Limitations of current monitoring practice (Siobal, 2016; Restrepo et al., 2014)

- Monitoring of respiratory status in this PACU currently uses continuous pulse oximetry, respiratory rate from electrical impedance with ECG leads, and intermittent visual assessment.
- Visual assessment has limitations including the inability for it to be continuous, that chest wall movement still occurs even with obstruction or hypoventilation, and visualization of fogging is not possible once oxygen mask is removed for cannula or room air.
- Similarly, electrical impedance is limited because chest wall movement occurs with obstruction and hypoventilation, and the accuracy can be affected by lead placement, patient movement, positioning, multiple blankets ect. So respiratory depression, obstruction, and hypoventilation could all occur without respiratory rate monitoring detecting it.
- Continuous pulse oximetry is a routine and reliable measure of oxygenation. It can be affected by decreased perfusion or artificial nails, but even when it is completely accurate **it is not a measure of ventilation**. Decreased oxygen saturation is a **late sign** of hypoventilation, especially in the presence of supplemental oxygen which almost all PACU patients use. If healthy subjects are preoxygenated with 100% oxygen and ventilate effectively and then become apneic, it may take up to 6 min for an adult and 4 min for child (3–12 years old) before $SpO2$ drops below 90% and alarms signal (Restrepo et al., 2014).

i. Research comparing $ETCO_2$ monitoring to pulse oximetry monitoring

- Combined data from multiple capnography studies showed that continuous $ETCO_2$ compared to continuous pulse oximetry identified 8.6% more respiratory depression events and the odds of recognizing respiratory depression was 5.8 times higher in the capnography groups (Lam et al., 2017).

- There have been numerous RCT and meta-analysis comparing CPOX to $ETCO_2$ in both adult and pediatric populations and they have all concluded that $ETCO_2$ detects respiratory depression better than CPOX (Langham et al., 2016; Waugh et al., 2011; Saunders et al., 2017).

ii. Research on monitoring hypoventilation in presence of supplemental oxygen

- Studies have also shown that in the presence of supplemental oxygen, alveolar hypoventilation is not detected by pulse oximetry but it is detected by $ETCO_2$ (Arakawa et al., 2013).

B. Benefits of using $ETCO_2$ monitoring (Siobal, 2016; Restrepo et al., 2014; Kodali, 2014)

- $ETCO_2$ monitoring provides the most accurate respiratory rate. Respiratory rate is continuous and measures every effective breath at the airway. It is not measured by chest movement so it is not altered body habitus, blankets, lead placement, or patient position.
- $ETCO_2$ monitors patient ventilation. No other monitoring technique monitors ventilatory status.
    - It provides breath to breath information on airway and ventilation status so that hypoventilation, apnea, or obstruction are detected immediately and can be treated quicker.
    - Is not affected by motion artifact, cold hands, or supplemental oxygen like CPOX.
- Allows trending of $ETCO_2$ and therefore a clinical estimate of $PaCO_2$. Can also be used to help determine if an ABG is or is not indicated.
- Indicator of proper intubation, adequate CPR, and ROSC during code blue (Sandroni, Santis, & D'Arrigo, 2018).

C. Accuracy of postoperative $ETCO_2$ monitoring

- $ETCO_2$ level is 2-5 mmHg different than $PaCO_2$ obtained from a blood gas in a patient with normal physiology
- $ETCO_2$ monitoring with nasal cannulas have been found to be accurate and within the 2-5 point physiologic difference from $PaCO_2$, even in patients who are obese and have OSA. Differences in accuracy do exist between the type and brand of $ETCO_2$ nasal cannulas, with cannulas that include mouth pieces being more accurate. However, each patient's **trend** in $ETCO_2$ values and waveforms is more important than any individual number. (Kasuya et al., 2009).
- Ideally, for $ETCO_2$ monitoring to be most effective, baseline $ETCO_2$ levels should be determined for each patient prior to receiving opioids or anesthesia.

D. National organizations recommendations on $ETCO_2$ monitoring

- The Anesthesia Patient Safety Foundation, The Joint Commission, The Institute for Safe Medication Practices, The American Society for Pain Management Nursing, and the American Society of Perianesthesia Nursing have all recommended the use of capnography for high risk patients receiving opioids (Jarzyna et al., 2011; ASPAN, 2014; Joint Commission, 2012; Weinger, 2008).
- The Joint Commission's 2012 sentinel alert on safely using opioids recommends using capnography to better detect OIRD in **all** patients receiving opioids. The Joint Commission warns providers "not to rely on pulse oximetry alone because pulse oximetry can suggest adequate oxygen saturation in patients who are actively experiencing respiratory depression, especially when supplemental oxygen is being used – thus the value of using capnography to monitor ventilation" (Joint Commission, 2012, p. 3).

III. When should we use $ETCO_2$ monitoring?

A. Use of $ETCO_2$ monitoring in Code Blue situations (Sandroni et al., 2018).

i. $ETCO_2$ monitoring is recommended to confirm endotracheal intubation

- $ETCO_2$ is the most specific criterion to confirm correct ETT intubation.
- Can use qualitative $ETCO_2$ (Easy cap CO_2 detector) initially but continuous monitoring ensures ETT not displaced during CPR or transfer

ii. $ETCO_2$ monitoring is recommended to assess adequacy of CPR

- $ETCO_2$ correlates to cardiac output so monitoring $ETCO_2$ values shows the effectiveness of CPR being performed. Goal to maintain $ETCO_2$ >/= 10mmHg during CPR to increase survivability of a patient.

B. Use of $ETCO_2$ monitoring in patients identified as high-risk patients for hypoventilation and respiratory depression (Lee et al., 2015; Gupta et al., 2018; Joint Commission, 2012; Carlisle, 2015).

- Not all postoperative patients need to have $ETCO_2$ monitoring, but patients with 1 or more risk factors may benefit from additional monitoring

i. Review of risk factors for respiratory depression

- Obesity (BMI >30)
- Age (>55 years or <17 years)
- Obstructive Sleep Apnea (diagnosed or predictors for OSA)
- Chronic Obstructive Pulmonary Disease
- Longer length of time receiving general anesthesia (>2 hours)
- Patient Controlled Analgesic use

- Concurrent use of other sedating medications: benzodiazepines, antihistamines, promethazine etc.
- Renal failure (Creatinine >1.5)
- Heart failure
- Multiple comorbidities: Diabetes Mellitus, Hypertension, tobacco use, etc.
- No recent opioid use
- Thoracic or other surgical incisions that may impair breathing
- ASA score >2

ii. ETCO$_2$ monitoring can be initiated by RNs upon identification of high-risk patients.

- Anesthesiologists can order ETCO$_2$ monitoring for their patients but a physician order is not required to initiate ETCO$_2$ monitoring.

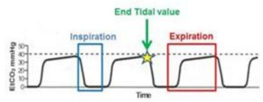
IV. How do we use ETCO$_2$ monitoring?

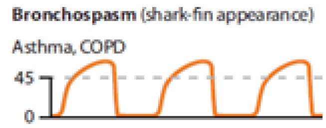
A. Interpreting ETCO$_2$ numeric values (Siobal, 2016; Kodali, 2014; DiCorpo et al., 2015)

- Normal ETCO$_2$ values range from 35-45 mmHg
- Values <35 mmHg are generally considered diagnostic of hyperventilation or hypocarbia
- Values >45 mmHg indicate hypoventilation or hypercarbia
- Monitor trends in ETCO$_2$ values and always interpret ETCO$_2$ values in combination with overall clinical picture of each patient

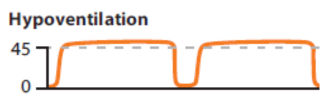
B. Interpreting ETCO$_2$ waveforms (Siobal, 2016; DiCorpo et al., 2015; Kodali, 2014).

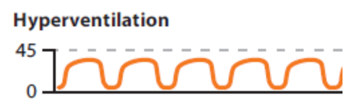
- Capnography waveforms provide additional information about a patient's airway and pattern of breathing that used in combination with numeric values and overall clinical picture can provide clinicians with a more complete assessment of patient status
- Normal Waveform: ETCO$_2$ waveform is the opposite of a normal respiratory rate waveform from ECG monitoring because it follows expiration instead of inspiration. A normal ETCO$_2$ waveform has an almost rectangular shape with a rapid upstroke from beginning expiration creating a rise in CO$_2$ levels, followed by a flat plateau period corresponding to the complete exhalation period, and then a sharp drop in the waveform at the beginning of inhalation/inspiration of new breath where there is no CO$_2$. ETCO$_2$ values are obtained at the endpoint of exhalation (A).

A. 

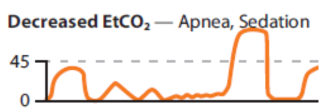
B. 

- Bronchospasm: With airway obstruction the capnogram waveform has an initial upstroke that is more gradual than normal and without the flat plateau, creating a ‘Shark fin’ appearance from difficulty exhaling (B)
- Hypoventilation: increased $ETCO_2$ value with lower respiratory rate that shows as a tall, long waveform (C)

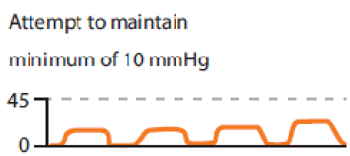
C. 

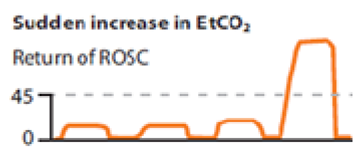
D. 

- Hyperventilation: lower $ETCO_2$ value with faster respiratory rate that shows as a short, narrow, more rapid waveform (D)
- Apnea: Periods of no waveform or decreasing shallow waveforms with sudden breaths of higher CO_2 levels (E)

E. 

- CPR Waveform: Waveform corresponds to each compression. Attempt to maintain at least 10 mmHg CO_2 (F) and look for a sudden increase in $ETCO_2$ that may indicate return of spontaneous circulation or ROSC (G)

F. 

G. 

- Loss of waveform: No waveform present may indicate apnea, obstruction, cardiac arrest, or disconnection from monitor

C. Understanding changes in $ETCO_2$ levels (DiCorpo et al., 2015; Siobal, 2016; Restrepo et al., 2014; Kodali, 2014)

- Any changes in cellular metabolism, pulmonary perfusion, and ventilation will impact $ETCO_2$ levels. In diseased states where there is a V/Q mismatch, the $PaCO_2$ - $ETCO_2$ difference will increase. This does not mean that $ETCO_2$ is not accurate, it actually provides clinicians with useful information related to cause of the mismatch, the severity of condition, and ability to trend for signs of improvement or worsening condition.

i. Increase in $ETCO_2$ may indicate:

- Hypoventilation
- COPD
- Asthma
- Increased muscular activity- shivering, seizures
- Increased cardiac output
- Fever
- Sepsis
- Equipment malfunction: exhausted CO_2 absorber, contamination of monitor

ii. Rapid large increase in $ETCO_2$ may indicate:

- Malignant hyperthermia
- Return of spontaneous circulation (ROSC)
- Resolution of complete obstruction or bronchospasm
- Bicarb infusion

iii. Decrease in $ETCO_2$ may indicate:

- Hyperventilation
- Pulmonary edema
- Bronchospasm or obstruction
- Decreased muscle activity
- Decreased cardiac output
- Hypothermia
- Metabolic acidosis
- Equipment malfunction: blockage in tubing, disconnection

iv. Rapid large decrease in $ETCO_2$ may indicate:

- Severe hypotension
- Cardiac arrest
- Pulmonary Embolism
- Large hemorrhage

D. Troubleshooting (DiCorpo et al., 2015; Siobal, 2016;)

i. **Always assess patient first!** Does overall clinical picture align with $ETCO_2$ waveform and values?

ii. Check Equipment

- Assess for obstructions or disconnections
- Look at monitor for $ETCO_2$ alarms that indicate problem with equipment
- Sensors in $ETCO_2$ nasal cannulas can become saturated/contaminated with patient secretions and need to be replaced
- $ETCO_2$ monitoring may not be accurate when patients are eating

iii. If there is no identifiable issue with equipment and abnormal $ETCO_2$ values or waveforms raise clinical suspicion of patient issue that cannot be addressed by nursing intervention then notify provider.

D. Charting $ETCO_2$ monitoring in Cerner

- When $ETCO_2$ initiated on bedside monitor and monitor is associated with patient in the chart, then $ETCO_2$ values will automatically transfer into charting along with all other vitals.
- Up to nursing discretion if they want to write a note or right click and "add comment" to first $ETCO_2$ value to indicate why $ETCO_2$ was started i.e. "Patient is high risk d/t known OSA and COPD" or "ordered by anesthesiologist".

E. Demonstration of initiating $ETCO_2$ monitoring

i. $ETCO_2$ nasal cannulas

- Obtained from PACU storage room
- Placed on patient like normal nasal cannula but ensure small holes near nasal prongs face upward
- May connect nasal cannula to oxygen (max of 5L like normal NC) but does not have to be connected to oxygen to use $ETCO_2$ monitoring.

ii. $ETCO_2$ monitor adaptors

- All monitors in PACU have $ETCO_2$ adaptors in place
- Slide down cover on the left side of adaptor and gently screw orange nasal cannula adaptor into bedside monitor outlet (shown in pictures on handout). *Do not screw in orange adapter tight, it makes it very difficult to remove and is not necessary to activate monitoring*
- If $ETCO_2$ monitoring section does not automatically appear on screen when orange adapter is screwed into module, then activate $ETCO_2$ monitoring adaptor, the same way as for activating arterial line monitoring.

iii. $ETCO_2$ in-line adaptors

- There are in line adaptors available that work with both ventilator and BIPAP circuits.
- When you call respiratory for a BIPAP or ventilator you can ask them for $ETCO_2$ monitoring adaptor as well. These adaptors are not currently stocked in PACU and must be obtained from respiratory
- RTs will attach the in-line adaptors to the circuit being used when they are setting it up, but the waveform and values are the same as when used with nasal cannulas.

E. Hands-on practice session with $ETCO_2$ monitoring equipment

i. Equipment available to practice with

- $ETCO_2$ nasal cannula
- Phillips bedside monitor with $ETCO_2$ adaptor

V. Summary

- $ETCO_2$ monitoring is an additional tool available to clinicians that can be utilized in order to improve the quality and safety of patient care in the PACU. Respiratory depression is a real risk for the patients we care for, and for those patients known to be at a higher risk, $ETCO_2$ monitoring provides an easy and effective way to detect and treat respiratory depression faster in order to prevent patient harm. $ETCO_2$ monitoring is an accurate measure of ventilation that is not affected by supplemental oxygen and provides immediate notification of respiratory depression, hypoventilation and apnea. $ETCO_2$ monitoring provides an accurate respiratory rate, an $ETCO_2$ numeric value, and a waveform tracing for each breath, all of which taken together with a patient's overall clinical picture provides clinicians with a more accurate and complete assessment of patient status. $ETCO_2$ monitoring is recommended by numerous national organizations for both extreme cases such as cardiac arrest and respiratory distress and for everyday monitoring of high-risk patients so that opioids and sedatives can be administered in a safe manner.

VI. Question and Answer session

APPENDIX E:

EXPERT APPROVAL LETTER

THE UNIVERSITY OF ARIZONA
College of Nursing

As a provider with knowledge and experience in End Tidal CO_2 monitoring, I certify that I have read and reviewed this nursing education presentation and pre/post-test prepared by Rachel Ramirez and approve that the content is accurate and appropriate for educating bedside RNs on this topic.

Heather L Carlisle

____ Date: ____May 31, 2019_______ Dr. Heather Carlisle, DNP, AGACNP

____ Date: ___May 30, 2019________
Dr. Caroline Zawilski, MD, Anesthesiology

APPENDIX F:

PRE-TEST

Pre-test

Please circle the correct answer for each of the following questions

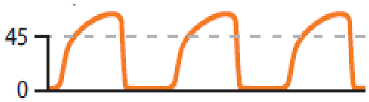
1. Pulse oximetry is an accurate measure of:
   A. Oxygenation
   B. Ventilation
   C. Respiratory rate
   D. Both A and B

2. Which patient would be the highest risk for postoperative respiratory depression:
   A. 20-year-old smoker
   B. 40-year old with heart failure
   C. 75-year-old on a Patient Controlled Analgesic pump
   D. 54-year-old diabetic

3. $ETCO_2$ monitoring should be initiated:
   A. On every patient who received general anesthesia
   B. Only with a physician order
   C. On a patient receiving CPR
   D. Only on intubated patients

4. A patient with an $ETCO_2$ reading of 49 mmHg should be assessed for:
   A. Hyperventilation
   B. Hypoventilation
   C. Apnea
   D. Nothing, that is a normal value

5. Which condition is most likely present if this $ETCO_2$ waveform is seen:



   A. Obstructive Sleep Apnea
   B. Chronic Obstructive Pulmonary Disease
   C. Opioid induced respiratory depression
   D. Return of Spontaneous circulation (ROSC)

6. Respiratory depression would be demonstrated by:
   A. SaO2 of 91%
   B. Respiratory rate of 9 bpm
   C. $ETCO_2$ of 35 mmHg
   D. Audible snoring

7. If you are having frequent alarms on your $ETCO_2$ monitor you should:
   A. Adjust the alarm settings
   B. Notify the provider
   C. Check the patient and tubing
   D. Silence the alarms until they stop

8. Increased $ETCO_2$ values can be caused by:
   A. Hypothermia
   B. Shivering
   C. Hyperventilation
   D. Severe pulmonary edema

9. Predictors of Obstructive Sleep Apnea include:
   A. BMI >35
   B. Neck Circumference >41 cm
   C. Male
   D. All of the above

10. The reversal agent for opioid induced respiratory depression is:
    A. Midazolam
    B. Glycopyrrolate
    C. Flumazenil
    D. Naloxone

11. Effective compressions during a Code Blue are indicated by an $ETCO_2$ level of:
    A. $\leq$ 45 mmHg
    B. $\geq$ 10 mmHg
    C. $\geq$ 35 mmHg
    D. $ETCO_2$ values do not correlate to effective compressions

12. The Joint Commission recommends the use of $ETCO_2$ monitoring:
    A. On patients that are high risk for respiratory depression
    B. On all patients that are receiving opioids
    C. On all postoperative patients
    D. On patients receiving supplemental oxygen

13. The accuracy of current respiratory rate monitoring using ECG leads is affected by:
    A. ECG lead position
    B. Patient position and movement in bed
    C. Body habitus of the patient
    D. All of the above

14. $ETCO_2$ monitoring is an accurate measure of
    A. Oxygenation, respiratory rate, & airway obstruction
    B. Ventilation, respiratory rate, & airway obstruction
    C. Oxygenation, airway obstruction, & level of consciousness
    D. Ventilation, airway obstruction, & level of consciousness

15. Which of the following is NOT true about $ETCO_2$ nasal cannulas?
    A. The small holes near the nasal prongs need to face upward
    B. The orange end of the cannula screws into the Phillips bedside monitor
    C. The nasal cannula needs to be connected to oxygen in order to monitor $ETCO_2$
    D. The nasal cannulas are routinely stocked in the PACU storage room

For each of the following questions please circle the response that best reflects your attitude toward each statement.

16. I feel confident in my ability to read and interpret $ETCO_2$ waveforms.

1. Strongly Disagree	2. Disagree	3. Neither Agree or Disagree	4. Agree	5. Strongly Agree

17. I feel confident in my ability to set up and start $ETCO_2$ monitoring on a patient.

1. Strongly Disagree	2. Disagree	3. Neither Agree or Disagree	4. Agree	5. Strongly Agree

18. I feel confident in my ability to identify patients at high risk for respiratory depression.

1. Strongly Disagree	2. Disagree	3. Neither Agree or Disagree	4. Agree	5. Strongly Agree

19. I feel confident that I have the skills and knowledge to utilize $ETCO_2$ monitoring effectively when needed in my everyday practice.

1. Strongly Disagree	2. Disagree	3. Neither Agree or Disagree	4. Agree	5. Strongly Agree

20. I think it is likely given my current knowledge that I will initiate $ETCO_2$ monitoring for at least 1 patient in the next month.

1. Strongly Disagree	2. Disagree	3. Neither Agree or Disagree	4. Agree	5. Strongly Agree

APPENDIX G:

POST-TEST

Post-test

Please circle the correct answer for each of the following questions

1. Predictors of Obstructive Sleep Apnea include:
    A. Neck Circumference >41 cm
    B. Male
    C. BMI >35
    D. All of the above

2. The reversal agent for opioid induced respiratory depression is:
    A. Midazolam
    B. Naloxone
    C. Glycopyrrolate
    D. Flumazenil

3. Respiratory depression would be demonstrated by:
    A. SaO2 of 91%
    B. $ETCO_2$ of 35 mmHg
    C. Respiratory rate of 9 bpm
    D. Audible snoring

4. Which of the following is NOT true about $ETCO_2$ nasal cannulas?
    A. The orange end of the cannula screws into the Phillips bedside monitor
    B. The nasal cannula needs to be connected to oxygen in order to monitor $ETCO_2$
    C. The small holes near the nasal prongs need to face upward
    D. The nasal cannulas are routinely stocked in the PACU storage room

5. If you are having frequent alarms on your $ETCO_2$ monitor you should:
    A. Notify the provider
    B. Check the patient and tubing
    C. Adjust the alarm settings
    D. Silence the alarms until they stop

6. $ETCO_2$ monitoring should be initiated:
    A. On every patient who received general anesthesia
    B. Only with a physician order
    C. Only on intubated patients
    D. On a patient receiving CPR

7. $ETCO_2$ monitoring is an accurate measure of

A. Oxygenation, airway obstruction, & level of consciousness

B. Ventilation, airway obstruction, & level of consciousness

C. Oxygenation, respiratory rate, & airway obstruction

D. Ventilation, respiratory rate, & airway obstruction

8. A patient with an $ETCO_2$ reading of 49 mmHg should be assessed for:

A. Hypoventilation

B. Apnea

C. Hyperventilation

D. Nothing, that is a normal value

9. Pulse oximetry is an accurate measure of:

A. Oxygenation

B. Ventilation

C. Respiratory rate

D. Both A and B

10. The accuracy of current respiratory rate monitoring using ECG leads is affected by:

A. ECG lead position

B. Patient position and movement in bed

C. Body habitus of the patient

D. All of the above

11. Which patient would be the highest risk for postoperative respiratory depression:

A. 20-year-old smoker

B. 40-year old with heart failure

C. 54-year-old diabetic

D. 75-year-old on a Patient Controlled Analgesic pump

12. The Joint Commission recommends the use of $ETCO_2$ monitoring:

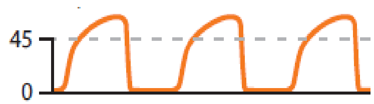
A. On patients that are high risk for respiratory depression

B. On all postoperative patients

C. On all patients that are receiving opioids

D. On patients receiving supplemental oxygen

13. Which condition is most likely present if this $ETCO_2$ waveform is seen:



A. Obstructive Sleep Apnea

B. Return of Spontaneous circulation (ROSC)

C. Opioid induced respiratory depression

D. Chronic Obstructive Pulmonary Disease

14. Increased $ETCO_2$ values can be caused by:

A. Hypothermia

B. Severe pulmonary edema

C. Shivering

D. Hyperventilation

15. Effective compressions during a Code Blue are indicated by an $ETCO_2$ level of:

A. ≥ 10 mmHg

B. ≥ 35 mmHg

C. ≤ 45 mmHg

D. $ETCO_2$ values do not correlate to effective compressions

For each of the following questions please circle the response that best reflects your attitude toward each statement.

16. I feel confident in my ability to read and interpret $ETCO_2$ waveforms.

1. Strongly Disagree	2. Disagree	3. Neither Agree or Disagree	4. Agree	5. Strongly Agree

17. I feel confident in my ability to set up and start $ETCO_2$ monitoring on a patient.

1. Strongly Disagree	2. Disagree	3. Neither Agree or Disagree	4. Agree	5. Strongly Agree

18. I feel confident in my ability to identify patients at high risk for respiratory depression.

1. Strongly Disagree	2. Disagree	3. Neither Agree or Disagree	4. Agree	5. Strongly Agree

19. I feel confident that I have the skills and knowledge to utilize $ETCO_2$ monitoring effectively when needed in my everyday practice.

1. Strongly Disagree	2. Disagree	3. Neither Agree or Disagree	4. Agree	5. Strongly Agree

20. I think it is likely given my current knowledge that I will initiate $ETCO_2$ monitoring for at least 1 patient in the next month.

1. Strongly Disagree	2. Disagree	3. Neither Agree or Disagree	4. Agree	5. Strongly Agree

APPENDIX H:

INSTITUTIONAL REVIEW BOARD (IRB) DISCLOSURE FORM

IRB Disclosure Form

Improving the Effective Use of End-Tidal Carbon Dioxide Monitoring Postoperatively Through Nursing Education

Principal Investigator: Rachel Ramirez

The purpose of this this quality improvement project is to provide evidenced-based education to the PACU nursing staff at Northwest Medical Center on $ETCO_2$ monitoring in order to increase nursing knowledge, confidence, and ability to utilize $ETCO_2$ monitoring effectively in the postoperative setting.

If you choose to take part in this project, you will be asked to take a 20 question pre-test, listen to an educational presentation, followed by a 20 question post-test. This will take approximately 30 minutes to complete the tests and presentation. There are no foreseeable risks associated with participating in this project and you will receive no immediate benefit from your participation. Survey responses are anonymous.

If you choose to participate in the project, participation is voluntary, refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may withdraw at any time from the project. In addition, you may skip any question that you choose not to answer. By participating, you do not give up any personal legal rights you may have as a participant in this project.

For questions, concerns, or complaints about the project, you may call Rachel Ramirez, RN, DNP Student at (702) 415-9481 or reramirez@email.arizona.edu

APPENDIX I:

SITE APPROVAL LETTER

NORTHWEST
MEDICAL CENTER

6200 North La Cholla Boulevard ▪ Tucson, Arizona 85741 ▪ **Phone:** 520-742-9000 ▪ **Web:** NorthwestMedicalCenter.com

Northwest Medical Center
6200 N. La Cholla Blvd.
Tucson, AZ 85741

Date: 7/15/2019
University of Arizona Institutional Review Board
c/o Office of Human Subjects
1618 E Helen St
Tucson, AZ 85721

Please note that Mrs. Rachel Ramirez, University of Arizona Graduate Student, has the permission of Northwest Medical Center to conduct her Quality Improvement Project titled, "Improving the Effective Use of End-Tidal Carbon Dioxide Monitoring Postoperatively Through Nursing Education" in the Post Anesthesia Care Unit (PACU) of Northwest Medical Center's 6200 N. La Cholla campus.

Mrs. Ramirez will contact employees that are bedside Registered Nurses in PACU to recruit them to attend an education presentation to learn about End Tidal Carbon Dioxide (ETCO2) monitoring. Those who attend the education session will be invited to take a pre-test and post-test on ETCO2 monitoring content and nursing confidence in using ETCO2 monitoring. The pre and post-tests are voluntary, anonymous, and collect no demographic or personal information that could be traced back to individuals.

Mrs. Ramirez will complete this project on her own time and nurses who participate will receive in-service time. Mrs. Ramirez has offered to provide a copy of the University of Arizona IRB-approved, stamped consent document before she recruits participants on campus, as well as the results of the Quality Improvement project. This project will be completed no later than November 2019.

If there are any questions, please contact my office.

Signed,

Jorge Salas
Chief Nursing Officer
Northwest Medical Center

APPENDIX J:

RECRUITMENT FLYER

You're Invited

To An

Educational Presentation

To Learn About

End-Tidal CO2 Monitoring

& Best Practice for Patient Care

October 2nd & 3rd at 0700 & 1500

In PACU Break Room

All Perioperative RNs Welcome

& Refreshments Provided

Presented by Rachel Ramirez, RN as a requirement for the DNP Program at University of Arizona

APPENDIX K:

THE UNIVERSITY OF ARIZONA INSTITUTIONAL REVIEW BOARD APPROVAL LETTER

THE UNIVERSITY OF ARIZONA
Research, Discovery & Innovation

Human Subjects Protection Program

1618 E. Helen St.
P.O.Box 245137
Tucson, AZ 85724-5137
Tel: (520) 626-6721
http://rgw.arizona.edu/compliance/home

Date:	September 17, 2019
Principal Investigator:	Rachel Elizabeth Ramirez
Protocol Number:	1909967478
Protocol Title:	Improving the Effective Use of End-Tidal Carbon Dioxide Monitoring Postoperatively Through Nursing Education
Determination:	Human Subjects Review not Required

Documents Reviewed Concurrently:

Data Collection Tools: *Post Test.docx*
Data Collection Tools: *Pre Test.docx*
HSPP Forms/Correspondence: *Advisor Confirmation Email.pdf*
HSPP Forms/Correspondence: *IRB form 2019 9.8.pdf*
Informed Consent/PHI Forms: *Disclosure Form IRB Ramirez.doc*
Other Approvals and Authorizations: *COI Certification Complete for 1909967478.msg*
Other Approvals and Authorizations: *Site appproval letter-NW.pdf*
Participant Material: *Educational Presentation Outline.docx*
Recruitment Material: *ETCO2 Education Flyer.docx*

Regulatory Determinations/Comments:

- Not Human Subjects Research as defined by 45 CFR 46.102(e): as presented, the activities described above do not meet the definition of research involving human subjects as cited in the regulations issued by the U.S. Department of Health and Human Services which state that "Human subject means a living individual about whom an investigator (whether professional or student)conducting research: (i) Obtains information or biospecimens through intervention or interaction with the individual, and uses, studies, or analyzes the information or biospecimens; or (ii) Obtains, uses, studies, analyzes, or generates identifiable private information or identifiable biospecimens. "

The project listed above does not require oversight by the University of Arizona.

If the nature of the project changes, submit a new determination form to the Human Subjects Protection Program (HSPP) for reassessment. Changes include addition of research with children, specimen collection, participant observation, prospective collection of data when the study was previously retrospective in nature, and broadening the scope or nature of the study activity. Please contact the HSPP to consult on whether the proposed changes need further review.

The University of Arizona maintains a Federalwide Assurance with the Office for Human Research Protections (FWA #00004218).

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