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Implementation of Capnography Monitoring to Improve Outcomes among Intensive Care Unit Patients on Patient-Controlled Analgesia or Opioids

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Implementation of Capnography Monitoring to Improve Outcomes among Intensive Care Unit Patients on Patient-Controlled Analgesia or Opioids

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Abstract

Background: Patient-controlled analgesia (PCA) administration of opioids is associated with risk for respiratory depression. Capnography is a non-invasive way to identify early respiratory depression and prevent adverse patient events.

Purpose: This project evaluated the effectiveness of capnography versus standard monitoring in reducing adverse events among patients admitted to an intensive care unit (ICU) who were prescribed PCA opioids and evaluated patients at high-risk for respiratory depression according to age, gender, diagnosis, co-morbidities, and type of opioid prescribed.

Methods: This project used a pre- and post-intervention design to compare differences in the number of adverse events among 20 adult patients admitted to an ICU during a six-month period who were prescribed PCA opioids and received either capnography monitoring or standard monitoring. A chi-square test was conducted to evaluate group differences.

Results: The number of adverse events was not significantly different between patients who received standard monitoring versus those who received capnography (X^2=0.00, df=1, N=20, p>0.05). Adverse events were not significantly associated with age, gender, number of co-morbidities, type of opioid, and diagnosis (p>0.05).

Conclusions: Implementation of capnography among ICU patients on PCAs did not decrease the number of adverse events. However, there were favorable trends noted with regards to sedation level and a decrease in the occurrence of bradypnea in patients receiving capnography. Results from this project will guide the implementation of capnography throughout the institution.

Introduction

Opioids used for pain control are recognized to be a main factor for respiratory depression (The Joint Commission, 2012) and account for a rising number of patient deaths in hospitals. This has raised alarm from both The Joint Commission (TJC) (2019) and the Institute for Safe Medication Practices (ISMP) (2009, 2013). The risk for respiratory depression increases with the use of patient-controlled analgesia (PCA) and frequent administration of high doses of opioids without PCA (ISMP, 2013). This increased mortality results from failure to recognize some patients at high risk for respiratory depression with opioid administration and lack of close monitoring of these same patients.

Professional organizations suggest institutions define patient characteristics that are associated with a high-risk for respiratory depression based on their community's population (American Society of Anesthesiologists (ASA), 2018; Jarzyna, et. al., 2011). These same organizations, as well as TJC and ISMP, encourage hospitals to develop policies and procedures for monitoring all patients receiving opioids, particularly those at high-risk for respiratory depression, and to use technology to assist with monitoring. Capnography detects early respiratory failure and is a sensitive tool for identifying respiratory depression before vital sign and sedation level deterioration.

This evidenced-based practice (EBP) project compared capnography monitoring versus standard monitoring among patients prescribed epidural or intravenous (IV) PCAs or high doses of opioids and evaluated the number and type of adverse events including rates of hypercapnia and/or hypoxia, hypotension, sedation level, and bradypnea. This project also evaluated the impact of age, gender, diagnosis, type of opioid prescribed, and number of co-morbidities on the number of adverse events to identify patient characteristics associated with a high risk for

respiratory depression and define criteria for capnography monitoring. The project informed the development of criteria for capnography monitoring for patients receiving opioids at an academic research hospital and provided evidence to guide the development of policies, procedures, and education for nursing and medical professionals when capnography is implemented throughout the hospital.

Significance

The risk of death from respiratory depression due to opioid therapy increases with the use of patient-controlled analgesia (PCAs). In 2008, an analysis of 500 hospitals revealed that 6.5% of PCA errors caused patient harm, as compared with 1.5% general medication errors (Hicks, Sikirica, Nelson, Schein, Cousins, 2008). In a retrospective review of national, multi-institutional post-operative opioid overdose, Cauley, et. al. (2017) described that the frequency of overdose doubled from 0.6 to 1.1 per 1000 cases from 2002 to 2011. The authors concluded that recognition of patients who were at high risk for overdose and implementation of proper monitoring should be employed to prevent fatalities. In 2012, TJC issued a sentinel alert advising hospitals to implement policies for the early assessment of opioid induced respiratory depression. The Joint Commission has no specific monitoring recommendations other than identifying patients as high risk and implementing evidenced based guidelines (TJC, 2019). The ISMP recommends regular interval monitoring of vital signs, physical assessment, pain and sedation assessment, and monitoring of respiratory status using technology (ISMP, 2013). Capnography is a sensitive method for measuring ventilation and respiratory rate. It can provide early warning of respiratory failure hours before pulse oximetry detects oxygen desaturation (Burton, Harrah, Germann, & Dillion, 2006; Kopka, et. al., 2007). Implementing capnography has the potential to detect respiratory deterioration early in order to institute measures to prevent respiratory

depression, improve outcomes, and decrease adverse events among patients receiving PCA and opioids in the ICU.

Background

Capnography is a sensitive technology used for identifying normal oxygen exchange. Capnography, or end tidal carbon dioxide (ETCO2) monitoring, detects levels of carbon dioxide in a person's blood. Normal ETCO2 levels are between 35-45 mm Hg. High levels of ETCO2 are called hypercapnia and indicate that the person is retaining carbon dioxide. This happens with depressed respiratory rate. Capnography has the advantage of detecting early respiratory depression as the ETCO2 will start to rise before the oxygen level in the blood begins to fall (Jarzyna, et. al., 2011; Burton, Harrah, Germann, & Dillion, 2006; Kopka, et. al., 2007)

In 2017, the Surgeon-in-Chief at the institution where this project was implemented requested that capnography be employed as a non-invasive way to identify early respiratory depression for patients on both epidural and intravenous patient-controlled analgesia (PCA). The current process for monitoring all patients in the ICU consists of continuous vital sign monitoring, including pulse oximetry, and sedation level. Pain and sedation are assessed every four hours or more frequently if the patient is not achieving satisfactory pain control or if there are rate changes to the PCA or extra doses of opioids administered for those not on a PCA. Capnography monitoring is currently not routinely used for patients on PCAs or receiving opioids in the ICU.

At the same time as the Surgeon-in-Chief's request, the institution underwent a voluntary survey by the ISMP. The ISMP recommended utilizing advanced technology, such as capnography, for recognizing early respiratory depression for patients on PCAs. Although vital sign and sedation monitoring is crucial, capnography is a more sensitive method to recognize

early respiratory depression. Based on both the Surgeon-in-Chief's' request and the ISMP recommendations, the Oncology Clinical Nurse Specialist was charged with researching best practices and tools for detecting early respiratory depression in patients receiving opioids through a PCA.

It was agreed at the outset of this initiative that it would not be necessary for every patient on a PCA or receiving opioids in the hospital to be placed on capnography based on the recognition that not all patients would be at high risk for respiratory depression. Therefore, following recommendations from professional organizations (ISMP, 2013; ASA, 2018; Jarzyna,et. al., 2011), defining the characteristics of what makes a patient who is prescribed opioids as "high-risk" for respiratory depression is of interest to the organization where this project was conducted. It was also pointed out by the pediatricians and pediatric nurses that children do not tolerate the large nasal cannula used for capnography. Currently, children at this institution on PCAs and receiving high doses of opioids are monitored using continuous pulse oximetry. Therefore, children were excluded from this project. A group of stakeholders met in 2017 to determine the criteria which would qualify a patient as high-risk for respiratory depression with opioid use and thus require capnography monitoring. The original stakeholder group consisted of practitioners from the Pain and Palliative Service, surgeons, physicians, and nurse practitioners from service areas outside of surgery, plus Clinical Nurse Specialists and nurses from across the hospital. The final criteria developed focused exclusively on dosages of opioids and adjunct medications prescribed; patient characteristics such as age and co-morbidities that could also qualify a patient as high-risk were assumed left to the discretion of the prescriber or nurse.

Based on the work done by the stakeholder group, a pilot project was proposed to implement and evaluate capnography monitoring in the ICU before deploying this equipment to the entire

hospital. The results of this EBP project will contribute to final policy and procedure development. This project added important elements for the development of nursing and practitioner education through the experience of the staff in the pilot unit. It identified technological issues that will impact delivery of care. With publication of results, the project could help other institutions decide if implementation of capnography monitoring would be beneficial for their patient population.

Needs Assessment

A Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis of barriers and facilitators for this initiative was conducted (see Appendix A). The implementation of capnography monitoring in the ICU for patients at high-risk for respiratory depression from opioids had strong support from medical and nursing leadership at the institution. Facilitators included a group of stakeholders with expertise in pulmonary medicine and pain management among medicine, nursing, respiratory therapy, and pharmacy. Guidance from accrediting organizations concerned with patient safety and evidence in the literature also provided validation of the need for using technology to improve assessment in patients receiving opioids (TJC, 2019; ISMP, 2009, 2013). Capnography has been demonstrated through randomized controlled studies to be superior in providing non-invasive monitoring for early respiratory depression (Deitch, et. al., 2010; Friedrich-Rust, et. al., 2014; Li, et. al., 2018). New vital sign machines with capnography capability have been purchased for units outside of the ICU. End tidal carbon dioxide will be able to be monitored outside of the ICU for patients on PCAs or receiving high doses of opioids and at risk for respiratory depression. This has the advantage of allowing nurses to perform "softer" interventions such as withholding the narcotic or re-positioning rather than administration of naloxone or other rescue measures. Other facilitators included a robust nursing shared governance model that is committed to implementing best

evidenced based practice in the care of our patients. Nurses newly employed by the Clinical Center also bring experience from the community and champion best practices. A strong nursing education department and CNS group who are engaged with the nurses can quickly develop education plans and competencies to enhance nursing practice of patients receiving opioid or narcotic infusions.

Barriers included concerns from our cybersecurity department about hacking into informatic systems. The capnography equipment will be wireless, requiring the informatics security department to fully test the wireless functionality for breeches interfacing with the medical records informatic enterprise. Other barriers included agreement on the definition of patients considered high risk for respiratory depression and based on long tenured practitioners, some may not be up to date on current practice. There is also the possibility for resistance to placing patients on capnography due to the fear that capnography would interfere with research interventions. Continued assurance that this intervention will not interfere with research objectives while ensuring ongoing best clinical care of the patient is necessary to prevent derailment of this initiative.

Problem Statement

Currently, patients in the ICU on PCAs and opioids are not monitored with capnography. Implementing capnography monitoring for ICU patients on PCAs and opioids had the potential to decrease the incidence of adverse events and identify patients who would most benefit from this level of monitoring.

Use of naloxone from January 2019 through May 2020 throughout all units of this institution to treat respiratory depression secondary to opioids had been 37 occurrences. Detection of early respiratory depression using capnography allows prescribers and nurses to intervene with less

invasive interventions before requiring the administration of naloxone. It allows the nurse to perform interventions such as repositioning and/or decreasing or withholding opioid doses before administration of naloxone as this antidote is not without adverse effect.

Purpose Statement

The purpose of this project was to evaluate the effectiveness of capnography versus standard monitoring to improve outcomes among patients admitted to an intensive care unit (ICU) who were prescribed patient-controlled analgesia (PCA) or high doses of opioids and were considered at high risk for respiratory depression.

Aims and Objectives

The aims for this project were to:

1. Implement capnography monitoring for all ICU patients on PCAs and high doses of opioids beginning September 8, 2020 through December 1, 2020.
2. Conduct a retrospective chart review to create a data set with outcomes for ICU patients on PCAs and high dose opioids who received standard monitoring for 3 months prior to implementation of capnography.
3. Compare differences in number of adverse patient events (defined as hypercapnia and/or hypoxia, decreased sedation, bradypnea, hypotension) between ICU patients on PCAs or high doses of opioids monitored with capnography versus standard monitoring by December 31, 2020.
4. Compare differences in number of episodes of adverse patient events (hypercapnia, hypoxia, hypotension, decreased sedation level, bradypnea) as well as variation in age, sex, diagnosis, co-morbidities, and type of opioid between ICU patients on PCAs or high

dosages of opioids to better define high-risk for respiratory depression versus not high-risk by December 31, 2020.

Objective for this EBP initiative included:

1. Decrease in adverse respiratory events in adult high-risk patients in the ICU who received PCAs or high doses of opioids to zero during the 3-month period after implementation of capnography by December 2020.
2. Analyze data and use project findings to inform the development of policies and procedures for capnography monitoring for patients on PCAs or receiving opioids by January 2021.

Literature Review

A literature search was conducted on September 10, 2019 to determine if capnography was superior at detecting early respiratory depression as opposed to pulse oximetry, a measurement of oxygen saturation, in patients receiving moderate sedation and/or opioids. The literature search was conducted with the assistance of one of the research librarians at the institution in which this project was implemented. Databases searched were PubMed, Medline, CINAHL, Google Scholar, and Web of Science. Terms used for the literature search, which included Boolean terms, were “capnography”, “capnography monitoring AND opioids”, “capnography AND moderate sedation”, “capnography/or analgesia”, “capnography/or anesthesia” and “end tidal CO2”. MeSH terms for PubMed were applied including “capnography” “analgesia” and “monitoring”. Limits for the search included articles no older than 15 years and articles published in English or translated into English. The search yielded a total of eight usable articles

(Campbell, et. al., 2016; Deitch, Miner, Chudnofsky, Dominici & Latta, 2010; Friedrich-Rust, et. al., 2014; Gupta, et. al., 2018; Jarzyna, et. al., 2011; Mehta, et. al., 2016; Li, et. al., 2018; Sites, Surprise, McNeil, Northrop & Ruyter, 2017). (See Appendices B and C)

Inclusion criteria for the search included 1) Use of capnography, 2) Adult population greater than 18, 3) Moderate sedation or patient controlled analgesia, 4) Articles published in English 5), Articles published in the last 15 years, 6) Randomized controlled trials, 7) Position statements/Clinical Practice Guidelines from professional organizations, and 8) Systematic Reviews.

Since capnography is also used in intensive care units and the operating room, exclusion criteria included the use of capnography in clinical areas where it is standard of practice. This includes 1) Use of capnography in operating rooms, 2) During resuscitative events and 3) During intubation or endotracheal tube placement. Also excluded were opinion papers and case reports.

All randomized controlled studies but two found monitoring for respiratory compromise with capnography technology was superior to other forms of non-invasive monitoring. Several trials found that patients who received capnography monitoring, as opposed to continuous pulse oximetry, had fewer events of hypoxemia, hypoventilation, and earlier detection of respiratory compromise (Deitch, et. al., 2010; Friedrich-Rust, et. al., 2014; Li, et. al., 2018; Stites, et. al., 2017). A systematic review by Gupta, et. al. (2018) found that monitoring with pulse oximetry and capnography, as well as sedation level, resulted in decreased respiratory adverse events for patients defined as high-risk. This study identified common factors that put a patient at high-risk of respiratory depression. Common factors in the studies that put a patient at higher risk of OIRD included preoperative gabapentin or sustained release oxycodone, time from surgery (first 24 hours after surgery (in PACU), with a predominance in the first 12 hours), age (>60 years), sex

(female) and comorbidities such as obstructive sleep apnea, cardiac disease, obesity, two or more comorbidities, and opioid dependence. Professional organizations, including the American Society of Anesthesiologists, American Society for Pain Management Nursing and ISMP endorse capnography as the most sensitive method for non-invasive monitoring of ventilation.

Although capnography is a sensitive method for detecting impaired ventilation, two of the randomized controlled trials found that frequent monitoring of sedation level, pulse oximetry, and vital signs was as effective as capnography in obtaining safe outcomes for the patient. The studies by Campbell et. al. (2016) and Mehta, et. Al., (2016) were randomized controlled trials that enrolled patients older than 16 years of age undergoing procedural sedation. The researchers found no differences in clinical outcomes between those receiving frequent monitoring versus those patients receiving capnography. Though capnography detected hypoxia earlier than pulse oximetry alone, the researchers concluded that frequent monitoring of sedation, vital signs and pulse oximetry was as effective as capnography monitoring.

Conversely, other studies found added value when capnography was utilized during moderate sedation. Dietch, et. al. (2010) found a 15% decrease in the incidence of hypoxia with use of capnography versus standard monitoring in participants who were receiving propofol in an emergency department. Friedrich-Rust, et. al., (2014) found parallel results when using propofol for patients undergoing colonoscopy or colonoscopy plus endoscopy. Patients in the capnography group experienced fewer episodes of hypoxemia (18% vs. 32%). Li, et. al. (2018) studied women who were receiving propofol while undergoing lumpectomy. This study replicated the above studies in that the control group received standard monitoring plus ETCO2 monitoring that could be visualized by the provider. The researchers found that CO2 retention

was lower in the control group, episodes of apnea occurred less frequently in the control group, and women who had ETCO2 monitoring had shorter recovery times.

Use of capnography allows nurses to intervene early on recognition of opioid induced respiratory depression. Stites, et. al., (2017) studied nurses' recognition of increased CO2 levels and actions taken to correct impending respiratory distress. This study looked at the number of rapid response calls (RRT) for opioid induced respiratory depression in patients who received opioids through a PCA before and after hospital wide implementation of capnography for all patients on PCAs. They found that the number of RRTs decreased after implementation of capnography (0.04% pre-intervention vs. 0.02% post-intervention) indicating that nurses were identifying opioid induced respiratory depression early.

Many studies support the use of capnography as a sensitive way to monitor for early respiratory depression. A systematic review by Gupta, et. al. (2018) was conducted that summarized risk factors of opioid induced respiratory depression in the postoperative period and monitoring interventions that decreased adverse events. The review comprised 13 studies with 871,912 surgical patients. Monitoring of sedation level, pulse oximetry and capnography in patients at risk of opioid induced respiratory depression (OIRD) decreased adverse respiratory events. The authors recommended that monitoring ETCO2 and oxygen saturation coupled with assessment of risk factors listed above will decrease adverse events in post-operative patients.

Finally, the American Society of Pain Management Nursing (ASPMN) agrees with the ISMP, The Joint Commission, American Society of Anesthesiologists (2018), and other agencies concerned with patient safety that capnography can provide early detection of respiratory compromise in a high-risk patient thus allowing nurses to intervene before cardiac arrest (Jarzyna, et.al., 2011). Their published position statement was based on extensive review of the

literature, external peer review of applicability, and accuracy of the literature. Based on review of the literature, risk factors of OIRD are divided into four categories: Individual risk, iatrogenic risk, pharmacology, and monitoring capabilities. The ASPMN acknowledges that the cost of capnography equipment, diverse patient populations, training of nursing staff, and non-consensus of monitoring frequency are challenges when interpreting guidelines.

Evidenced Based Translation Model

The model that was selected for this project was the Rosswurm and Larrabee model (Rosswurm & Larrabee, 1999). The purpose of this model is to integrate evidenced based practice into care and move away from traditional practice models. The model consists of six steps: Assess the need for change, link outcomes, synthesize the evidence, design the practice change, implement, and integrate and maintain (see Appendix D). This model mirrors the practice of a Clinical Nurse Specialist (CNS). It is a linear model that allows for in-depth analysis at each step. The details surrounding this model for the project include:

1. Assess need for change in practice: The need for more sensitive monitoring for patients on PCAs and receiving escalating doses of opioids had been identified. A group of stakeholders from different specialty areas met. Data regarding adverse events was reviewed at the initial meeting and the need for improvement in our practice was identified.

2. Link outcomes: Outcomes for the implementation of capnography monitoring were identified. Rapid response calls and events surrounding respiratory depression with opioids (naloxone use) in the post-anesthesia care unit were discussed. Though the

history of adverse events has been low for patients on PCAs, these events were discussed with the goal towards avoiding future events.

3. Synthesize evidence: A literature search was conducted. At issue in the literature was the need for defining the "high risk" patient who would benefit from capnography. Over 30 definitions of "high risk" were discovered in the literature. Including all these definitions was neither feasible nor realistic for our population.

4. Design the practice change: In light of all the definitions, the stakeholder group re-convened and decided on the definition of "high risk" for the population that we see at the NIH.

5. Implementation: This pilot project was conducted in preparation for implementation to the rest of the hospital. Nursing policy was updated and education was planned while awaiting final details on arrival and installation of the equipment. Order sets and a medical policy were developed. A final definition of high-risk will be decided upon after review of the findings from this pilot project. Flow sheets will be revised in the future so that nurses have a place to document capnography monitoring.

6. Integrate and Maintain: Policy and procedures will either need to be created or revised once this project is implemented hospital wide.. Whether this change will be integrated into existing nursing policy on non-invasive ventilation, or a medical policy created or revised will need to be decided upon by nursing and medical leadership. Staff education will need to be developed as well. Ongoing, implementation of this new process will need to be evaluated to include patients defined as high-risk, nursing and licensed independent practitioner ongoing education and competency validation, and identification

of equipment issues such as, the number of false alarms. Process and clinical outcome measures will need to be developed to assure that new technology and criteria are being used appropriately, and clinical outcomes demonstrate improvement. Documentation standards and practices will need to be evaluated for consistency.

Methodology

This EBP project implemented and evaluated the effectiveness of capnography versus standard monitoring for improving outcomes among adult ICU patients (defined as aged 18 years or older) on PCAs or receiving opioids. The project design was a pre-and post-intervention comparison of outcomes for ICU patients on PCAs who received standard monitoring over a three-month period compared with those patients who received capnography monitoring for a 3-month period. During implementation of the project, all patients on IV or epidural PCA or those not on PCA but meeting high risk criteria (use of two or more pain control or adjunct agents simultaneously or frequent escalating doses of oral or IV intermittent narcotics) were placed on capnography.

Data was entered into the Statistical Package for Social Sciences (SPSS) software for data analysis. The final sample size was 20 patients: 10 patients in the "Retrospective" sample (hereafter referred to as the "standard monitoring group") and 10 patients in the "Implementation" (referred to as the "capnography group") sample. The spreadsheet was sent to the primary and secondary project advisors, for review of data accuracy. There were no outliers or missing data.

Setting

The setting for this project was a 12-bed ICU in an academic research hospital in the Mid-Atlantic region. This ICU is the only ICU in the hospital and admits medical and surgical patients, including pediatrics.

The ICU has capnography equipment installed and the nurses are experts at interpreting capnography as part of standard critical care competency. Capnography is currently not used routinely on ICU patients who are administered opioids or prescribed PCAs. This form of monitoring is typically only used post-resuscitation for up to 24 hours.

Participants

Eligibility criteria for inclusion in this project for both the standard monitoring and capnography groups included adult patients over the age of 18 who were prescribed either an IV or epidural PCA or opioids administered by another route. Exclusion criteria included those who received sedation due to critical illness and patients who received end of life care. Patients who received sedation due to intubation or critical illness were excluded as they were too critically ill to differentiate if adverse events were due to the opioids or illness.

Recruitment

The sample for this project was a convenience sample of patients admitted to the ICU during the project period who met eligibility criteria.

Risk/Harms

Risk with using capnography is minimal. The nasal cannula is larger than an oxygen cannula so it can be uncomfortable. This can prompt a patient to remove it. Also, cannulas can cause

pressure injury to the ears and nose. Like an oxygen cannula, nurses assessed for pressure injuries caused by devices as part of regular assessment.

Cost and Compensation

Budget requirements were non-existent. Capnography equipment is already installed in the ICU. The ICU nurse educator and CNS provided support for this project and were able to provide ongoing assistance with education of capnography monitoring. The project did not require extra staff support for implementation. Patients were not compensated for their participation.

Interventions

Standard Monitoring Group: A retrospective chart review was conducted to identify all ICU patients prescribed PCAs or opioids three months before implementation of capnography from June through August 2020. These ICU patients received standard monitoring. Standard monitoring consisted of continuous vital sign monitoring including continuous pulse oximetry, pain assessment every four hours, and continuous sedation assessment. Capnography in the ICU during this time period was only used for post-resuscitative events for approximately 24 hours; it was not routinely used for patients receiving PCAs or opioids. Data collection from these patients includes the variables listed in Appendix E.

Capnography Group: Before the implementation phase of the project began, a meeting was called with the medical, nursing, pharmacy, and respiratory staff to describe the project. All patients admitted to the ICU for three months of the intervention period, September through December 8, 2020, on IV or epidural PCAs or those meeting high risk criteria not on PCA (use of two or more pain control or adjunct agents simultaneously or frequent escalating doses of oral

or IV intermittent narcotics) were placed on capnography (Appendix F). In addition to the capnography monitoring, all patients received standard monitoring as described above.

Monitoring equipment utilized in the ICU is the Philips MX800 critical care monitor. This monitor consists of a bedside monitor next to each ICU bed, central monitors at the nursing station and monitors at regular intervals along the upper wall in the hallway (4 hallway monitors). Visualization of all patients can occur anywhere in the ICU main and overflow areas (except the break room, conference room, bathroom, or offices). The central monitor can accommodate up to 12 patients. The equipment measures pulse, respiratory rate, blood pressure, oxygen saturation, and mean arterial pressure with waveforms through the arterial line. For patients without an arterial line and for emergencies in case the arterial line is not functioning well, a blood pressure cuff is placed on the patient and inflated at intervals determined by the nurse and physician to measure blood pressure, pulse, and mean arterial pressure. Oxygen sensors can be placed on fingers, toes, or ears to capture oxygen saturation for those without an arterial line. The monitors record cardiac rhythm through a five-lead electrocardiogram monitoring system. End tidal carbon dioxide (ETCO2) is measured through a nasal cannula designed for ETCO2 measurements. This cannula connects into the monitoring equipment at the bedside to capture values. All patient measurements are continuously recorded and electronically interfaced with the critical care medical record at hourly intervals. All monitors automatically default to the normal value of ETCO2 35-45mmHg and for the purposes of this project, the normal ETCO2 values of 35-45mmHg were utilized.

Outcomes Measured

Outcomes measured included the number and type of adverse events defined as hypercapnia (if on capnography), hypotension, hypoxia, sedation level, and bradypnea.

Hypercapnia was defined as an ETCO2 greater than 45mmHg. Hypotension was defined as a blood pressure <90/60. Hypoxia was defined as an oxygen saturation less than 90 percent. Respiratory rate that was considered an indication of respiratory depression is less than 12 breaths per minute. Sedation level was monitored using the sedation scale associated with the institution's pain scale ranging from alert and oriented to hallucinating/confused to unarousable (see Appendix E).

Measurement of pain utilized the Numeric Pain Rating Scale (McCaffery & Beebe, 1993). This pain scale is a validated pain scale that is widely used throughout the United States. Patients rate their pain from 0 (no pain) to 10 (worst pain). Pain and sedation level were assessed by the nurses every four hours and recorded on the "Pain Flowsheet" in the chart. Medication administration via PCAs was documented on both the Medication Administration Record (MAR) and the PCA Flowsheet. When pain medication was administered or a non-pharmacologic intervention to alleviate pain had been performed (such as a heat pack), pain was reassessed within 60 minutes of the intervention. If the patient continued to verbalize unsatisfactory pain relief, the nurse intervened by either administering more pain medication based on orders from the physician or performing a non-pharmacologic intervention. Administration of extra doses of pain medication were recorded in the MAR and recorded in the PCA Flowsheet.

For patients who were not on PCAs, but prescribed more than one opioid, an opioid plus adjunct medication to achieve satisfactory pain control or escalating doses of opioids, the patient was placed on capnography. Only one patient in the capnography group met this criterion (Appendix F).

Data Collection

The data and variables collected for this project are listed in the Data Dictionary (Appendix E). All data was stored in SPSS software on a password protected computer. Each patient was de-identified and assigned a random participant number and demographic data of age, gender, diagnosis, co-morbidities, and reason for admission was collected from the patient chart. The standard monitoring sample from the retrospective chart review was obtained with the assistance of pharmacy who was able to generate a report of all patients on PCAs or receiving opioids in the ICU for the three months specified. Data collection for both the standard monitoring and capnography groups included date of data collection, assignment of participant number, age, gender, procedure type or reason for ICU admission, diagnosis, type of PCA or receiving high doses of opioids (not IV or epidural), number of and list of specific co-morbidities, adverse events (if any) and nursing actions taken in response to the event, and capnography monitoring (for the capnography group only). All data were retrieved from the medical record and the PI rounded in the ICU daily to see patients and have conversation with the practitioners and nurses. The ICU nurses and respiratory therapists use the electronic Critical Care Flowsheet to document care and events. The Philips monitors automatically transfer information into the critical care flowsheet hourly so patient measurements (including ETCO2) can be retrieved. There was no missing data for this project.

Adverse events that occurred with the PCA and the interventions used to reverse the event were recorded in the medical record. The nurses documented on all events within the Pain Assessment and PCA flowsheets.

Data analysis

Data analysis included descriptive statistics of the sample and variables (see Table 1, Appendix F). After the descriptive statistics of the sample were completed, chi-square analyses were performed to evaluate the impact of capnography monitoring. The independent variable was capnography monitoring, and the dependent variables are adverse events defined as episodes of hypoxia, hypercapnia, hypotension, bradypnea, and sedation level. Alpha was set at *0*.05. The final sample size consisted of 20 patients: 10 in the standard monitoring group and 10 in the capnography group.

Timeline

This project took place from June through December 2020. Support for this project was obtained from nursing and medical leadership in the ICU. Review of background of the project, criteria for capnography with the high risk versus low-risk criteria (Appendix G), and normal ETCO2 values were provided to nursing, respiratory therapists, and practitioner staff in the ICU. Contact information for the investigator was provided in case of questions and the PI rounded in the ICU at least daily Monday through Friday during the implementation period.

Resources Needed

Stakeholders for this project included the ICU leadership (nursing management and attending physicians), ICU medical fellows, the nursing service educator for the ICU, respiratory therapists in the ICU, the ICU pharmacists, and the nursing staff. Nursing, medical, and respiratory therapy staff provided care as is routine in the ICU except for needing to manage the capnography equipment and alarms. This increased the workload of the staff due to issues with the nasal cannula (described in the Results section). The educator, CNS, managers, and charge nurses for the ICU assisted in trouble shooting the equipment and helped identify patients for whom capnography would be beneficial.

Ethical Considerations

The capnography equipment is associated with minimal harm and this intervention is already a standard of care in the community, so no research interventions were conducted. Identifiable patient information was not collected for this project. The Institutional Review Board at the project site deemed this project as exempt from board review due to minimal risk to subjects and not a research intervention.

Security

All patients were de-identified and assigned a random number. All data was stored in SPSS on a password protected computer.

Results

The purpose of this project was to evaluate the effectiveness of capnography versus standard monitoring to decrease adverse events among patients admitted to the intensive care unit (ICU) who were prescribed patient-controlled analgesia (PCA) or high doses of opioids and were considered at high risk for respiratory depression. There were 10 patients who received capnography and 10 patients who received standard monitoring. Most of the patients in both the capnography and standard monitoring groups were over 55 years of age and male (60%). The most common diagnosis was cancer (80%). Within the standard monitoring group half of the patients had at least one co-morbidity. Within the capnography group, 90% of patients had at least one co-morbidity. The descriptive statistics for the patients are reported in Table 1 (Appendix G).

Analysis of the data, using chi-square test of independence, showed no statistically significant differences in the number of adverse events between those patients who were

monitored with capnography and those who received standard monitoring, (X^2(1, N=20) = 0.00, p=1.00) (Appendix H, Table 2). Analysis of each of the aims of the study were as follows:

1. For Aim 1, capnography monitoring was implemented between September 8, and December 1, 2020 for 10 ICU patients receiving intravenous, epidural PCAs or high doses of opioids. There were 30% of the patients on capnography who had an adverse event specifically, hypercapnia, hypoxia, hypotension, decreased sedation level, or bradypnea during the implementation timeframe (Appendix I, Table 3).
2. For Aim 2, a retrospective chart review was conducted for June 2020 through August 2020, and 30% of 10 ICU patients on intravenous, epidural PCAs or high doses of opioids who received standard monitoring had an adverse event including: Hypoxia, hypotension, bradypnea, or decreased sedation level (Table 3).
3. Differences in number of episodes of adverse events between 10 ICU patients on PCAs or high doses of opioids monitored with capnography versus 10 patients on standard monitoring was compared with chi-square test of independence. There was no statistical difference between the two groups, X^2(1, N=20) = 0.00, p=1.00. (Table 2).
4. Differences in the number of episodes of hypercapnia, hypoxia, hypotension, decreased sedation level, bradypnea (adverse patient events) was compared according to variation in age, gender, diagnosis, and co-morbidities among ICU patients on PCAs or high dosages of opioids using crosstabs comparison and chi-square test of independence for each variable. Adverse events were not significantly associated with age, gender, number of co-morbidities, type of opioid, and diagnosis (p>0.05) (Table 4, Appendix J). However, a higher number of adverse events were observed in patients older than 55 years (30%), those on epidural opioids (25%), females (20%), and those with two or more co-

morbidities including lung/cardiac disease and a history of >20 pack year smoking history (20%) (Table 4). Additionally, the percentage of patients with the occurrence of different monitoring events related to blood pressure, carbon dioxide, oxygen saturation, respiratory rate and sedation level are presented in Table 3 (See Appendix I). Interestingly, the capnography monitoring group showed modest favorable trends compared with the standard monitoring group related to respiratory rate and sedation level. Specifically, there was a decrease in the percentage of patients who had a respiratory rate less than 12 breaths per minute in the capnography group (20%) compared with the standard monitoring group (30%). There was also a decrease in the percentage of patients who were difficult to arouse in the capnography group (0%) versus the standard monitoring group (10%).

Discussion

Many randomized controlled trials have demonstrated that capnography monitoring is superior to monitoring with vital signs, pulse oximetry, and sedation level alone (standard monitoring) in detecting early respiratory depression. Rising ETCO2 levels is a sensitive and specific sign of respiratory distress and occurs before changes in vital signs or decrease in oxygenation levels. Based on the results of these research studies, professional and regulatory organizations recommend that sensitive technology be utilized as a method for detecting early respiratory depression. Capnography is a non-invasive, sensitive mechanism for recognizing changes in patient status before harm occurs.

The advantage of capnography monitoring is it allows nurses to perform interventions to reverse respiratory depression before resorting to the administration of naloxone. The study by Stites, et. al., (2017) demonstrated that the number of rapid response calls (RRT) for opioid

induced respiratory depression in patients who received opioids through a PCA before and after hospital wide implementation of capnography decreased. Naloxone is not without potential for harm as not only does it cause a complete reversal of pain control but can cause adverse effects along with the reversal of the opioid. These adverse effects can include the need to re-establish adequate pain control and at the extreme, psychosis, arrhythmias, and cardiopulmonary arrest. Use of "softer" nursing interventions to gently reverse the effect of the opioid would be preferable to naloxone administration.

At issue is the type of patient who would be appropriate for capnography monitoring. Over 30 patient characteristics have been described within clinical trials that would warrant consideration for capnography. Since it is not feasible that every patient at this institution would require capnography monitoring, this project attempted to narrow criteria among our population that would benefit from this type of intensive monitoring. Among characteristics identified in the literature that were examined for the purposes of this project included patients older than 55 years, those with multiple co-morbidities including obstructive sleep apnea, smoking history greater than 20 pack years and patients with a history of lung and/or cardiac disease. More adverse events among these groups were observed during this project, further supporting which patient type should receive capnography.

This project evaluated if capnography monitoring improved outcomes in terms of decreasing adverse events among ICU patients who were receiving opioids through an epidural or intravenous PCA, or high doses of opioids administered via other routes. A retrospective sample of patients who received standard monitoring was evaluated for adverse events and compared with patients who received capnography monitoring. The sample size and descriptive characteristics for both groups were similar; there was no statistically significant difference in

the number of adverse events for patients receiving capnography versus standard monitoring. In addition, there were no significant differences in the number of adverse events with respect to age, gender, opioid type, number of co-morbidities, and diagnosis. Although not statistically significant, patients older than 55 years of age, females, those receiving epidural patient-controlled analgesia, and those with two or more co-morbidities plus a history of lung or cardiac disease, obstructive sleep apnea, or greater than a 20-pack year history of smoking, had more observable adverse events. These findings indicate patient characteristics that may be associated with a higher risk for respiratory depression. Implementing capnography monitoring among patients with these identified risk factors may allow for early intervention to prevent complications and adverse events.

Limitations of this study included the impact of the COVID-19 pandemic, the setting in which this project was implemented (ICU), eligibility criteria for patient inclusion in the project, and the nasal cannula equipment used for the capnography. The impact of the pandemic resulted in a small sample size for both the standard monitoring and capnography implementation groups. Patients diagnosed with COVID-19 admitted to the ICU were critically ill and therefore did not meet eligibility criteria for inclusion in this project.

Secondly, all patients enrolled into the study were patients under ICU level care. Patient observation in an ICU is closely monitored as all patients were connected to monitoring equipment such as continuous vital sign monitoring. Nursing care was also provided under a one-to-one ratio so that a slight change in patient condition would be detected before the patient became hypercapnic. Therefore, hypercapnic episodes had been low throughout this study. However, capnography monitoring among the capnography group allowed for earlier detection of hypotension, hypoxia, and decreased sedation (Table 3). None of the patients in the

capnography group required naloxone; instead, nursing interventions (stopping or decreasing the PCA dose and re-positioning) reversed the effects of the opioids while maintaining adequate pain control. As the intent of this project is to eventually implement capnography monitoring on the non-ICU medical units, and nursing care is not provided one-to-one for the most part, the true benefit of capnography monitoring is yet to be determined.

Eligibility for inclusion into the study may also have impacted results. As the ICU also admits children (defined as younger than 18 years), the nursing and medical staff observed that some teenagers may have benefited from capnography monitoring. These teenagers (ranging in age from 15-17 years) had increased confusion, somnolence, hypoxia, or hypotension from the opioids (epidural and intravenous). Inclusion of adolescents into the project may have demonstrated that capnography would benefit this population too.

The last observation was difficulty with the nasal cannula equipment that was used for ETCO2 monitoring. Nurses and respiratory therapists observed that as the nasal cannula became moist with patient respiration, the cannula stopped detecting accurate ETCO2. The readings on the modules displayed false readings of hypocapnia. The nasal cannula on patients needed changing every eight to ten hours to continue to obtain accurate measurements. This resulted in anecdotal decreased nurse satisfaction and could have a potential impact on implementation of this project for the rest of the hospital.

For the institution in which this project was conducted, the recommendation is that capnography monitoring should be used in patients receiving epidural or IV PCAs until stable doses are reached for satisfactory pain control and the patient has been without hypotension, hypoxia, decreased sedation level, bradypnea, or hypercapnia for at least 24 hours. Patients who are receiving frequent, escalating doses of opioids, not on PCAs, can also benefit from

capnography. Patient types who would most benefit from initial capnography include patients older than 55 years, those on epidural opioids, females, and those with two or more co-morbidities including obstructive sleep apnea, lung/cardiac disease, and a history of >20 pack year smoking history. Although not a part of the sample for this project, teenagers aged 14-17 years may also benefit.

Plans for Sustainability and Future Scholarship

Vital sign machinery with capnography technology has been purchased for this institution. There will now be the opportunity to perform capnography monitoring outside of the ICU. Discussion among the Pain and Palliative Service, medical team and nursing leadership is underway for the employment of capnography monitoring among patients who are considered high risk for respiratory depression. Policies and procedures will need to be created. Nursing and physician education will need to be developed. Integrating capnography monitoring as a standard of practice will provide sustainability to this initiative.

Future directions with capnography monitoring at this institution include further defining patients, including teenagers, who would profit from capnography. In addition, determining if added equipment purchases are needed will require consideration. Future scholarship opportunities include ongoing assessment of the benefit of capnography through auditing of naloxone use in the institution, impact of capnography on alarm fatigue among nurses, and if capnography results in improved patient satisfaction with pain management.

Conclusion

Randomized controlled trials have demonstrated that capnography monitoring in patients receiving opioids can be beneficial in detecting early respiratory compromise before adverse

outcomes occur. This project was limited by the small sample size and ICU level care patients received. However, observable results from this project suggested that capnography monitoring may be most useful in patients 55 or older, those receiving epidural opioids, and those with multiple co-morbidities including smoking history, obstructive sleep apnea, and lung and/or cardiac disease. Teenagers may also benefit from capnography based on anecdotal observation.

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Appendix A

SWOT Analysis

	Helpful To achieving the objective	**Harmful** To achieving the objective
Internal Origin {Attributes of the organization}	**Strengths** • Stakeholder involvement • Commitment of leadership in all departments • A commitment to providing excellent clinical care • Employee engagement • Nursing shared governance • Strong nursing education department • Strong CNS group • New vital sign equipment purchase	**Weaknesses** • Budgetary constraints • Outdated clinical knowledge due to "institutialization" of researchers. • No central telemetry monitoring on each unit that admits patients with PCAs
External Origin {Attributes of the organization}	**Opportunities** • Accreditation and survey by outside organizations concerned with patient safety • Wanting to bring NIH up to highest clinical practice standards • Influx of new personnel who have practiced in the community and are knowledgeable about best practices • Defining a high-risk patient based on research	**Threats** • Unwillingness to change culture in some areas of the NIH • Cybersecurity concerns about the capnographic equipment • Consensus on the clear definition of who a high-risk patient would be who would require capnography • Attitude by some that research outweighs clinical care

Appendix B

Evidence Table

Article #	Author & Date	Evidence Type	Sample, Sample Size, Setting	Study findings that help answer the EBP Question	Observable Measures	Limitations	Evidence Level & Quality
1	Campbell, S., Magee, K., Zed, P., Froese, P., Etsell, G., LaPierre, A….Petrie, D. (2016).	Randomized Controlled Trial	Patients receiving procedural sedation and analgesia in an emergency department including orthopedic manipulation, cardioversion, and abscess incision and drainage. **Control Group:** Monitoring during procedural sedation using standard of care which consisted of continuous oxygen delivery, pulse oximetry and cardiac monitoring, and blood pressure measurement every 5 minutes	Control and intervention groups were similar in demographics and sedatives used Patients in the end tidal capnopmetry (ETC) group had more use of airway repositioning maneuvers and hypotension Although ETC detected hypoxia earlier than pulse oximetry alone, it did not make a difference as far as clinical	There was no difference in patients experiencing de-saturation (SaO2<90%) between the two groups; however, patients in the ETC group were more likely to require airway repositioning (12.9% vs. 9.3%, P=0.003). Hypotension (SBP<100 mmHg or <85 mmHg if baseline <100 mmHg) was observed in 16	Limitations: Conducted in a real-world setting. No standardized sedative regimen used Not blinded	Level I B-Good quality

			Intervention Group: Standard of care (as above) plus continuous end tidal CO2 monitoring which was recorded every 5 minutes Total: 986 Control: 501 Intervention: 485	outcomes in this trial **Conclusion:** Use of capnography did not improve clinical outcomes for patients receiving sedation in the ED	(3.3%) patients in the ETC group and 7 (1.4%) in the control group (P=0.048).		
2	Deitch, K., Miner, J., Chudnofsky, C., Dominici, P. and Latta, D. (2010).	Randomized Controlled Trial	Patients receiving propofol in an ED **Control Group**: Standard monitoring which included pulse oximetry, cardiac monitoring, blood pressure monitoring plus capnography that MDs could monitor **Intervention Group:**	Capnography provides early warning of respiratory depression	Both control and blinded capnography groups equal in demographics, dosing of propofol, diagnosis (drainage of abscess, joint reduction, and fracture reduction), Ramsey scores	Limitations: Higher than expected disqualification rate	Level I A-High quality

			Standard monitoring as above but MDs could not visualize the capnometer Total: 132 Control Group (capnography): 68 Intervention (blinded capnography group): 64 screen		and time to recovery Respiratory depression rates similar between groups Hypoxia was more frequent in the blinded capnography group (42% in blinded capnography as compared to 25% in capnography group) Physician interventions to improve respiratory status more frequent in the capnography group (35% vs 22% in blinded group) Capnography use decreased the rate of hypoxic events by 17%		

3	Friedrich-Rust, M., Welte, M., Albert, J., Meckbach, Y., Hermann, E., Kannennglesser, M…..Bojunga, J. (2014).	Randomized Controlled Trial conducted at two centers	Patients receiving propofol for endoscopy/colonoscopy **Control Group:** Standard care with continuous pulse oximetry, cardiac monitoring (some patients), 2l O2, blood pressure measurement every 3 minutes and clinical observation **Intervention Group:** Standard care plus capnography Total: 533 Control: 266 Intervention: 267	Use of capnography decreased incidence of hypoxemia	Hypoxemia occurred less in the capnography group compared to standard care group (18% vs. 32%) Time between detection of apnea and hypoxemia was 22 seconds in the capnography group Severe hypoxia occurred in 6% of capnography group vs 8% of standard group No difference between groups in need for assisted ventilation, hypotension or bradycardia	Limitations of study: Different sedative regimens used at both centers Patients who received endoscopy were not in the blinded arm	Level I A-High

4	Gupta, K., Prasad, A., Nagappa, M., Wong, J., Abrahamyan, L., & Chung, F. (2018).	Systematic Review	Primary objective of this study is to review and summarize the risk factors of OIRD in the postoperative period N: 13 studies 871,912 total number of surgical patients over 10 studies	Monitoring of sedation level, pulse oximetry and capnography is recommended in patients at risk of opioid induced respiratory depression (OIRD)	Incidence of OIRD varies from 0.1 to 23.7% Preoperative gabapentin or sustained release oxycodone was found to be a contributory factor of OIRD. Out of the 871,912 post- op patients, 4337 patients acquired postoperative OIRD, with a prevalence of 0.5% Predominantly OIRD occurred mostly within the first 24 hours after surgery (in PACU), with a predominance in a the first 12 h. The mean age of patient with OIRD was greater than 60 years in eight studies and greater than 50 years in three studies.	Limitations: Staffing ratios Training and education of staff to implement changes in practice. Cost of new equipment needed to implement capnography and other monitoring.	Level I A/B- Good

					In nine studies, a higher proportion (50-60%) of women were reported to have OIRD. The following comorbidities were identified to be associated with a higher risk of OIRD: Obstructive sleep apnea (OSA) Chronic obstructive pulmonary disease (COPD) cardiac disease diabetes mellitus hypertension neurologic disease (stroke, dementia) renal disease obesity-two or more comorbidities		

					-opioid dependence 8. In Weingarten et al. reported that general anesthesia was significantly associated with a higher incidence of OIRD (312 per 1000 cases) compared with neuraxial anesthesia (144 per 1000 cases). 9. In Lee et al. closed claim's analysis, OIRD was associated with administration of morphine in 64% cases, hydromorphone in 25% cases and fentanyl in 25% of cases. 10. In Lee et al. 62% of patients were deeply sedated before OIRD. In 31% of		

					claims, monitoring of vital signs, sedation levels and pulse oximetry by nurses was inadequate.		
5	Jarzyna, D, Jungquist, C., Pasero, C., Willens, J., Nisbet, A., Oakes, L…Polomano, R. (2011).	Position Statement/Clinical Guidelines	Position statement for nurses on monitoring patients for opioid induced respiratory depression and sedation by the American Society for Pain Management Nursing	Recommendations developed based on review of the literature that divided risk factors of OIRD into four categories: Individual risk Iatrogenic risk Pharmacology Monitoring	The ASPM developed recommendations based on extensive review of the literature, external peer review of the applicability and accuracy of the literature. Monitoring practices, education of nurses, and implementation strategies were included. Search strategies for literature was included in this article. The American Society of	Limitations: Lack of RCTs that examine outcomes associated with monitoring techniques Lack of standardized definitions of outcomes across studies	Level IV A/B- High

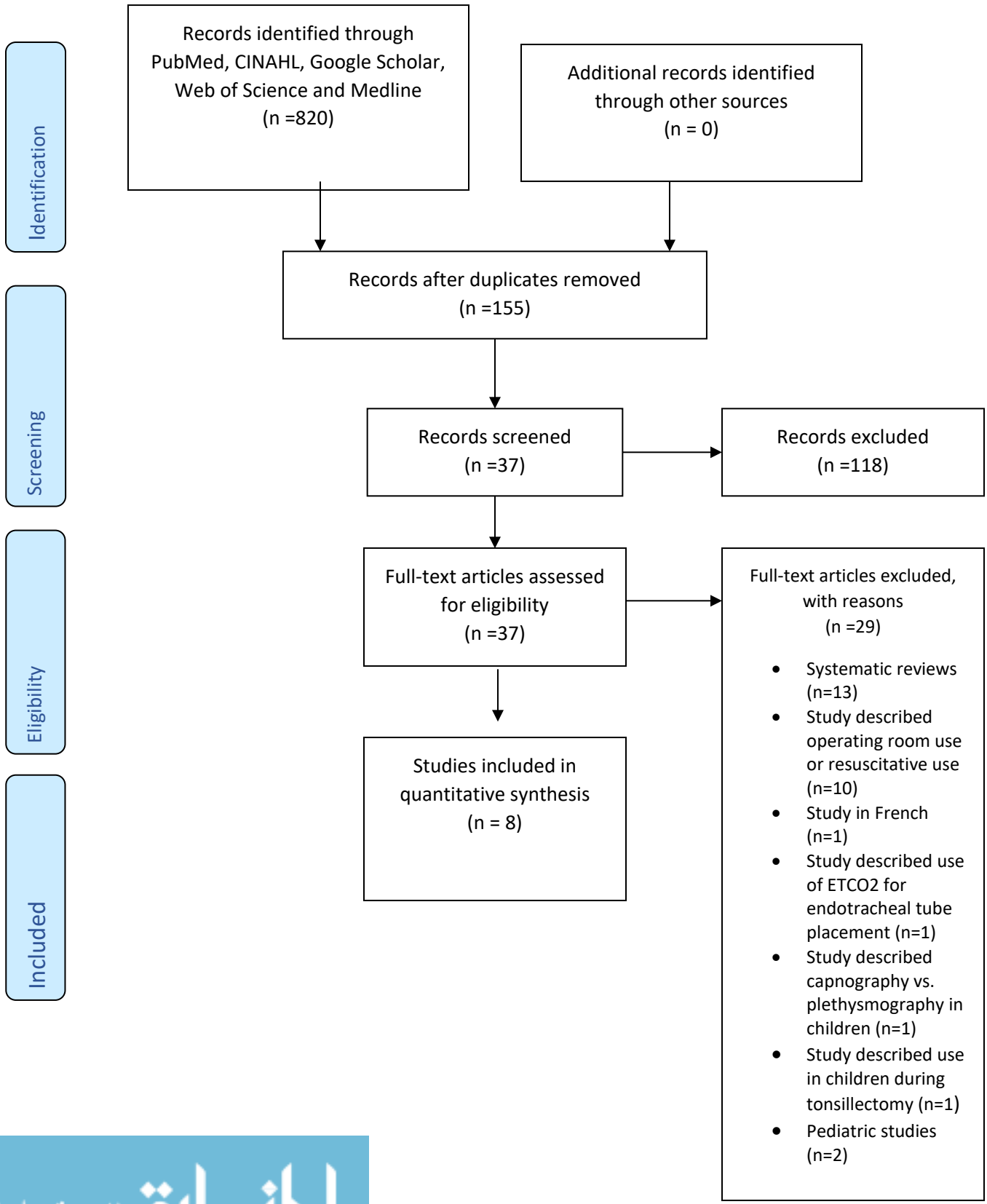
					Anesthesiologists Evidence Categories was used to rate the studies.		
8	Li, M., Liu, Z., Lin, F., Wang, H., Niu, X., Ge, X…..Li, C. (2018).	Randomized Controlled Trial	Women receiving propofol during lumpectomy **Control Group:** Standard monitoring (continuous pulse oximetry, vital signs) plus ETCO2 monitoring that providers could visualize **Intervention:** Providers blinded to ETCO2 monitoring Total: 188 Control: 94 Intervention: 94	Addition of ETCO2 monitoring improves patient safety	CO2 retention occurred less in the monitored group (10% vs 87%) Number of airway interventions was higher in the control group vs experimental group (9.8 vs 1.2) Apnea occurred less often in the control group vs experimental group (0 v 10%) Recovery time shorter in the control group vs experimental group (9.9 min. vs 11.4 min)	Limitations: All participants were women Time needed for CO2 recovery (use of ABGs to accurately measure CO2) was not assessed due to clinical need to control bleeding and not cause further pain	Level I B- Good

9	Mehta, P., Kochhar, G., Albedawi, M., Kirsh, B., Rizk, M., Putka, B……Vargo, J. (2016).	Randomized Controlled Trial	Use of capnography in patients undergoing endoscopy or colonoscopy who receive moderate sedation **Control Group:** Capnography visualized, and findings verbalized to provider **Experimental Group**: Capnography blinded to provider EGD Group Total: 208 Control: 101 Blinded Group: 108 Total Colonoscopy Group: 231 Control: 117 Blinded: 114	No statistical difference in rates of hypoxemia detection between the groups for both arms	There was no significant difference in rates of hypoxemia between the blinded and open capnography arms for EGD (54.1% vs. 49.5; P =0.5) or colonoscopy (53.8 vs. 52.1%; *P*=0.79)	No standardized definition of hypoxemia Single institution study	Level I A- High quality
10	Stites, M., Surprise, J., McNeil, J.,	Prospective cohort study	Capnography use Patients on PCA	Capnography added benefit of detecting opioid	Decrease in percentage of opioid-receiving	Further research should be	Level II

	Northrop, D., and Ruyter, D. (2017).		Pre-intervention: 34,855 Post-intervention: 93,412	induced respiratory (OIRD) earlier thus reducing RR calls	patients experiencing OIRD in rapid response from 0.04% pre-intervention (153 events in 34, 852 patients) to 0.02% post intervention (200 events in 93,412 patients). Statistically significant reduction in RR calls associated with IRD when patients receiving PCA were monitored with capnography	focused on risk stratifying patients to determine those who would benefit most from additional monitoring Naloxone use identified as criteria for inclusion into study though naloxone can be used for other indications as well Alarm fatigue identified by nursing staff	A- High

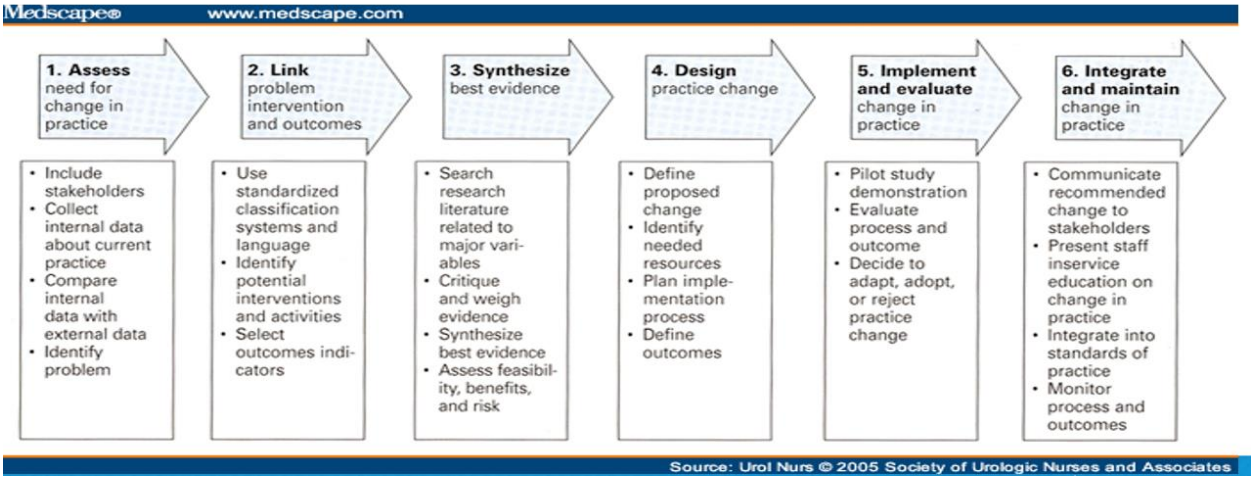
Appendix C

PRISMA Diagram



Appendix D

Rosswurm and Larrabee Model



Appendix E

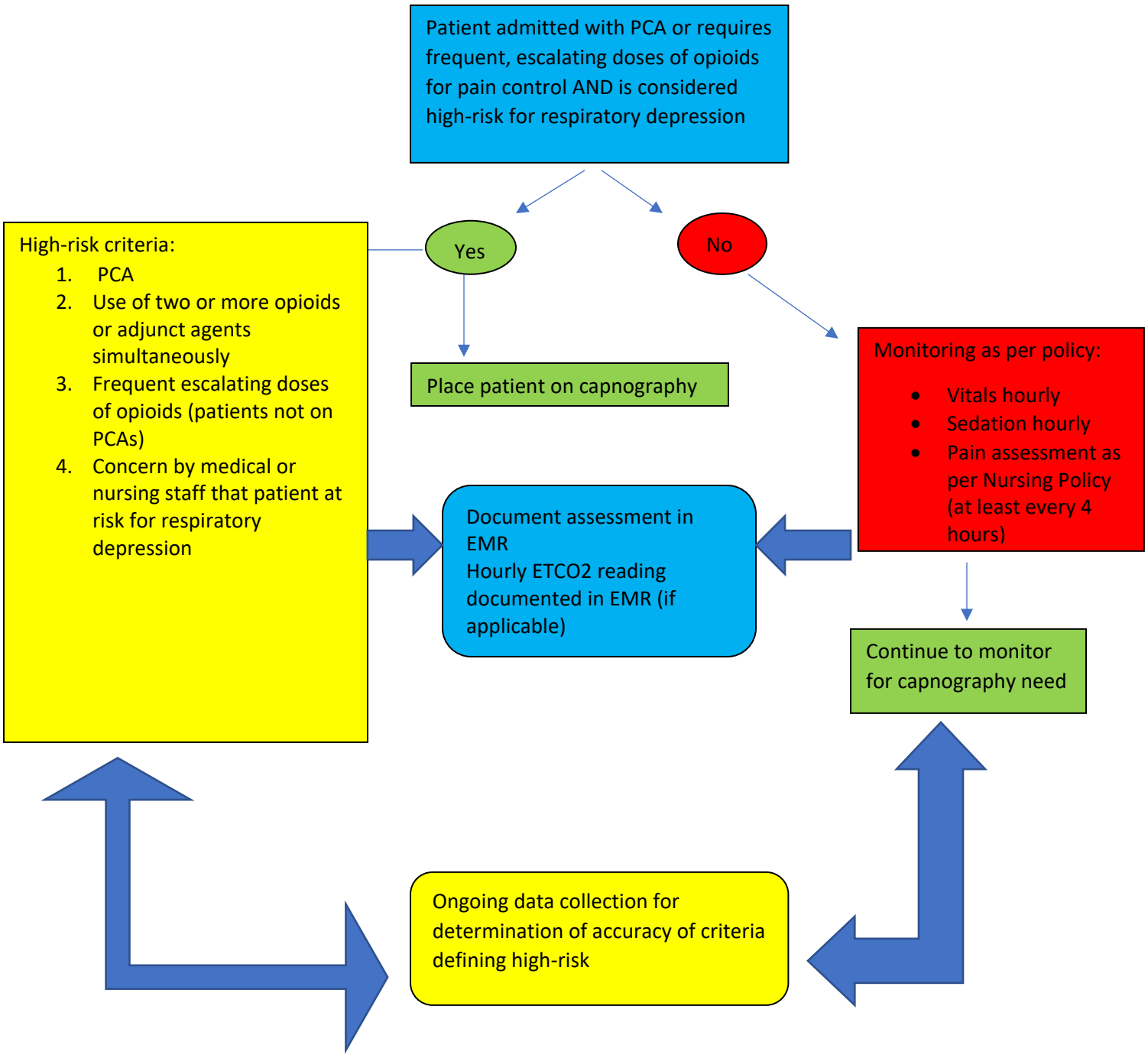
Data Dictionary

Data Element	Data Label	Data Type	Definition/Purpose	Data Values & Coding
Patient Identifier	ID	Numeric	Unique identifier assigned by PI	Numeric
Age in years	Age	Categorical	Age of patient 55 years or older OR less than 55 years	0= 55 or > 1=< 55
Gender	Gender	Categorical	Biological gender from EMR	0=male 1=female
Diagnosis	Primary diagnosis	categorical	Diagnosis of patient that brought patient to ICU	0=cancer 1=Immunodeficiency/transplant 2=Other
Co-morbidities	COM	Categorical	Number of co-morbidities	0=no co-morbidities 1=1 co-morbidity or smoker (>20pack years), lung/cardiac dz., and/or OSA 2=≥2 co-morbidities including above
Type of opioid prescribed	OPI	Categorical	Route and type of opioid	0=epidural 1=IV PCA 2=high dose not IV or epidural
Capnography	CAP	Categorical	Use of capnography monitoring	0=No capnography 1=capnography monitoring
Hypotension	HTN	Categorical	Blood pressure <90/60	0=no hypotension 1=hypotensive
Hypercapnia	HYC	Categorical	ETCO2 >45mmHg	0=no hypercapnia 1=hypercapnic
Hypoxia	HYP	Categorical	Pulse oximetry <90%	0=no hypoxia 1=hypoxic
Sedation level	SED	Continuous	Level of sedation while on PCA	0=alert/drowsy/easily aroused 1=sleeping/difficult to arouse 2=confused/hallucinating 3=unable to arouse
Bradypnea	RR	Categorical	RR<12 breaths per minute (bpm)	0=12-20 bpm 1=<12 bpm
Adverse Event	AE	Categorical	Type of AE that is possibly attributed to the PCA/opioid	0=no AE 1=AE

Nursing actions for adverse event	NA	Categorical	Type of nursing actions: 0. none 1. Hold PCA or opioids 2. Repositioning 3. PCA settings or narcotics dosing decreased 4. Rescue	0= none 1=Hold PCA or opioids 2=Repositioning 3=PCA settings or narcotics dosing decreased 4=Rescue, including naloxone

Appendix F

Decision Tree



Appendix G

Table 1: Descriptive Characteristics of the Patients

Characteristics	Standard Monitoring	Capnography Monitoring
Age	58.1 (± 18)	59.7 (± 15)
Gender		
Male	60%	50%
Female	40%	50%
Primary Diagnosis		
Cancer	80%	70%
Immunodeficiency/ transplant	10%	20%
Other	10%	10%
Number of co-morbidities (COM)		
None	50%	10%
One COM or smoker, lung/cardiac disease, OSA	10%	40%
Two or more COM plus Above	40%	50%
Opioid Type		
Epidural PCA	40%	70%
IV PCA	60%	20%
High dose opioids	0%	10%

Appendix H

Table 2: Comparison of Capnography Monitoring and Number of Adverse Patient Events

Capnography Events	***N***	**Adverse**		**Chi Square Statistics**			
		N	**%**	***df***	***N***	***p***	X^2
No capnography	10	3	30%	1	20	1.00	0.00
Capnography	10	3	30%				
Total	20	6	30%				

Appendix I

Table 3: Percentage of patients with monitoring events

Monitoring Event	Standard Monitoring	Capnography Monitoring
Systolic BP<90/60		
Yes	10%	20%
No	90%	80%
ETCO2>45		
Yes	N/A	30%
No	N/A	70%
SpO2<90		
Yes	10%	30%
No	90%	70%
Respiratory Rate		
12-20 breaths per minute	70%	80%
<12 breaths per minute	30%	20%
Sedation Level		
Alert/oriented	90%	80%
Difficult to arouse	10%	0%
Confused hallucinating	0%	10%
Unable to arouse	0%	10%

Appendix J

Table 4: Comparison of Adverse Events with Age, Gender, Number of Co-morbidities, Opioid Type and Diagnosis

N=20

Variable	**Adverse Event (percentage)**	***Df***	***p***	**Chi-Square Statistic (X^2)**
Age				
55 or older	30%	1	.091	2.857
< 55	0%			
Gender				
Male	10%	1	.202	1.626
Female	20%			
Number of Co-morbidities (COM)				
None	5%	2	.440	1.640
One COM or > 20py smoking or lung/cardiac disease and/or OSA	5%			
Two COM + above	20%			
Opioid Type				
Epidural	25%	2	.241	2.846
IV PCA	5%			
High dose not epidural or IV PCA	0%			
Diagnosis				
Cancer	30%	2	.240	2.857
Immunodeficiency/transplant	0%			
Other	0%			