Published in final edited form as:
J Crit Care. 2014 December ; 29(6): 1035–1040. doi:10.1016/j.jcrc.2014.06.021.

Experiences with Capnography in Acute Care Settings: A Mixed-Methods Analysis of Clinical Staff

Melissa L. Langhan, MD MHS[1], **Jordan C. Kurtz, BS BA**[2], **Paula Schaeffer, MA**[3], **Andrea G. Asnes, MD**[3], and **Antonio Riera, MD**[1]

[1]Department of Section of Emergency Medicine Yale University School of Medicine

[2]Department of St. George's University School of Medicine

[3]Department of Pediatrics, Yale University School of Medicine

Abstract

Purpose—While capnography is being incorporated into clinical guidelines, it is not used to it's full potential. We investigated reasons for limited implementation of capnography in acute care areas and explored facilitators and barriers to its implementation.

Methods—A purposeful sample of physicians and nurses in emergency departments (ED) and intensive care units (ICU) participated in semistructured interviews. Grounded theory, iterative data analysis and the constant comparative method were used to analyze the data to inductively generate ideas and build theories.

Results—Nineteen providers were interviewed from five hospitals. Six themes were identified: variability in use of capnography among acute care units, availability and accessibility of capnography equipment, the evidence behind capnography use, the impact of capnography on patient care, personal experiences impacting use of capnography, and variable knowledge about capnography. Barriers and facilitators to use were found within each theme.

Conclusions—We observed varied responsiveness to capnography and identified factors that work to foster or discourage its use. This data can guide future implementation strategies. A deliberate strategy to foster utilization, mitigate barriers and broadly accelerate implementation has the potential to profoundly impact use of capnography in acute care areas with the goal of improving patient care.

Keywords

Capnography; Implementation; Emergency department; Intensive care unit

Correspondence: Melissa L. Langhan, MD MHS Department of Pediatrics, Section of Emergency Medicine Yale University School of Medicine 100 York St, Suite 1F New Haven, CT 06511 P: 203-737-7440 F: 203-737-7447 Melissa.Langhan@yale.edu.

Purpose

Capnography, or continuous end-tidal carbon dioxide ($ETCO_2$) monitoring, is the graphic representation of carbon dioxide expired during the respiratory cycle. From its inception in the 1960s, evidence has grown to support capnography for a variety of indications and patient populations.[1-5] This has led to its inclusion into national guidelines for recommended use.[6-9]

Large gaps exist between evidence and practice. As demonstrated in studies of emergency departments (EDs) and intensive care units (ICUs), capnography is available in these settings, but not used to its full extent.[10-14] Although there are many factors involved in the successful adoption and implementation of new technologies, little research exists to describe how new bedside, patient-care devices are incorporated for routine use in the work environment.[15, 16] Physicians, nurses, or hospital administrators can initiate the purchasing phase of a new device. Thereafter, the ways in which medical units implement new technologies is based on repeated behaviors dictated by policy and customs that characterize these units' daily activity and is often influenced by adult learning practices.[16] As medical technology advances, implementation of new technologies becomes evermore commonplace and these routines often change. It is important to incorporate learning theory and identify variables necessary for technology adoption to be successful. Some barriers to adoption and implementation are based on physician perceptions and local culture. Overall, these processes are not well understood.[17]

This is the first study to assess current perceptions about capnography and investigate reasons for limited implementation at the bedside in acute care areas. Our goal was to learn from clinician experiences in acute care settings with capnography and explore the facilitators and barriers to its implementation. Identification of these key issues and their relationship to adult learning theory is required in order to identify effective implementation strategies for acute care settings.

Materials and Methods

In order to better understand medical providers' perceptions, experiences and beliefs about capnography, a mixed-methods, exploratory study was conducted at five sites in Connecticut.[18, 19] To achieve a broad perspective, sites included Yale-New Haven Hospital, an urban, tertiary care, academic center; Connecticut Children's Medical Center, a freestanding, academic children's hospital; Yale-New Haven Children's Hospital, a non-freestanding, academic children's hospital; Bridgeport Hospital, an urban, private hospital; and Norwalk Hospital, a suburban, community hospital. Using semistructured interviews, we explored health care provider experiences with capnography and obtained insight into facilitators and barriers to its implementation in ICUs and EDs.[18, 20]

Our interdisciplinary research team consisted of an administrative coordinator with experience in qualitative interviewing (P.S), a general pediatrician with expertise in qualitative methods (A.G.A.), two pediatric emergency medicine physicians with experience in qualitative research (A.R, M.L.L.), and a medical student (J.C.K). We employed

purposeful sampling of interviewees in an effort to enroll participants that would have had an opportunity to use capnography at the bedside.[18, 20, 21] Departmental heads and nurse managers from each unit were contacted by the study investigator (M.L.L.) and asked to identify colleagues who spent the majority of their time in a clinical role. One doctor and one nurse from the ED and ICU of each site were targeted for enrollment. Individuals were contacted by telephone or email about study participation and provided a written information sheet. A small monetary incentive was provided at the completion of the interview. Basic demographic information was collected from participants. The institutional review board of each participating hospital approved this study.

Data collection ran from July 2012 through December 2012. Interviews took place within the participants' institution at a time and place convenient to the participant and were all conducted by one investigator (P.S.). A semistructured interview guide with probes was used, which explored providers' knowledge and opinions about capnography, and their experiences with capnography in caring for patients.[18, 20] This was part of a larger interview which discussed new technology in general. Participants for whom capnography was available but who did not use capnography were queried about potential reasons for non-use. The interview guide was piloted with a nurse and physician who have utilized capnography in the clinical care of patients. The interviews, which lasted an average of 30 minutes, were audio-recorded and professionally transcribed. Missing text from the transcriptions were compared to the original audio recordings and re-transcribed for completeness by one investigator (M.L.L.). The interview guide was iteratively adapted after the first several interviews.

Data Analysis

The principles of grounded theory were applied, including iterative data analysis and the constant comparative method, such that the data was used to inductively generate ideas and build theories.[18, 21, 22] Three investigators read and independently coded each transcript (M.L.L, A.R, J.C.K). The coding team then met and reviewed each transcript line-by-line. Discrepancies in coding were discussed until group consensus on the data was established. Related concepts were then combined into categories and emergent themes were identified consistent with a grounded theory approach in order to describe key issues and experiences discussed by the participants. [18, 21, 22] [18, 21, 22] (18, 21, 22) (18, 21, 22) 18,21,22 18, 21, 22 18, 21, 22 18, 21, 22 18, 21, 22 18, 21, 22 An iterative process of data analysis occurred such that codes were revised, added and deleted to refine the code structure.[18, 20-22]

The first and second rounds of analysis focused on questions within the interview guide in order to allow subsequent interviews to be shaped by the preceding analysis. Changes to the interview guide based on the inductive analysis were explained and recorded in order to enhance reliability and reproducibility of the study.[20, 21] Recruitment and interviews continued until data reached theoretical saturation: that is until no new themes emerged.[18] Once the code structure was finalized, the primary author (M.L.L.) reviewed all transcripts to ensure that the data was coded consistently. One study investigator (A.G.A.) independently reviewed selected transcripts in the process of data triangulation.[18, 20, 21] An audit trail was created to provide systematic and detailed documentation of analytical

decision-making during this process. HyperResearch (ResearchWare, Inc.), a qualitative analysis software tool, was used to organize the analysis of transcribed data. This allowed us to collate data by type of participant, unit, and hospital.[20, 23]

Cohen's kappa was used to assess the agreement in reporting of use between providers from the same unit. Fisher's exact test and Student's T-test were used to analyze demographic data and assess for differences among those reporting capnography use and non-use.

Results

Nineteen acute care providers were interviewed from ten hospital units. The nursing staff from one ED refused to participate. Participant characteristics are summarized in Table 1. There was excellent agreement between respondents (kappa 0.89, 95% confidence interval 0.68-1.0); that is, physicians and nurses from the same unit expressed similar views about the availability and overall use of capnography in their setting. Three units (two ICUs and one ED) reported that capnography was used rarely or not at all. All remaining units had some degree of capnography use. There was no statistically significant difference in report of use by type of unit (p=0.63), by age of providers (p=0.85) or number of years for which the provider was working on the unit (p=0.31).

We identified six themes surrounding use of capnography. These include existence of variability in capnography use among acute care units, availability and accessibility of capnography equipment impacts use, dissimilar interpretation of the evidence behind capnography use, disparate views on capnography's ability to impact patient care, experiences with capnography impacting future use, and diversity of knowledge about capnography interpretation. Categories corresponding to barriers and facilitators within these themes are summarized below and presented in Table 2 along with illustrative quotes.

Variability exists in capnography use among acute care units

Capnography use varied among ED and ICU staff. Most participants reported use for selected patient populations and indications as well as lack of use for others. More importantly, there was variable use among staff members within a unit. On some units, staff champions promoted the use of capnography for certain indications, but it was perceived that capnography was not used as often when these individuals were not present. This is in contrast to other units where policies are in place to standardize use by staff. Overall, cultural and administrative issues within the units were reported that influenced providers' patterns of use.

Availability and accessibility of capnography equipment impacts use

The ability for providers to quickly access capnography is a key factor that providers identified as a facilitator of use in acute care areas. ICUs with better accessibility reported more routine use. For instance, ICUs in which responsibility for storage and setup of capnography is largely placed on respiratory therapists exemplified this enhanced availability. Similarly, the presence of capnography monitors within each patient room was noted to make regular use easier.

One of the main barriers consistently found within ICUs and EDs with more sporadic or poor use is lack of availability and accessibility of equipment. Many participants recalled difficulties in finding or setting up capnography, if it is available at all. This appears to have hindered use, as providers reported that they are not incentivized to take the time out from their busy patient care activities to perform these tasks. Despite these issues, active proponents of capnography reported that they will go out of their way to access capnography equipment for their patients, even if it is not part of policy or the standard of care in their unit.

Dissimilar interpretations of the evidence behind capnography use is apparent

Many of the providers who use capnography in our study cite its use as a standard of care in their patient populations. Policy plays a role on some units as well. In these cases, capnography may be used as a matter of course, but how the data capnography generates are used is less clear. This was found with respect to capnography use during procedural sedation in non-intubated patients as well as in the monitoring of intubated patients.

Occasionally providers did not feel there was sufficient evidence to support the use of capnography. For the indication of sedation, some providers expressed desire for consensus statements or hospital policies requiring its use before instituting it within their unit. More comprehensive data on capnography use is felt to be needed prior to applying this device in patients.

Disparate views exist as to the ability of capnography to impact patient care

Many acute care providers recognize the benefits of capnography for a number of populations and indications. This is most clearly demonstrated for patients receiving sedation. Interview participants often discussed capnography's ability to be an earlier detector of respiratory depression compared to other monitoring modalities. Knowledge about the benefits of capnography is also described for continuous monitoring of intubated patients, particularly when compared to blood gas analysis. Fewer physicians and nurses discuss the benefits of capnography use during cardiopulmonary resuscitation (CPR).

Some subjects feel that the device is not helpful with specific patient populations and therefore makes capnography unnecessary. This is particularly true for patients who are not intubated. Some nurses expressed feelings that capnography is not a valuable tool and did not benefit the patient or the staff. Physician-nurse hierarchies are noted here as well. Whereas many participants report the ability to discuss use of technology in an open, team-centered approach, others did not. Several instances are reported where a nurse who considers capnography in a patient may be precluded from using it if the physician does not feel it is necessary or if they are not comfortable with capnography.

Personal or anecdotal experiences with capnography can impact future use

Whether due to advances in technology, expanding literature or the natural diffusion of this technology, capnography is being used more often in some units. This increase in use may be more generalized or may be specific to certain types of patients. The addition of staff training, as well as positive reinforcement by other staff members and leadership, were noted to facilitate use. Similarly, the use of capnography by other departments is reported to encourage use on acute care units.

Some ICU physicians in this sample reported instances where capnography use was reduced or even abandoned. The main issues reported are inaccurate readings, difficulties with use, and a lack of benefit of capnography to their medical-decision making. This was often coupled with lack of knowledge about advances to the machine itself or new evidence in the literature. However, personal experience is not always the factor, as some physicians report that negative opinions expressed by colleagues impacted their use prior to personal experiences.

Diversity of knowledge and provider sophistication with data interpretation is evident

There are several nuances to the theme of knowledge translation in regards to capnography. While several participants exuded confidence and comfort with their knowledge about capnography, we observed significant knowledge gaps irrespective of comfort level. One physician repeatedly stated that capnography was a measure of oxygenation. Others talked about a single indication for capnography use and showed no understanding of use for the device in other populations. This was most evident in discussions related to intubated versus non-intubated patients. When it comes to intubated patients, some providers in both the ED and ICU believe that once the endotracheal tube position is secured, there is no need for further monitoring. Participants seemed to rely on physical examination and pulse oximetry for this purpose, and were unaware of the superior sensitivity of capnography for detection of tube dislodgement. For non-intubated patients, misconceptions about how the device works and lack of knowledge about nasal-oral cannulas to measure end-tidal CO_2 were identified.

The general knowledge gaps we observed are reinforced by a lack of comfort shown by many that are expected to use the device. Participants felt that a lack of adequate capnography training perpetuated their apprehension with the use, of capnography. Particularly among ICU physicians, there is a fear that staff do not possess enough knowledge to accurately use the device or that they are inappropriately relying on this data.

Discussion

Capnography use is varied among ICU and ED providers and there are few clear trends for use in acute care settings. While some individuals consider capnography to be standard of care and develop policies for consistent use, others feel there is no need for this device at all. Even within individual responses there lies confusion and a lack of clear understanding

about the indications for use and evidence behind this monitoring device. This study provides useful insight into both users and non-users of capnography, which can be used to develop more effective implementation strategies for this technology or other new technologies.

There are several studies evaluating the availability and utilization of capnography in EDs and ICUs.[10-14] Despite the increasing literature base for capnography and its incorporation into national guidelines, capnography is not being utilized to its full potential.[6-9] However, it is not due to lack of it's physical presence on the unit (its adoption), but to a failure of incorporation into clinical practice (its implementation).[24] While our key themes relate to important points in many current adult learning models such as Bloom's knowledge, skills and attitude, Kolb's experiential learning theories, or the Trio model of professional learning, we have found that these theories do not encompass all of the important concerns of our subjects.[25-27] Overall, our themes can be condensed into three major areas: environment, experiences and knowledge translation (Figure 1). This study helps shed light on several modifiable factors related to the successful implementation of technology in these areas.

When considering the environment where a new technology will be introduced, one novel, easily modifiable strategy to improve the use of capnography would be to enhance accessibility. If this device and its components are not stocked and immediately available to staff, few providers are willing to go out of their way to find it. Keeping a monitor in a central location, involving support personnel to maintain adequate supplies of connectors and cannulas, and informing staff as to the location of the device are several options. Administrators should consider making these monitors available in all patient rooms in the ED and ICU, where their presence would be most valuable. Supply personnel also need to be aware of the various size cannulas and tubing required for infants, children and adult patients to eliminate this barrier. Similarly, since the American Heart Association has endorsed capnography for monitoring during intubation and cardiopulmonary resuscitation, this should be considered an essential piece of equipment on hospital code carts.

Also within the realm of the environment are standards for use – whether the use of a technology will be driven by adherence to a protocol or whether use is based on an individual staff member's decision and personal preference. Unlike adopted technology that mandates use, such as electronic medical records, physicians and nurses must independently implement capnography. While the incorporation of capnography into clinical protocols or guidelines may increase its use, as suggested by several participants, this may not be an effective strategy for all bedside technology.[28] Mandating use through protocols is a controversial way to increase implementation.[29-31] Protocol-driven practice change has varied success rates and often requires additional mechanisms such as audits, feedback, education or incentives. Furthermore, routine use of capnography espoused by a protocol does not ensure that the data is being correctly used or interpreted in clinical decision-making.

Within the realm of experiences, the complexity of a new technology and its ease or difficulty of use needs to be considered. While capnography possesses several features

attributed to successful innovation such as low risk, low complexity and clear benefits, it is unclear why this technology has failed to gain more ground.[32] This may be due to the passive diffusion of this technology without active or planned efforts for implementation within an organization or lack of local leadership to promote use.[33] Also, the personal experiences of providers and how they perceive a certain technology impacts patient care is critically important. Since capnography has been shown to improve morbidity and mortality outcomes, it is important to understand the reasons for this failure in order to facilitate change. While negative experiences with capnography can dissuade use, disseminating positive staff experiences and the benefits of the device may augment use of capnography among providers. A staff champion could serve in this role and has been shown to be valuable. Encouragement by an array of peers, however, may be better suited in acute care settings where the clinical schedules of staff can be erratic. Since capnography possesses the benefit of trialability, that is, a provider can experiment with its use without the risk of harm to patients, staff should be encouraged to discover the benefits for themselves and share their experiences with others.[32] The positive resurgence of use for certain indications may naturally lead to increasing use in other patient populations.

The realm of knowledge translation emerged as one of the greatest barriers to consistent capnography use. Evident in both ED and ICU interviews, there is an incomplete understanding of capnography in terms of how to interpret data produced by this device and how it can be applied to patients with various clinical problems. Our subjects often described episodes where providers applied the technology prior to obtaining the knowledge and understanding about how to use and analyze the data it provides, thus the inverse of Bloom's taxonomy.[27] Sometimes this came across as a general lack of awareness or specific deficits in knowledge; at other times this could impact opinions about the current evidence base or the perceived need for capnography for patient care. More widespread dissemination of knowledge and education of staff are needed in order to improve the use of capnography. In particular, focusing on a specific indication, such as CPR or sedation, with emphasis on the available evidence, interpretation of data, and the potential benefits of capnography monitoring is likely to be more effective than a broad overview of the device and potential applications. This will then serve as a gateway to future use for other applications. It is promising to see that some participants in our study expressed resurgence in use of this device, are educating staff and are beginning to use capnography in different patient populations.

There are limitations to our study. The themes and codes generated in this study reflect the experiences of our interview sample, and therefore cannot be generalized to all acute care providers. While our sample size is small, we did achieve thematic saturation. Since data collection and analysis occur simultaneously, had we continued to discover new categories from the transcripts, additional physicians and nurses would have been approached for enrollment so that novel concepts would not be left unexplored. We also purposefully sampled both physicians and nurses who provide direct patient care in a variety of hospital settings to help us understand a broader culture for capnography use. As institutions and units vary significantly from one another, only certain strategies described in our manuscript may be applicable to one's one environment. These results can next be used in larger scale quantitative studies where they can be further assessed to determine if there are institution or

unit level factors that are associated with individual barriers or facilitators. The focus on capnography in our interview guide was the secondary aim of a larger interview, which looked at implementation of technology in general.

Conclusions

There is a wide range of capnography use in acute care settings. Although this monitoring modality is used to some extent, it has yet to reach full potential for certain indications and patient populations. Modifiable factors that may increase the use of capnography in these settings include improvements to device accessibility and knowledge translation. We have developed a list of strategies that can help facilitate successful implementation. A deliberate strategy to foster utilization, mitigate identified barriers and broadly accelerate implementation has the potential to have a profound impact on improving patient outcomes.

Acknowledgments

Melissa Langhan was supported by CTSA Grant Number UL1 RR024139 from the National Center for Research Resources (NCRR) and the National Center for Advancing Translational Science (NCATS), components of the National Institutes of Health (NIH), and NIH roadmap for Medical Research. Its contents are solely the responsibility of the authors and do not necessarily represent the official view of NIH. She also received funding from the Yale Pediatric Faculty Scholar Program for this study. In 2011, she received an honorarium from Oridion Capnography for presentation at an expert panel meeting.

References

1. Sullivan KJ, Kissoon N, Goodwin SR. End-tidal carbon dioxide monitoring in pediatric emergencies. Pediatr Emerg Care. 2005; 21(5):327–332. [PubMed: 15874818]
2. Eipe N, Doherty DR. A review of pediatric capnography. J Clin Monit Comput. 2010; 24(4):261–268. [PubMed: 20635124]
3. Ahrens T. Monitoring carbon dioxide in critical care: the newest vital sign? Crit Care Nurs Clin North Am. 2004; 16(3):445–451. [PubMed: 15358391]
4. Hisamuddin NA, Rashidi A, Chew KS, Kamaruddin J, Idzwan Z, Teo AH. Correlations between capnographic waveforms and peak flow meter measurement in emergency department management of asthma. Int J Emerg Med. 2009; 2(2):83–89. [PubMed: 20157449]
5. Kartal M, Eray O, Rinnert S, Goksu E, Bektas F, Eken C. $ETCO_2$: a predictive tool for excluding metabolic disturbances in nonintubated patients. American Journal of Emergency Medicine. 2011; 29(1):65–69. [PubMed: 20825776]
6. Kleinman ME, Chameides L, Schexnayder SM, Samson RA, Hazinski MF, Atkins DL, et al. Part 14: pediatric advanced life support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation. 2010; 122(18 Suppl 3):S876–908. [PubMed: 20956230]
7. Neumar RW, Otto CW, Link MS, Kronick SL, Shuster M, Callaway CW, et al. Part 8: adult advanced cardiovascular life support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation. 2010; 122(18 Suppl 3):S729–767. [PubMed: 20956224]
8. American Society of Anesthesiologists. Standards for Basic Anesthetic Monitoring.; Anesthesiology House of Delegates. 2011. p. 1-3.
9. Jarzyna D, Jungquist CR, Pasero C, Willens JS, Nisbet A, Oakes L, et al. American Society for Pain Management Nursing guidelines on monitoring for opioid-induced sedation and respiratory depression. Pain Manag Nurs. 2011; 12(3):118–145. e110. [PubMed: 21893302]
10. Langhan ML, Chen L. Current utilization of continuous end-tidal carbon dioxide monitoring in pediatric emergency departments. Pediatr Emerg Care. 2008; 24(4):211–213. [PubMed: 18431217]

11. Langhan M. Continuous end-tidal carbon dioxide monitoring in pediatric intensive care units. J Crit Care. 2009; 24(2):227–230. [PubMed: 19327292]
12. Shavit I, Leder M, Cohen DM. Sedation provider practice variation: a survey analysis of pediatric emergency subspecialists and fellows. Pediatr Emerg Care. 2010; 26(10):742–747. [PubMed: 20881903]
13. Deiorio NM. Continuous end-tidal carbon dioxide monitoring for confirmation of endotracheal tube placement is neither widely available nor consistently applied by emergency physicians. Emerg Med J. 2005; 22(7):490–493. [PubMed: 15983084]
14. Erasmus PD. The use of end-tidal carbon dioxide monitoring to confirm endotracheal tube placement in adult and paediatric intensive care units in Australia and New Zealand. Anaesth Intensive Care. 2004; 32(5):672–675. [PubMed: 15535493]
15. Greer AL. Scientific knowledge and social consensus. Control Clin Trials. 1994; 15(6):431–436. [PubMed: 7851105]
16. Edmondson A, Bohmer R, Pisano G. Disrupted Routines: Team Learning and New Technology Implementation in Hospitals. Administrative Science Quarterly. 2001; 46(4):685–716.
17. Kimberly JR, Evanisko MJ. Organizational innovation: the influence of individual, organizational, and contextual factors on hospital adoption of technological and administrative innovations. Acad Manage J. 1981; 24(4):689–713. [PubMed: 10253688]
18. Patton, MQ. Qualitative Research & Evaluation Methods. 3rd ed.. Sage Publications; Thousand Oaks, CA: 2002.
19. Sinuff T, Cook DJ, Giacomini M. How qualitative research can contribute to research in the intensive care unit. J Crit Care. 2007; 22(2):104–111. [PubMed: 17548020]
20. Hanson JL, Balmer DF, Giardino AP. Qualitative research methods for medical educators. Acad Pediatr. 2011; 11(5):375–386. [PubMed: 21783450]
21. Mays N, Pope C. Qualitative research in health care. Assessing quality in qualitative research. BMJ. 2000; 320(7226):50–52. [PubMed: 10617534]
22. Bradley EH, Curry LA, Devers KJ. Qualitative data analysis for health services research: developing taxonomy, themes, and theory. Health Serv Res. 2007; 42(4):1758–1772. [PubMed: 17286625]
23. Weitzman EA. Analyzing qualitative data with computer software. Health Serv Res. 1999; 34(5 Pt 2):1241–1263. [PubMed: 10591282]
24. Bowles TM, Freshwater-Turner DA, Janssen DJ, Peden CJ. Out-of-theatre tracheal intubation: prospective multicentre study of clinical practice and adverse events. Br J Anaesth. 2011; 107(5): 687–692. [PubMed: 21828342]
25. Kolb, D. Experiential Learning. Prentice Hall; Upper Saddle River, NJ: 1984.
26. Sheckley, B.; Kehrhahn, M.; Bell, S.; Grenier, R. Proceedings of the 49th Annual Adult Education Research Conference. University of Missouri; St. Louis: 2008. Trio: An Emerging Model of Adult Professional Learning..
27. Bloom, B. Taxonomy of Educational Objectives, Handbook 1: The Cognitive Domain. David McKay Co Inc.; New York, NY: 1956.
28. Scott SD, Osmond MH, O'Leary KA, Graham ID, Grimshaw J, Klassen T. Barriers and supports to implementation of MDI/spacer use in nine Canadian pediatric emergency departments: a qualitative study. Implement Sci. 2009; 4:65. [PubMed: 19828086]
29. Doolan DF, Bates DW. Computerized physician order entry systems in hospitals: mandates and incentives. Health Aff (Millwood). 2002; 21(4):180–188. [PubMed: 12117128]
30. Studnicki J, Remmel R, Campbell R, Werner DC. The impact of legislatively imposed practice guidelines on cesarean section rates: the Florida experience. Am J Med Qual. 1997; 12(1):62–68. [PubMed: 9116534]
31. Kumar S, Aldrich K. Overcoming barriers to electronic medical record (EMR) implementation in the US healthcare system: A comparative study. Health Informatics J. 2010; 16(4):306–318. [PubMed: 21216809]
32. Rogers, EM. Diffusion of Inovations. Fifth edition ed.. Free Press; New York, NY: 2003.

33. Greer AL. Adoption of medical technology. The hospital's three decision systems. Int J Technol Assess Health Care. 1985; 1(3):669–680. [PubMed: 10276734]

Highlights

- There is variability in capnography use among emergency and critical care units
- Environmental factors such as equipment availability and unit policies affect use
- Knowledge translation is a key factor in consistent, wide spread, appropriate use
- Personal experiences impact the implementation of a new technology
- Implementation strategies include fostering utilization and mitigating barriers

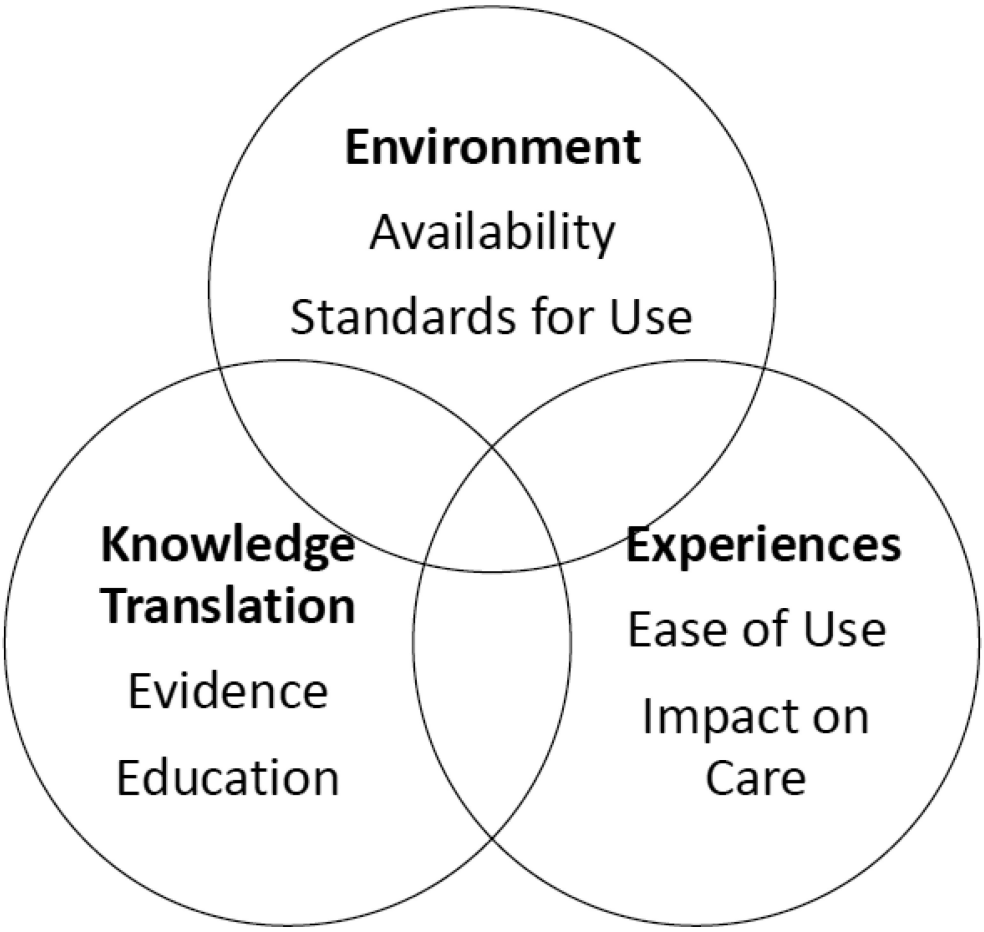

Figure 1.
Modification of Trio Model of Professional Learning for Implementation of New Technology.

Table 1

Characteristics of study participants.

Unit and Provider Type, N (%)	
Emergency Department	9 (47)
Physician	5 (26)
Nurse	4 (21)
Intensive Care Unit	10 (53)
Physician	5 (26)
Nurse	5 (26)
Age in years, Mean (Min, Max)	43 (27, 62)
Years working on unit, Mean (Min, Max)	9.5 (1, 40)

Table 2

Barriers and facilitators to capnography use that emerged within each main theme along with illustrative quotes.

Theme	Barrier	Facilitator
Variability exists in capnography use among acute care units	*Inconsistent use of capnography within a group* ED Nurse: "I've used it more so than others, and they don't use it, because they have these other things to use. And I think over time it's going to be not just the exception, but right now it's the exception; some people use it, some people don't." ICU Nurse: "I think it's a lack of a hard stance that it's mandated every patient getting conscious sedation, it's kind of you use your discretion." ICU Physician: "I don't know if everyone is using it during sedation. I think we're starting to do that more frequently...I suspect when I'm not around, it may not always be used."	*Policies for and promotion of use of capnography* ICU physician: "The decision was made that it would be helpful for all intubated patients. We all agreed on having that policy rather than having to specifically ask for it on certain intubated patients. So, no matter who gets it even our transport team, when they go out to get patients, they have end tidal setups in their transport bags, so any intubated patient that they pick up from an outside hospital or if they have to intubate the patient, it gets put right on and it's part of the vital signs." ED Nurse: "You'll use it a lot with one doc and not at all with another.... If more docs use it more nurses will."
Availability and accessibility of capnography equipment impacts use	*Lack of availability of capnography* ICU Physician: "Usually the respiratory therapist or the nurses have to go hunting around for the little module that plugs into the Philips monitors, and then the respiratory therapists have to go around trying to find the...tubing that comes off of the endotracheal tube attachment...we usually have to sort of spend an hour or so trying to find the stuff." ED physician: "Yesterday I was in a room that didn't have it (the monitor), and I just basically didn't use it." ICU Nurse: "I usually borrow it from SICU, because I don't think we have one down here."	*Easily accessible equipment* ICU Nurse: "The device is in all our rooms. Our monitors have the ability to monitor CO_2. All you need is the probe; we have a stock of them in the unit. And we have the cannulas, too." ICU Physician: "It's portable and it's close by, and the people who know how to use it, who understand it, the respiratory therapists, are the ones who have access to it and know where if find it."
Dissimilar interpretations of the evidence behind capnography use is apparent	*Lack of sufficient evidence to support use of capnography* ED physician: "I was hoping there would be like more robust literature saying like, look really it does make a difference. And there are some positive papers, but they're not overwhelming, not enough to tell those people who are confident that they're doing fine already to say like, wow, I really am missing the boat." ICU physician: "I think if I had more data to say that it more accurately reflected arterial carbon dioxide levels, I might be more inclined to use it, even if it was in certain situations...Or that there was other data that it was helpful maybe in other ways. So I guess I would need some specific data around it."	*Capnography as a standard of care* ICU physician: "Generally, I feel that in intubated patients it is in 95% of the situations a mandatory mode of monitoring that patient. It's become my practice. I'd say it's practice of almost all of us in the ICU that this is an effective and useful way of monitoring their response to mechanical ventilation." ED physician: "It's pretty much standard of care once they get intubated that they're hooked up to the capnography." ED physician: "It's now standard for any sedation...You tell the nurse you're going to do conscious sedation for a procedure. That generates paperwork and a procedure list for them, the time out and all that stuff. And part of their list is capnography."
Disparate views exist as to the ability of capnography to impact patient care	*Lack of perceived need* ICU physician: "There may be a patient population of un-intubated patients that it's useful (for), but I just haven't come across the need to use it yet on somebody who is not intubated. I'm not sure that it really works with or is useful in patients that are un-intubated." ED Nurse: "Our sedation protocols are so strict here with such intense supervision of the child both at a physician and nurse level that recognizing early changes is typically not something missed." ED Physician: "When people are like, no, we've been doing sedations for a while, and things have been going fine. We haven't had people needing-- we haven't had bad outcomes. Is this really going to add much?"	*Observed benefits to patients and providers* ICU nurse: "I think it's vital with a lot of our patient, especially the intubated ones. Especially when they're unstable, because it gives us a continuous, frequent analysis of their respiratory status, essentially... if there are any sudden or acute changes, you'll know. It can tell us if the tube is dislodged pretty much instantly with the alarm." ICU Nurse: "I think that the big reason that we use it is if we're having to do frequent blood gases, we like to have a trend to go by; and it just helps us-- if the number starts looking much different than it was, it might cue us to do a blood gas sooner than what we might have." ED Nurse: "It's really fast. Well, it takes like 30 seconds or so. You put it on and in about 30 seconds you can see the nice wave. And when they start sleeping and lessen you automatically can see it." ICU Physician: One of the newer tenets of CPR is that you don't stop the CPR part, or you try to minimize discontinuing. In the old days, we used to stop and see if there was a pulse and see if things were working. You don't need to do that anymore using CO_2 monitoring. It's a major advance for how we do CPR."
Personal or anecdotal experiences with capnography can	*Negative experiences leading to non-use of capnography* ICU Physician: "On the few occasions when I have used it I have found that the number that it generates does not allow me to make an accurate evaluation of the patient's	*Recent resurgence of use of capnography* ICU Nurse: "I think it's gotten revitalized, and people are, "Ooh, what's our end-tidal CO_2? Let's start tracking that on

Theme	Barrier	Facilitator
impact its future use	pulmonary dead space, which means that I don't really have a good sense of the patient's pulmonary blood flow." ICU Nurse: "They don't always correlate that well. It's sort to just fallen out of favor. They're sort of a pain to use, also. It's not a necessarily easy technology. It does plug into these monitors so that it's probably somewhat easier to use. But, you've got to hook it up to the ventilator, you've got to get it calibrated and use it." ED Nurse: "Probably the most I've been exposed to that is, they use it in the field, with EMS. So paramedics will bring patients in with it from the field. But we take it right off usually."	patients. It is getting more utilized now that it's been more widely understood." ICU Physician: "I've reintroduced end-tidal CO_2 monitoring for the cardiac arrest setting. In that setting, it's a superb technology and we're routinely using it now...For the management of cardiac arrest, looking at the quality of CPR and the return of spontaneous circulation, it's transformational. It's a huge advance in CPR." ED Physician: "Once everyone knows they use it for all the sedations in the PICU and they use it for all the sedations that Anesthesia does, then they're like, okay, I guess we'll use it too."
Diversity of knowledge and provider sophistication with data interpretation is evident	*Lack of knowledge regarding application and interpretation* ICU physician; "I think it's part of understanding the technology. Again, it's very simple stuff. But it's not emphasized, maybe not even taught in the earlier levels of training, like interns and residents." ED nurse: "They don't know it...They have only used it a couple of times, so they feel safer with what they know." ICU physician: "I'll tell you that in the ICU Oversight Committee that I chair...brought forward the idea of employing this technology widely, believing and swearing up and down that it's about ventilation, and it's absolutely not about ventilation. It's only partly about ventilation. And that misconception will lead to misinterpretation of the data that comes out of the monitor, and that is potentially dangerous." ED Physician: "Let's take procedural sedation, when a person is sedated it gives a more accurate depiction of their oxygen status, rather than pulse oximetry, which used to be the standard."	*Knowledge and understanding of principles of capnography* ED physician: "When you sedate somebody, they can lose their respiratory drive, and a lot of times there's a lag time between when the oxygen drops, which has been the easier thing to monitor with the fingertip pulse oximeter. So by the time the oxygen's dropping, they haven't taken a breath in a while, especially if they're on supplemental oxygen, then you're already way behind. So now when you start to react, you've lost valuable time to evaluate the patient. It's a much more immediate marker for over-sedation." ICU Nurse: "If they start desatting it's obvious there is an issue, but there is much more subtle modalities like the end-tidal CO_2 trending that can alert you of problems a little before you have to emergency intubate them." ICU Physician: "And CPR, it gives you a signal of the quality of CPR while it's going on, and it tells you without stopping CPR that the heartbeat has returned; the heart function has returned." ICU Nurse: "Definitely as far as ACLS guidelines and everything, they've shown that when you have capnography on board while you're in a cardiac arrest and performing CPR, that it is indicative of patient outcome. And I think we've seen that in our arrests here. And it's a quick indicator for us to see right at bedside, is our CPR effective."