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Improving Capnography Use for Critically Ill Emergency Patients: An Implementation Study

Rahul Shah, MD,* Douglas A. Streat, MPH,† Marc Auerbach, MD, MSc,‡
Veronika Shabanova, MPH, PhD,* and Melissa L. Langhan, MD, MHS‡

Objectives: Capnography has established benefit during intubation and cardiopulmonary resuscitation (CPR). Implementation within emergency departments (EDs) has lagged. We sought to address barriers to improve documented capnography use for patients requiring intubation or CPR.

Methods: A controlled before- and after-implementation study was performed in 2 urban EDs. The control site had an existing policy for capnography use. Interventions for the experimental site included a 5-minute informational video, placement of capnography monitors with a shortened warm-up period in all resuscitation rooms, laminated reminder cards, and feedback during staff meetings. Staff members were surveyed about knowledge before and after the intervention. Records were reviewed for documented capnography use for 3 months before and 6 months after the intervention. Change in documented use at the experimental site was compared with the control site.

Results: At the experimental site, 118 providers participated and 190 records were reviewed; 544 records were reviewed from the control site. There was a significant increase in the proportion of documented capnography use at the experimental site (8% versus 19%, $P = 0.04$) compared with the control site (64% versus 71%, $P = 0.10$). However, there was no significant trend over time at the experimental site after the intervention ($P = 0.86$). Despite high baseline knowledge about capnography, providers had improvements in survey responses regarding indications for intubation and CPR, normal values, and minimum effective values during CPR.

Conclusions: Documented capnography use increased with simple interventions but with no positive trend. Additional work is needed to improve use, including further evaluation of capnography's implementation in the ED.

Key Words: capnography, intubation, cardiopulmonary resuscitation, emergency department, implementation

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The American Heart Association recommends the use of capnography, the graphical representation of carbon dioxide released throughout the respiratory cycle, in the setting of intubation

and cardiopulmonary resuscitation (CPR) in their adult and pediatric advanced life support guidelines.^{1,2} In patients undergoing CPR, capnography has been associated with improved chest compression quality by providing real-time feedback to providers.³ In addition, capnography decreases the need to pause CPR for pulse checks, as return of spontaneous circulation (ROSC) may be detected through a rapid rise in end-tidal carbon dioxide (ETCO₂).^{4,5} Capnography has a definitive role in the management of intubated patients as well and is more reliable than any bedside alternative in confirming the correct position of an endotracheal tube (ETT).⁶

Although the pool of evidence regarding the beneficial use of capnography after intubation and during CPR has been accumulating since the 1980s such that it is now incorporated into national guidelines, there are still large gaps and variations in emergency department (ED) use. Uptake of capnography use has been variable between medical institutions, with reported use between 15% and 66% for patients requiring intubation or CPR.^{7–11} Incorporation of new technologies into everyday practice is complex, with factors ranging from physical availability and knowledge of use to organizational factors impacting implementation. Such variances may explain the inconsistent adaptation of best practices throughout different medical centers.¹² It is common to see certain technologies adopted with great variability across different institutions.¹³ It is therefore prudent to explore the barriers to capnography use in the ED and devise strategies to further implement this practice.^{14,15}

Two barriers to use that have been identified are knowledge gaps among providers regarding applicability and use of capnography, and difficulties accessing equipment. Only one prior study assessing the implementation of capnography was identified, which evaluated its use in a postoperative care unit.¹⁶ To continuously improve patient outcomes, consistent and widespread use of evidence-based care is essential. The objectives of our study were to develop a multifaceted implementation intervention in an ED using the knowledge transfer framework to improve the documented use of capnography among critically ill patients (defined, for the purposes of this article, as those requiring CPR or endotracheal intubation) and to conduct a local efficacy evaluation of the intervention.

METHODS

Study Design

This was a controlled before- and after-implementation study. The knowledge transfer framework incorporates identification of a message, target audience, messenger, process and communication, and evaluation.¹⁷ Details of the knowledge transfer framework used to guide the study are presented in Supplemental Table 1 (Supplemental Digital Content 1, <http://links.lww.com/JPS/A281>).¹⁷ This study was registered on ClinicalTrials.gov NCT02901197.

Study Population and Setting

Staff members of the ED were the target audience for intervention in this study, and ED patients who required intubation or CPR were the downstream recipients of implementation changes. Staff

From the *Department of Pediatrics, Yale University School of Medicine; †Yale School of Public Health; and ‡Section of Pediatric Emergency Medicine, Department of Pediatrics and Emergency Medicine, Yale University School of Medicine, New Haven, Connecticut.

Correspondence: Melissa L. Langhan, MD, MHS, Section of Pediatric Emergency Medicine, Department of Pediatrics and Emergency Medicine, Yale University School of Medicine, 100 York ST, Suite 1D, New Haven, CT 06510 (e-mail: Melissa.Langhan@yale.edu).

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included registered nurses, respiratory therapists, technical associates, physicians, physician’s assistants, and advanced practice nurse practitioners who fulfill most of their clinical duties in the ED. Staff members who work in the ED on a casual or per diem status were excluded.

Two sites were used for this study. The control site was an urban, academic tertiary care center, and the experimental site was an urban, community-based hospital. Both sites are trauma centers and have annual ED patient volumes >80,000, and used the same electronic health record (EHR). In each site, the use of capnography was assessed through reviewing both provider notes and vital sign flow sheets. In addition, both sites had the same available fields to document the use of capnography. The control site had previously created a departmental guideline regarding the placement of capnography monitoring in intubated patients. There was no similar guideline in place at the experimental site. The control site was thus used to measure secular trends and identify other special cause variations in use. This study received ethical approval from the human research protection program at the control site and the investigative review board at the experimental site.

Study Protocol

Study activities are outlined in Figure 1. A multidisciplinary team with members from both the control and experimental sites including an ED nurse, an ED nurse practitioner, a physician with expertise in capnography, a public health student, and a physician with community outreach experience engaged with staff at the experimental site as well as created and deployed targeted study interventions in keeping with our knowledge transfer framework. The intervention was focused on the following 3 key barriers to capnography use identified in a prior study: availability of equipment, knowledge of capnography, and awareness of potential patient benefits when capnography is applied in clinical settings.¹⁴ During a series of meetings in the 6 months leading up to the launch of the implementation intervention, study investigators visited the experimental site, obtained buy-in from departmental leadership, and explored environmental barriers to capnography use with key informants, which included nursing staff and front-line providers. Informants included the chair of the department of emergency medicine, attending physicians, a senior nurse practitioner, nursing leadership, and senior nurses. Barriers that have been previously published and those specifically discovered at

the experimental sites along with their mitigating interventions are presented in Table 1. Monitors (Capnostream 20; Medtronic) and capnography cannulas (Filterline; Medtronic) were placed in all resuscitation rooms. To address knowledge and impact on care, the study team created a professionally produced, 5-minute intervention video for ED staff. The video featured providers from the experimental site as well as content experts to facilitate further buy-in from staff and covered the following 4 main topics: (a) overview of capnography and the American Heart Association guidelines; (b) benefits and use of capnography for intubation, (c) benefits and use of capnography during CPR; and (d) how to use the monitor and document in the EHR. The video was piloted at the control site among pediatric ED staff to limit cross-contamination; staff completed a validated questionnaire after viewing the video. The questionnaire included items to evaluate barriers and facilitators to innovations and evaluate the acceptability of the video’s content.¹⁸ To facilitate knowledge retention given that intubation and CPR are relatively rare events and may occur at a time point distant from the viewing of the video, laminated cards with a simple mnemonic were created to serve as a reminder about key concepts in the video and were attached to the portable capnography monitors (Table 1).

Two study team members, the ED nurse and nurse practitioner from the experimental site served as local champions. They assisted in the deployment of the intervention and reminded staff about capnography use for critically ill patients. Two electronic surveys (REDCap) were distributed to staff at the experimental site before implementing the intervention. The first survey collected demographic data and used questions from a previously validated questionnaire as well as newly derived questions based on published data to assess barriers and facilitators to capnography use.¹⁸ The validated survey measures characteristics regarding the innovation, providers, patients, and the organizational, social, political, and societal context. The second survey was designed by study investigators to assess knowledge about capnography before and after viewing the video. Questions assessed knowledge of normal capnography ranges and use of capnography for intubation and CPR. Surveys were distributed via e-mail to all staff at the experimental site; nonresponders were reminded on a weekly basis to complete their surveys. After completion of the 2 surveys, ED staff members were invited to view the intervention video on a private web link and then complete the knowledge survey a second time. Numbers of views of the video were tracked online.

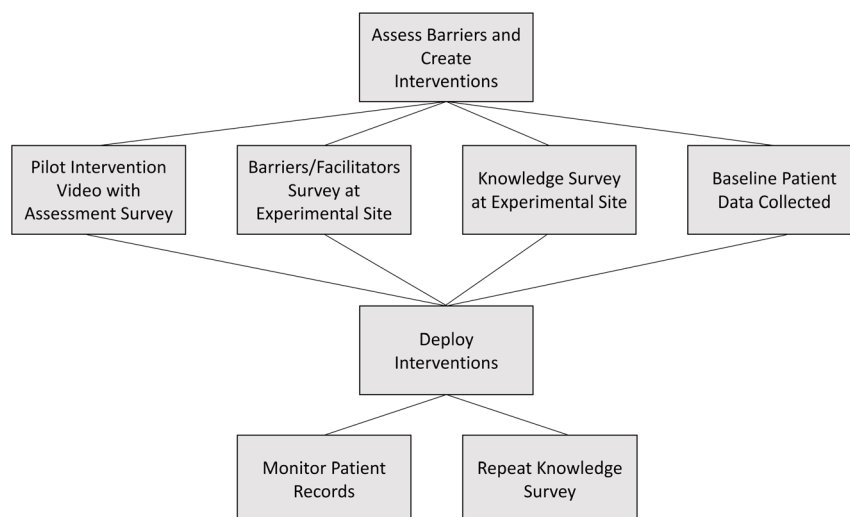


FIGURE 1. Flow diagram of study interventions.

TABLE 1. Addressing Barriers to Change at the Experimental Site

Barrier	Change
Equipment availability: providers discouraged to use capnography because of monitors being disconnected secondary to alarming when not in use; monitors then required 2-min warm-up period before obtaining readings	Portable monitors with a short “warm-up” time were made available in all resuscitation rooms.
Knowledge: providers may be unaware of capnography’s benefits for intubation and CPR and how to interpret the waveform.	A brief, informative video was created to instruct providers on the benefits of the use of capnography, as well as basics on how to apply the monitor and interpret the waveform.
Knowledge retention: providers may have difficulty recalling key points from educational video, as critically ill patients may present at time point distant from viewing.	Laminated cards (detailed below) with key concepts were created and attached to each portable monitor: Capnography is NICE Normal ETCO ₂ is from 35 to 45 mm Hg in an otherwise healthy patient Intubation: confirm placement and monitor ventilation CPR: good compressions leads to ETCO ₂ > 10–15 mm Hg; sudden steep rise = ROSC EHR: Do not forget to document your numbers!

Staff members were offered continuing education units for their participation.

For 4 months before and 6 months after the intervention launch, the EHRs of eligible ED patients from both the control and experimental sites were reviewed on a weekly basis. Charts were identified by searching for documentation of procedures (e.g., intubation) or critical care time. Patient data were collected, including age, sex, medical or traumatic chief complaint, intubation status, CPR status, documented ETCO₂ values, and the date, time, and site of visit. Data were abstracted onto an electronic form, and 25% of randomly selected records were reviewed for accuracy by a second investigator. Research assistants spent up to 20 hours per week as observers in the ED at both sites and compared the accuracy of observations with EHR documentation. Audit and feedback regarding documented capnography use were provided to the study coordinator at the experimental site to share with staff on a biweekly basis.

Outcomes

The primary outcome was EHR documentation of capnography use among ED patients requiring intubation or CPR. Documentation was used as a surrogate for adherence to national guidelines regarding the application of capnography after intubation and during CPR. Secondary outcomes included assessment of the intervention video and staff knowledge about capnography.

Data Analysis

Descriptive statistics were used to summarize participant characteristics and the overall outcomes and included percentages, means, and standard deviation (SDs). Variation in ED patient characteristics between the control and experimental sites, as well as proportions of patients with documented capnography, was expressed as differences in proportions and means with 95% confidence intervals (95% CIs). An interrupted time series analysis was used to assess the overall and site-specific trends in documented capnography use before and after the introduction of the intervention. This allowed the comparison of preintervention and postintervention adherence rates of capnography use while accounting for the preexisting rates of adherence at each site, preexisting trends, and the magnitude of change.¹⁹ Power calculations for designing interrupted time series analyses are generally based on simulation studies, which recommend that for approximately 12 observations per time point and a minimum expected effect size of 1.0 (sum of expected intervention effect plus the unit trend change, i.e., change per unit of time), the number of time points should be no less than 18 to have a

sufficient power of 80% or greater, with a projected autocorrelation of less than or equal to 0.30.²⁰ Through retrospective chart review, we aimed to capture 80% of all eligible patients at each site. Two methods were used to assess our outcomes. Differences in knowledge based on our pretesting and posttesting were assessed through *t* tests; paired analysis was not possible because the surveys were anonymous. To detect a 10% difference with an SD of 10% at a power of 0.9 and a 2-tailed α of 0.05, a total of 13 staff members were needed. Analyses were performed with IBM SPSS 24 and SAS 9.4 (Cary, NC). Statistical significance was established at an α value of 0.05.

RESULTS

One hundred eighteen (72%) of 164 ED staff at the experimental site completed the participant survey before the onset of the intervention. Staff demographics are presented in Table 2.

Documented Capnography Use

During the 9-month period, there were a total of 734 ED patient records reviewed. At the experimental site, there were 74 eligible

TABLE 2. Participant Data (n = 118)

Variable	Summary Statistic
Role, n (%)	
Physician	10 (8)
RN	86 (72)
APRN/PA	6 (5)
Technical associates	11 (9)
Other	5 (4)
Years of experience in current role, mean (SD)	10 (10)
How often have you applied or asked to apply capnography to an intubated patient?* mean (SD)	38 (34)
How often have you applied or asked to apply capnography to a patient requiring CPR?* mean (SD)	35 (34)

*Scale from 0 to 100, with 0 indicating never, 50 indicating sometimes, and 100 indicating very often.

APRN, advanced practice nurse practitioner; PA, physician’s assistant; RN, registered nurse.

patients before the intervention and 116 eligible cases after the intervention. At the control site, there were 185 eligible patients before the intervention and 359 eligible patients after the intervention. Patient characteristics are listed in Table 3. With the exception of capnography use and need for CPR, there were no differences in demographic or medical variables among the patients before or after the intervention.

Capnography use did not vary by sex or time of arrival across both sites. At the experimental site, there was a higher use of capnography among patients 18 years or younger compared with those older than 18 years (50% versus 13% [difference, 37%; 95% CI, 15%–60%]), whereas there was no significant difference at our control site. At the control site, there was a lower use of capnography among patients requiring CPR as opposed those requiring intubation alone (51% versus 74% [difference, 23%; 95% CI, 14%–31%]).

There was an overall increase in the proportion of all eligible patients with documented capnography use at the experimental site (8% versus 19% [difference, 11%; 95% CI, 0.3% to 21%]), but not at the control site (64% versus 71% [difference, 7%; 95% CI, –1% to 15%]). However, there was no significant association between the introduction of the intervention and the time trend as expressed by the postintervention monthly change in documented capnography use ($P = 0.86$; Fig. 2). There were very few direct observations of intubations at the intervention site; one of these observations demonstrated the use of capnography when this was not documented in the EHR.

Survey Results

The barriers and facilitators survey demonstrated that although most staff members expressed a willingness to use capnography in critically ill patients and did not express negative opinions about the device or its application, a large proportion did not feel comfortable with interpretation of capnography, desired more knowledge about capnography, and were unsure of its location in the ED (Supplemental Table 2, Supplemental Digital Content 2, <http://links.lww.com/SIH/A502>).

Barriers to Capnography Video and ED Application

The intervention video was piloted among 31 pediatric ED staff members at the control site. The questionnaire revealed no significant barriers to the use or message of the capnography video. After viewing the video, 5 respondents (16%) of the pilot cohort answered that they wished to know more about capnography before applying it to patients.

Staff Knowledge

One hundred three staff members completed the knowledge survey before the intervention, and 40 repeated the survey after

the video. The video was viewed 177 times during a 2-month period, with 100 of views occurring during the first 2 weeks. There was a high baseline knowledge regarding capnography. More respondents knew that capnography was an indicator of cardiac output after viewing the video; there were also increases in knowledge regarding uses of capnography for intubation and CPR, as well as normal values and the minimum effective ETCO₂ value during CPR (Table 4).

DISCUSSION

In this implementation study, a short, educational video about capnography use in patients requiring intubation or CPR was created by a multidisciplinary team, reviewed and well-received by our pilot subjects, and successfully deployed in an urban ED with low baseline capnography usage. The multifaceted intervention was able to improve ED staff knowledge about capnography and resulted in an overall increase in documented capnography use after our intervention; however, there was no change in the trend in documented use of capnography.

A baseline survey indicated that providers were amenable to making changes in their clinical practice, with approximately 90% of respondents indicating that they would be willing to apply capnography in patients who are intubated or undergoing CPR. Despite this assertion, most respondents did not put this into practice. Dissemination of knowledge is a key step before a change in practice. One prior study of capnography knowledge demonstrated a lower composite score among participants as compared with the high baseline knowledge in this study; however, this test was limited to anesthesiology nurses.²¹ A short video was chosen as one of the interventions in this study given the benefits and effectiveness of this format, allowing participants to view the video when time permitted.^{22,23} There were a large number of views of the online video, indicating that this methodology is effective. In our pilot phase, most staff members felt that the video provided sufficient information to trial capnography, which points toward acceptance and effectiveness of the film. Despite knowledge being a known barrier, the staff at our experimental site had high baseline knowledge about capnography use for intubation and CPR.^{14,16} Although there was a smaller proportion of staff that completed the postintervention knowledge survey, there was a significant increase in performance on this survey as compared with the preintervention knowledge survey.

Although there was low baseline use, documented application of capnography more than doubled at our experimental site and was sustained over time. However, the increase in use did not show a significant continuing trend toward improvement. The care of critically ill patients can be chaotic, and documentation has been found to be suboptimal; thus, this may not accurately reflect

TABLE 3. Patient Data

Variable	Intervention Site (n = 190)	Control Site (n = 544)	Difference (95% CI)
Age, mean (SD), y	55 (21.3)	55 (21.6)	–0.17 (–3.7 to 3.4)
% Male sex	62	58	5 (–4 to 13)
% Children aged ≤18 y	5	6	1 (–3 to 5)
No. intubation attempts	1.4	1.2	0.15 (–0.05 to 0.25)
Medical cause for intubation, %	74	74	0.6 (–10 to 11)
Documented esophageal intubation, %	1	2	–0.8 (–3 to 1)
Overall ETCO ₂ use, %	15	68	–54 (–61 to –46)
Required CPR, n (%)	33 (17)	134 (25)	–7 (–14 to –0.5)
Obtained ROSC, n (%)	13 (39)	75 (56)	–17 (–36 to 3)

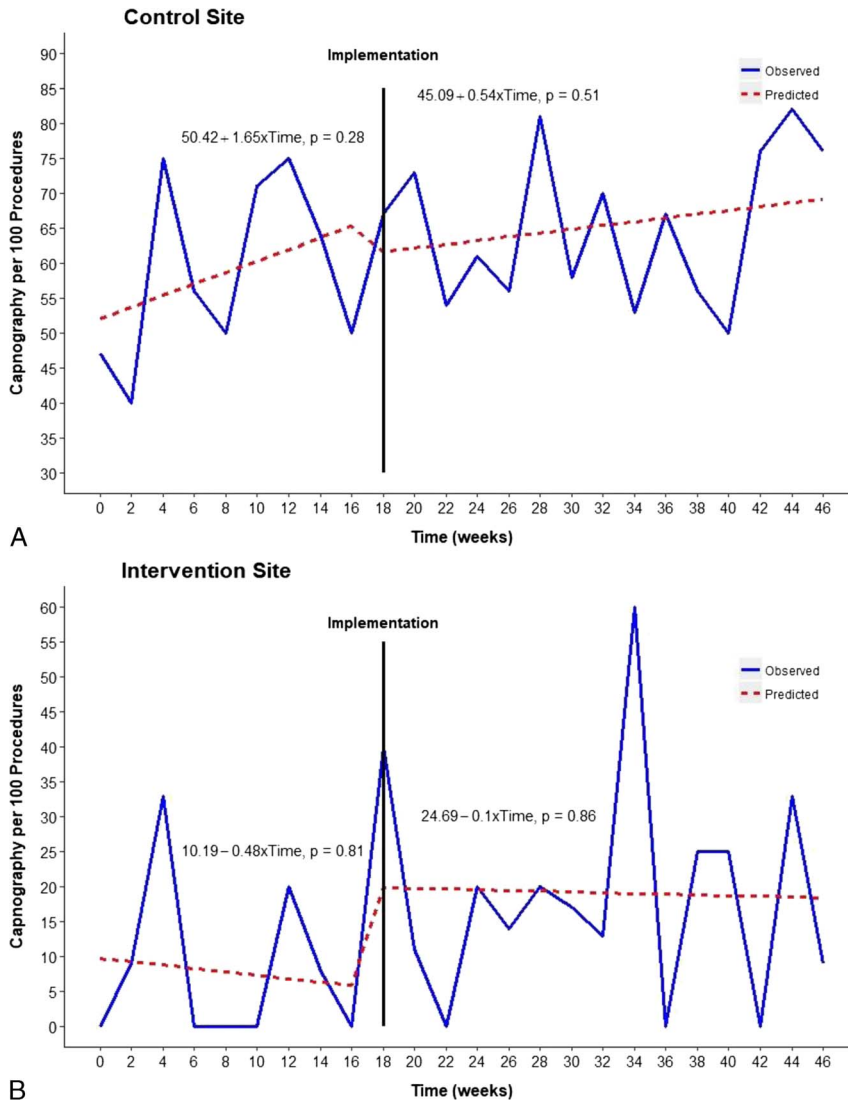


FIGURE 2. Interrupted time series evaluating the trend in documented capnography use at the control site (A) and experimental site (B).

true use. Appropriate documentation of ETT position has been positively associated with ROSC and survival to discharge among patients requiring CPR.⁹ This association held true at our control site; however, the small overall numbers of patients requiring CPR combined with the low use of capnography was not sufficient to draw conclusions from our experimental site. Although this overall increase in documented use indicates success of our intervention, the flat slope may reflect a limited increase among a subgroup of users at the site with limited overall culture change regarding capnography. This may reflect waning memory of our intervention in that providers may not have encountered a patient requiring intubation or CPR for weeks to months following the educational component of our intervention. Although we tried to combat this problem with laminated cards, the cards were attached to the capnography monitors and may not have been readily visible to the staff performing these tasks. On the other hand, there were anecdotal reports of increased capnography use for other indications, such as monitoring during moderate sedation, due to the increased availability of equipment. This implies diffusion of the technology and may reflect the perceived value of this tool by staff.

The uptake of capnography in the emergency setting is similar to another noninvasive monitor: pulse oximetry. Pulse oximetry only started to gain ground in the late 1980 but is now standard of care for triage, assessment, and monitoring of patients. Similar to capnography, many early articles discussed potential applications and comparisons with other more invasive technologies, and addressed limitations of this tool.^{24–27} Less is known about the process of adoption and implementation process for pulse oximetry, however. Reasons for failure of a larger scale of capnography implementation must then be considered.

It is not uncommon for the same technology to thrive in one institution yet fail in another, perhaps because of differences in the implementation process.¹³ Although staff at the experimental site indicated willingness to apply capnography at the beginning of this study, there may have been additional barriers that were not addressed.²⁸ In evaluating the theory of diffusion of innovation, capnography seems to have attributes of success such as ease of use, consistency with current experiences, ability to be trialed without harm to patients, and benefits over current devices.^{29,30} However, these may not have been enough to tip the balance in favor of

TABLE 4. Knowledge Survey Data From Experimental Site Staff

Knowledge Question	Correct Response Before Video, n (%)	Correct Response After Video, n (%)	Difference (95% CI), %
Respondents	103	40	
In the intubated patient, capnography can detect:			
Mainstem intubation	54 (53)	29 (73)	20 (38 to 2)
Hyperventilation	87 (85)	33 (83)	-2 (-15 to 12)
Hypoventilation	93 (90)	36 (90)	0 (-11 to 12)
ETT dislodgement	80 (77)	38 (95)	18 (3 to 31)
During CPR, capnography can indicate:			
Fatigue in performing chest compressions	72 (70)	35 (88)	18 (2 to 33)
ROSC	76 (74)	34 (85)	11 (-4 to 27)
Quality feedback	92 (89)	38 (95)	5 (-5 to 16)
Need for epinephrine	4 (4)	0 (0)	-4 (-10 to 2)
Ventricular fibrillation	5 (5)	1 (3)	-2 (-10 to 5)
Lower limit of normal	73 (71)	33 (83)	12 (5 to 28)
Upper limit of normal	74 (72)	32 (80)	12 (8 to 24)
Effective CPR minimum value	33 (32)	21 (53)	20 (3 to 38)

use.³⁰ The implementation of a policy at the control site was associated with significantly higher rates of capnography use when compared with the experimental site, but these rates are still far from perfect. Lack of buy-in or acceptance of guidelines and policies can inhibit the implementation of new technology or evidence.³¹ Although the research team included staff members from the experimental site and buy-in from departmental leadership was obtained, it may have been insufficient to champion this change.^{32,33} Although this study aimed to address the known barriers to capnography use, it remains to be discovered what interventions would further increase the use of capnography in the ED. Optimization of EHR to facilitate documentation, quality improvement efforts, monetary incentives, or regulatory requirements are all potential facilitators that could be explored in future studies.

Limitations

There are several limitations to our study. Although we acquired buy-in from ED leadership and key staff members, our intervention and goals may not have been a priority at the experimental site. Upon deployment of the electronic surveys, a hospital-wide survey was also initiated, which took precedence and led to a suboptimal response for our postintervention knowledge survey. Furthermore, not all staff members participated. We recognize the time constraints of ED personnel; this study was launched in January, typically a higher-volume season due to influenza. Although there is no specific ideal time to launch new efforts, increased participation may have occurred at a different time of the year.

Regarding our outcome measures, although some of the knowledge survey questions were adapted from a validated study, many others were derived de novo and not validated before use.²¹ In addition, the knowledge survey did not measure the ability of staff to interpret capnography values during patient-centered scenarios, so even those staff members with strong theoretical knowledge may not have felt comfortable applying it in practice. Moreover, although providers perceived that they applied capnography in approximately one-third of patients undergoing CPR, the documented use was far lower. This may be suggestive of a misperception in providers' own individual behavior or inadequate documentation. This study relied on accurate documentation in each patient's electronic medical records for data collection. Although the EHR does have specific fields in which to chart capnography data, these data were

found in several different areas within the EHR during manual review. Although the numerous areas in which ET_{CO}₂ could be recorded may represent a potential barrier to documentation, this was not assessed in our study. However, the flexibility of documentation areas in the EHR could also implicate that documentation itself should not have been a barrier. Given the unpredictable nature of EDs and the limited frequency of patients requiring intubation or CPR, significant resources would be required to directly observe all of these patients and ensure that documentation was accurate. Although very few cases were observed in this study, the documentation for those cases that were observed was found to be accurate in most cases. However, one case did demonstrate the use of capnography without documentation. Given the limitations of our observational assessments, we cannot confidently extrapolate to explore the implications of this discrepancy. Finally, despite providing this intervention in a high-volume ED, there were a smaller proportion of patients requiring intubation and CPR than what we had anticipated. We found overall differences in use, but they may have been underpowered to detect these changes in the long term with longitudinal analyses.

CONCLUSIONS

Using the knowledge transfer theory, an implementation-based intervention including a brief educational video and increased equipment availability in an urban ED led to increased proportion of documented use of capnography for patients requiring intubation or CPR; however, there was no change in the rate of documented use. These interventions can easily be deployed at institutions with low baseline capnography use and may improve adherence to national guidelines. However, further evaluation of barriers to use is needed to improve evidence-based care in this population.

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