CRNA Performance Using a Handheld, Computerized, Decision-Making Aid During Critical Events in a Simulated Environment: A Methodologic Inquiry

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Directives to improve patient outcomes and enhance safety within the healthcare system have led to development of technologies to assist practitioners in a variety of activities. The purpose of this study was to explore and evaluate a method for examining the effect of computer-assisted decision making (CADM) using a handheld device on the accuracy (ie, correct diagnosis and treatment) and speed of problem solving by Certified Registered Nurse Anesthetists (CRNAs) during simulated critical patient-care events.

A randomized crossover design with matched-pair sampling was used. In a high-fidelity human simulation environment, 4 CRNAs participated in 2 plausible critical anesthesia case scenarios. CRNA performance with and without CADM technology, environmental authenticity, and reliability and validity of data collection tools and simulated case scenarios were evaluated.

Time to correct diagnosis and treatment varied by scenario, taking less time with CADM for one but more with CADM for the other, likely due to differences in pace, intensity, and conduct of the 2 scenarios. We believe this study supports further exploration and application of CADM in complex patient scenarios involving anesthesia practitioners. Affirmation of environmental authenticity also validates the high-fidelity human simulation environment as an appropriate setting to conduct research in this area.

Key words: Anesthesia critical events, computer-assisted decision making, personal digital assistant, simulation.

Theories related to human problem solving and decision making attempt to describe how we use cognition, knowledge, and intuition in adjudicating among competing hypotheses. The importance of sound decision making, especially in the current climate of focused patient safety activity, urges the examination of relevant theories within the domain of patient care.[1] Identifying root causes of threats to patient safety and developing effective strategies that minimize misadventures in healthcare delivery has assumed national prominence.

Anesthesia practitioners make many decisions and perform multiple interventions, each with an attendant set of consequential side effects, often under the duress of time and production pressure. As a result, skill-based errors (accidents or execution failures) and knowledge- or rule-based errors (mistakes or planning failures) are not uncommon. It is widely acknowledged that the majority of adverse anesthesia-related outcomes are inextricably wedded to human error.[2,3] Although humans are destined to err, thoughtfully designed and robust systems can decrease the risk of human error and reduce negative patient outcomes.[1,4]

Decision making implies a selection among plausible or competing options. When a case or problem arises that falls outside of common occurrence or a well-defined pattern, providers are often forced to improvise, invent, or creatively engineer a solution that may be based as much on the unconscious reasoning associated with intuition as on the conscious use of knowledge. Intuition may lead to variations in practice and patient outcome.[5] When confronted with a clinical problem, registered nurses tend to be cognitively cautious in revising initial judgments or hypotheses.[6] Whether this applies to nurses educated at the graduate level or physicians has not been explored, but it suggests that early intuitive judgments and decisions may lead practitioners down a path that they are slow to reconsider.

To aid with problem solving and decision making during critical events, protocols and algorithms have been developed, such as Basic Life Support, Advanced Cardiac Life Support, Pediatric Advanced Life Support, the malignant hyperthermia protocol, and the American Society of Anesthesiologists Difficult Airway algorithm. One of the benefits of algorithm-driven responses to critical events is that they remove intuition and provider bias from the approach in favor of systematically defined interventions. The Basic Life Support,[7-9] Advanced Cardiac Life Support,[10,11] and Pediatric Advanced Life Support[12-14] algorithms and the malignant hyperthermia protocol[15,16]

have been shown to be effective in optimizing patient outcomes.

In general patient care, beneficial outcomes may result when physicians use computer-based interventional systems that minimize subjectivity and intuition-based approaches.[17] In anesthesia care, in which complicated technology interfaces directly with the user (much like aviation), computer-guided checkout is superior to routine practitioner checkout when evaluating an apparatus with prearranged, clinically relevant faults.[4] A multi-institutional study examining intensive care unit performance concluded that one factor important in preventing death, lowering complication rates, and saving money included the establishment of standard protocols in treating patients with specific conditions.[18]

No research examining the role of intuition or the use of computer-assisted decision making (CADM) by anesthesia practitioners was found in the literature. The advent of computer technology, particularly handheld devices, provides an opportunity for study into the area of CADM, with the ultimate goal of improving patient outcomes. The purpose of this study was to explore and evaluate a method for examining the effect of CADM on the accuracy and speed of problem solving by Certified Registered Nurse Anesthetists (CRNAs) during simulated critical patient care events.

Methods

After obtaining institutional approval and informed consent, a pilot study was conducted using high-fidelity human simulation. Plausible critical patient events occurring during and immediately following anesthesia were developed and implemented. A personal digital assistant (PDA) was preprogrammed with a catalog of common and uncommon clinical events that provided a protocol-driven, interventional approach to management. Performance of CRNAs with and without CADM technology, environmental authenticity, and reliability and validity of data collection tools and simulated case scenarios were evaluated.

A randomized crossover design with matched-pair sampling was used. A convenience sample of 4 paid study volunteers (2 male and 2 female CRNAs) were recruited and matched based on the following characteristics: sex, years of experience as a CRNA, and familiarity with simulation. Once the first male and female were recruited, a search for a person who fit the matched-pair profile was initiated.

Half of the participants were studied on day 1 and the other half on day 2. Random assignment to the order of simulation events was achieved via coin tossing. For simulation runs not using the PDA, participants were instructed to manage the event using their own knowledge, beliefs, customary approaches, and experiences. For simulation runs using the PDA, participants were instructed to use the PDA during management of the event in addition to using their own knowledge, beliefs, customary approaches, and experiences.

Two patient care scenarios were developed for this study. Experts in the domain of high-fidelity human simulation participated in this development to establish high face validity. Within each scenario, the simulated patient's problem or condition, if left unattended, could lead to a critical incident. Case scenario 1 (CS1) incorporated increasing peak airway pressure during a general anesthetic with mechanical ventilation for a 72-year-old, hypertensive man taking nadolol who was undergoing an inguinal herniorrhaphy. A gradually increasing airway pressure, due to developing pulmonary edema from iatrogenic overhydration and anesthetic-related myocardial depression, was introduced. Case scenario 2 (CS2) involved a healthy 28-year-old woman in the postanesthesia care unit (PACU) who was recovering from a general anesthetic for laparoscopic cholecystectomy. This case was complicated by delayed awakening secondary to profound hypoglycemia as a result of incidental, unrealized manipulation of an undiagnosed insulinoma. Participants were sequestered from one another to prevent information exchange.

Two Dell (Round Rock, Texas) Axim X5 model PDAs (Adobe Acrobat 5.0 software platform, Adobe, San Jose, California) were used. Each was programmed with an extensive catalog of more than 30 common and uncommon events that can arise during anesthesia. Some events were in the form of potential patient manifestations caused by a variety of underlying factors (eg, bronchospasm and hypotension), whereas others were specific states (eg, hyperthyroidism and anaphylaxis). This catalog was derived from recognized literature[19,20] and clinician experience and underwent rigorous review and numerous iterations by a group of 7 anesthesia-domain national experts that included CRNAs and anesthesiologists. All participants underwent a standardized tour of the simulation center, including an explanation of the features and limitations of the full-body simulator, and received explicit instructions in the operation and use of the PDA.

Responses from simulation-participant questionnaires, commenting positively on the "realness" of the experience, support the assumption of face validity of high-fidelity simulated environments.[21-24] The simulation center's design is based on established principles of patient management and technical and nontechnical skills related to patient care and is fully outfitted to provide realism and allows for testing across a broad range of phenomena.

Speed to diagnosis was measured as the actual time taken to reach the correct diagnosis. For this reason, consistency of the case simulations was crucial. Case scenarios were closely managed using simulator software and a predetermined timetable so the timing and sequence of

events during each case scenario was as consistent as possible. Domain experts filled the roles of operating room and postanesthesia recovery staff. Each domain expert was given a profile of the case and his or her specific role during the simulation. A single individual performed the same role for each simulation to maintain consistency. In addition, 1 domain expert ("resource person") was positioned in the room to offer standardized responses to each CRNA's questions about clinical signs that could not be simulated with the existing technology (eg, "Is the skin dry or moist?" and "Are the breath sounds clear or coarse?")

Relevant information was recorded using a "Simulation Observation Data Collection Tool" based on knowledge and expertise in the area under study. This tool was reviewed by a panel of experts in the field of high-fidelity simulation training and evaluation to achieve consensus and establish high face validity. Audiovideotaping permitted subsequent, detailed review of the simulation run. The outcomes measured in this study were as follows:

1. Time to identification of an abnormal event: the time from the start of the simulation to the first indication (verbal or nonverbal) of recognition of an abnormal event, to provide additional information in determining speed of problem solving as it relates to correct diagnosis.

2. Time to correct diagnosis: the time in minutes and seconds from the start of the simulation to the participant's first indication (verbal or nonverbal) of the correct diagnosis, to provide information on speed to problem solving as it relates to diagnosis (in minutes and seconds) and accuracy of problem solving as it relates to diagnosis (correct or incorrect).

3. Time to definitive intervention: the time in minutes and seconds from the start of the simulation to the indication (verbal or nonverbal) of definitive intervention, to provide information on speed of problem solving as it relates to appropriate treatment (in minutes and seconds) for the correct diagnosis.

To assess simulated environmental authenticity, the videotapes of the simulation runs were examined by 3 independent reviewers (IRs) with no experience in simulation training using an established "Videotape Coding Instrument."[25] A training session to educate and familiarize the IRs with the simulation center and the coding instrument was conducted before video review. Each of the 4 participants was videotaped twice (for CS1 and CS2), for a total of 8 videotaped recordings. The 3 IRs reviewed and filled out the coding instrument on each of the videotaped recordings for a total of 24 completed in-

Case scenario 1

Time				
A, No PDA	**B, PDA**	**C, PDA**	**D, No PDA**	**Action**
NA	14:34	07:31	NA	First refers to PDA
06:12	07:05	07:16	06:51	First verbalization of abnormal event
08:31	11:57	17:59	07:26	Administers albuterol
10:23	18:48	17:03	10:18	Crackles introduced
16:15	22:13	20:26	10:42	Mentions pulmonary edema[b]
16:15	29:38	20:26	17:03	Mentions furosemide
16:59	29:43	23:31	20:15	Administers furosemide

Case scenario 2

Time				
A, PDA	**B, No PDA**	**C, No PDA**	**D, PDA**	**Action**
02:20	NA	NA	03:43	First refers to PDA
10:30	NP	25:33	05:58	Requests glucose measurement
14:19	NP	22:57	05:29	Mentions hypoglycemia
14:03	NP	27:34	08:33	Reports glucose value
13:55	NP	28:01	08:52	Asks for 50% dextrose
14:31	NP	29:16	10:32	Administers 50% dextrose

Table 1. Definitive Moments for Case Scenarios[a]

[a] Times are given in minutes:seconds.
[b] or symptoms of pulmonary edema.

A, B, C, and D indicate participants A, B, C, and D, respectively; NA, not applicable; NP, not performed; PDA, personal digital assistant.

struments, 12 for each case scenario. Descriptive analysis of overall results was performed in terms of frequency and percentage distribution. Comparison of results between IRs were analyzed, and the modified tool was assessed for interrater reliability using the kappa coefficient.[26]

Results

• *Simulation observation data collection tool.* Table 1 summarizes sentinel events in each scenario for all study participants. Case scenarios were limited to a duration of 30 minutes. If the participant did not perform a listed action before the scenario was ended, it was indicated in the table as not performed, and calculations were made using an assigned time of 30 minutes. For CS1, the first verbalization of an abnormal event included decreased oxygen saturation or increased peak airway pressures. Values for abnormal event recognition were not calculated for CS2 due to the nature of the scenario. Times were recorded during the actual simulation run and validated by viewing the videotape. Table 2 presents results for abnormal event recognition, time to diagnosis, and time to treat.

• *Videotape coding instrument.* Question 1 asked the IRs to note each time they considered any of the following to be distracting: a microphone or headset, the observation mirror, mannequin "voice," video cameras, chest sounds, and equipment. A category of "other" was also provided. For CS1, the IRs indicated 6 cases in which they found chest sounds to be a distraction. In 5 cases, other was marked (difficulty finding suction, 1; Bovie noise, 1; difficulty hearing resource person, 2; and participant having to "repeatedly ask what he heard when auscultating breath sounds," 1). For CS2, the microphone or headset was indicated as a distraction twice.

Question 2 asked the IRs to rate the preceding items as very, somewhat, or not distracting. For CS1, there was 1 score of very distracting for chest sounds and 1 score of somewhat distracting for other (related to the participant having to repeatedly ask what was heard when auscultating breath sounds). All other items were scored as not distracting. In CS2, all items were scored as not distracting except in 2 cases in which the microphone or headset was rated as somewhat distracting.

Question 3 asked the IRs whether the participant appeared to "suspend disbelief" with regard to various aspects of the simulated environment. The IRs rated items on a 3-point scale as accepted, partly accepted, or not accepted as real. Assessment of CS1 included the mannequin, circulating nurse, surgeon, scrub technician, and the case scenario. For CS2, this included the simulator mannequin, PACU nurse, and the case scenario. The IRs indicated that the participants appeared to accept as real the circulating nurse, surgeon, scrub technician, and case scenario for CS1 100% of the time. The simulator mannequin was rated as accepted as real 92% of the time and partly accepted as real 8% of the time in CS1. Accepted as real was selected 100% of the time for all components of CS2.

	Mean (min)	SD (min)
Case scenario 1		
First recognizes abnormal event		
Overall	6.85	0.47
With PDA	7.18	0.13
Without PDA	6.53	0.46
First indicates correct diagnosis		
Overall	17.40	5.12
With PDA	21.33	1.27
Without PDA	13.48	3.92
Provides definitive treatment		
Overall	22.62	5.44
With PDA	26.62	4.38
Without PDA	18.62	2.31
Case scenario 2		
First indicates correct diagnosis		
Overall	18.19	10.62
With PDA	9.9	6.25
Without PDA	26.48	4.99
Provides definitive treatment		
Overall	21.18	10.13
With PDA	12.53	2.82
Without PDA	29.84	0.23

Table 2. Simulation Observation Data Collection Tool Results

PDA indicates personal digital assistant.

In question 4, the IRs rated whether they were able to suspend disbelief with regard to the same aspects as in question 3. The IRs chose accepted as real 100% of the time for all aspects of CS1. Results for CS2 were 100% accepted as real for the PACU nurse and case scenario. The simulator mannequin was rated accepted as real 83% (10/12) of the time and partly accepted as real 17% (2/12) of the time.

The IRs responded positively 100% of the time when asked in questions 5 and 6 if the arrangement of equipment and personnel was realistic. Question 7 asked if there was any indication that the participant had difficulty interacting with simulation faculty, with yes indicated 17% of the time.

Questions 9 through 13 related to PDA use. Question 9 queried whether the PDA had been used and was checked yes on 12 instruments with half being from CS1 and the other half from CS2, as expected. Results for questions 10 through 13 from CS1 and CS2 are presented in Table 3. Interrater reliability of the Videotape Coding Instrument using the kappa coefficient is reported for categorical data in Table 4.

Question	Yes responses (%)	
	CS1	CS2
Participant appeared to have technical difficulty using PDA	0	0
Participant appeared able to incorporate PDA into care	100	67
Participant appeared to find PDA helpful	83	67
PDA would be useful in clinical setting	100	100

Table 3. Videotape Coding Instrument, Questions 10-13

CS1 indicates case scenario 1; CS2, case scenario 2; PDA, personal digital assistant.

Question	κ[a]	
	CS1	CS2
Level of distraction		
Microphone or faculty headset	1	0.74
Video camera	1	1
One-way mirror	1	1
Questionable integrity of equipment	1	1
Patient voice or speaker	1	1
Chest sounds	0.88	1
Ability of participant to accept as real		
The "patient"	0.88	1
The "surgeon"	1	NA
The "circulating RN"	1	NA
The "scrub technician"	1	NA
The "PACU RN"	NA	1
The case scenario	1	1
Ability of rater to accept as real		
The "patient"	1	0.74
The "surgeon"	1	NA
The "circulating RN"	1	NA
The "scrub technician"	1	NA
The "PACU RN"	NA	1
The case scenario	1	1
Arrangement of equipment realistic	1	1
Arrangement of personnel realistic	1	1
Difficulty interacting with scenario staff	0.66	1

Table 4. Videotape Coding Instrument Kappa (κ) Coefficient Results

[a] A κ of 1.0 implies perfect agreement; a κ of 0.1 implies no agreement.

CS1 indicates case scenario 1; CS2, case scenario 2; NA, not applicable; PACU, postanesthesia care unit; RN, registered nurse.

	Mean	SD
Crackles introduced	14:08	4:26
Participant		
Mentions pulmonary edema	17:24	5:07
Administers furosemide	22:37	5:26
First crackles to mention of pulmonary edema	3:16	2:14
First crackles to administration of furosemide	8:29	2:17

Table 5. Variability of Response Time and Introduction of Crackles[a]

[a] In minutes:seconds. The table first shows the mean of recorded scenario times (based on a zero start time) for first mention of pulmonary edema, administration of furosemide, and introduction of crackles. Next, the time at which crackles were introduced was subtracted from the time for first mention of pulmonary edema and then for administration of furosemide. These results were averaged.

Discussion

Did the handheld CADM result in a faster accurate diagnosis during the simulated events? In the operating room scenario (CS1), the amount of time from the start of the scenario to accurate diagnosis was shorter for participants who did not have the PDA (16:15 and 10:42 vs 22:13 and 20:26, respectively, in minutes:seconds). The opposite occurred in the PACU scenario (CS2); less time was used by participants to state the correct diagnosis if they had the PDA (5:29 and 14:19 vs 22.57 and >30:00, respectively, in minutes:seconds). One participant did not reach the correct diagnosis within the maximum scenario time.

Although definitive conclusions are not possible, several questions emerge. Why was the correct diagnosis reached faster in one scenario without the PDA and in the other scenario with the PDA? Was it due to differences between CS1 and CS2 or the design of one of them in particular? Further evaluation of CS1 revealed inconsistencies in scenario management. In the scenario runs in which the participant did not have a PDA, crackles were introduced earlier (approximately 10 minutes into the scenario) than in the runs in which the participant had a PDA (approximately 18 minutes into the scenario). A scenario management timeline was developed for each scenario but was not consistently followed in these cases.

The symptom of crackles could only be introduced if the participant sought this type of information by auscultating the lungs. According to the scenario management

timeline, the introduction of crackles was not to occur until at least 15 minutes into the scenario. If the participant did not auscultate the lungs at or near the designated point on the timeline, this could account for the discrepancy. However, in reviewing case scenario times in Table 1, crackles were introduced almost 5 minutes too early in 2 scenarios. Therefore, other reasons must be considered, including lack of communication between the control center and the resource person, inadequate instruction of the management timeline to the resource person, and error by the resource person.

Additional calculations were made related to the effect of early introduction of crackles. Table 5 first shows the mean of recorded scenario times (based on a zero start time) for first mention of pulmonary edema, administration of furosemide, and introduction of crackles. Next, the time at which crackles were introduced was subtracted from the time for first mention of pulmonary edema and then for administration of furosemide. These results were averaged; when the discrepancy of the introduction of crackles is removed, the variability in time to these key events is reduced by more than half. This threat to internal validity underscores the importance of clear communication.

Did CADM result in faster, appropriate treatment? CRNAs without the PDA provided treatment in less time in CS1 (16:59 and 20:15 vs 23:31 and 29:43), whereas participants with CADM treated faster in CS2 (10:32 and 14:31 vs 29:16 and >30:00). When the delayed introduction of crackles to participants in CS1 with the PDA is accounted for, as shown in Table 5, the variability in time scores is reduced by more than half.

All participants reached the correct diagnosis and provided treatment with and without the PDA in CS1. In CS2, 1 participant without the PDA did not reach the correct diagnosis within the maximum scenario run time (30 minutes). A discrepancy in CS2 should be noted. In one case not using CADM, a laboratory order form was filled out by the PACU nurse based on a verbal order by participant B. In the other case not using CADM, the laboratory order form was filled out by participant C. The laboratory order form included a glucose level as one of the test options; this option may have prompted participant C to order this test, raising the question of whether participant C would have ordered the test had the PACU nurse completed the form. These flaws might jeopardize the internal validity of the study and serve as cautionary points for future investigators. Ironically, this example illustrates the potential of what this study is all about: that the CADM triggers behavior by directing behaviors in a manner that eliminates human variance.

Is the model used in this study feasible for future research? Based on the conduct and outcomes of our pilot study, the answer is equivocal. We proposed that a high-fidelity human simulation environment would provide a valid setting for the model. This was confirmed and supports previous independent observations.[27-32]

The rationale behind using a crossover design with matched-pair sampling was to allow for a smaller sample while retaining the statistical power of a parallel group design with a larger sample. Here, some of the advantages of this design were lost due to between-participant variation. It would be necessary to take this into account in determining the appropriate sample size for future studies using this design or a randomized cohort trial.

There are several limitations of this study. Current technology does not provide for a full-body mannequin that perfectly mirrors the human. Simulation, in part because of the attendant performance appraisal, evokes some degree of anxiety in virtually all participants. This heightened awareness and anxiety poses a threat to internal and external validity. Alternative designs using real patients carry unacceptable risks.

The small sample limits generalizability and precluded inferential analysis. The cost (money, time, resources) of conducting the study was the primary factor restricting the number of participants. Each participant spent nearly 7 hours at our center. Limiting the scenario run time to 30 minutes truncated the results; participants may have accurately diagnosed and intervened if given more time. In addition, matched-pair sampling may have missed important but unappreciated provider cofactors.

We believe this to be the first controlled trial of CADM in complex patient scenarios involving CRNAs, demonstrating that there may be robust applications in the domain. It also suggests that the high-fidelity human simulation environment provides an appropriate setting to conduct research in this area. Reduction of error by healthcare professionals and increased patient safety has been given a high priority by professional and lay communities. Our study may assist researchers in the conduct of future investigations into handheld CADM aids, CRNA problem solving, and clinician error.

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