

Original Article

Use of Point-of-Care Ultrasonography in Simulation-Based Advanced Cardiac Life Support Scenarios

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ABSTRACT

Background: Ultrasonography is an effective tool for diagnosing potential reversible aetiologies of cardiac arrest. We developed an educational curriculum for critical care ultrasonography involving multiple sequential cardiac arrest simulation scenarios and assessed the efficacy of participants' performance.

Methods: Didactic lectures and hands-on training sessions were provided before participants were divided into simulation teams for a series of five scenarios in which they were instructed to utilize ultrasonography during ongoing advanced cardiac life support (ACLS). Simulation sessions were videotaped and subsequently reviewed for extraction of parameters relating to ACLS adherence and performance of point-of-care ultrasonography examination. The primary outcome was duration of no-flow interval (NFI), the period during which chest compressions are halted and ultrasound examination is typically performed. We also collected data on NFI score (based on simulation team performance during NFI), time from arrest to first chest compressions, time from arrest to defibrillation, and other parameters describing team performance.

Results: Fifty-five course participants comprised 12 simulation teams. For all participants, the average NFI was 22.2 s (95% CI, 19.1-25.2) during scenario 1, with declines in duration thereafter ($P \leq 0.004$). In subsequent scenarios, an increasing proportion of NFI occurred within the interval of 10 s ($P = 0.018$).

Conclusion: Simulation is an effective teaching modality for critical care ultrasonography. Novice ultrasound users can be taught to perform point-of-care ultrasonography effectively during simulated cardiopulmonary arrest in an ACLS-compliant manner, a finding that may have significant implications for the clinical management of in-hospital cardiac arrest. (Funded by the Department of Anesthesiology and Critical Care Medicine, Johns Hopkins University School of Medicine, and Johns Hopkins Medicine Simulation Center.)

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Cardiac arrest occurs in approximately 209,000 adult inpatients each year in the United States, and this rate may be increasing (1, 2). Of these, 72.3% present with a non-shockable rhythm, defined as either asystole or pulseless electrical activity (PEA) (3). Treatment for PEA arrest includes high-quality cardiopulmonary resuscitation (CPR), as well as identification and treatment of reversible causes of arrest (4). Ultrasonography during PEA arrest can differentiate underlying abnormalities, such as ventricular failure, pulmonary embolism, hypovolemia, and cardiac tamponade (5-10), and may alter management of critically ill patients in up to 78% of cases (10). Additionally, ultrasonography provides prognostic information, as in cardiac standstill, which is associated with almost no likelihood of return of spontaneous circulation (11-15).

Indications for point-of-care (POC) ultrasonography continue to expand, and now encompass a range of critically ill populations from the emergency room, intensive care unit (ICU), and post-arrest states (16-19). POC ultrasonography is recommended for use in unstable patients and is now a basic competency for ICU providers (20, 21). Consequently, many image-based, goal-directed protocols have been developed (10, 22-24).

A 2014 survey of cardiac arrest resuscitation practices suggests that simulation training is used in most of United States hospitals. Responding hospitals shared a similar distribution of admission volume and teaching status (25). The literature suggests that simulation-based advanced cardiac life support (ACLS) training improves provider self-confidence, knowledge retention, mega-code performance, actual care, and overall training satisfaction (26-30). However, little is known regarding the most effective method for training providers in POC ultrasonography during arrest scenarios. When simulation is combined with didactics and hands-on training, novice practitioners are able to achieve proficiency in POC ultrasonography during cardiac arrest after a 1-day course (31). It is unclear, however, whether exposure to simulated arrest scenarios improves compliance with the ACLS goal to minimize duration of no-flow intervals (NFIs), periods during which chest com-

pressions are interrupted, pulse and rhythm checks are performed, and POC ultrasonography use is ideal. NFIs must be brief to maximize vital organ perfusion, and several guidelines recommend minimization of NFIs to 10 s (10, 32).

We hypothesized that multiple sequential simulated ACLS scenarios in addition to a one-day training course in critical care ultrasound (CCUS, a variation of POC ultrasonography) would improve participant adherence to recommendations in maintaining duration of NFIs to <10 s during simulated arrest scenarios, and that the use of ultrasound within ACLS could be learned effectively, without compromising overall ACLS performance.

MATERIALS and METHODS

Participants and setting

The Johns Hopkins Medical Institutions Institutional Review Board approved this study, and all participants provided written consent. Study participants were enrolled during three separate conferences held specifically for the instruction of CCUS within the Johns Hopkins Simulation Center. Two fellow-level educational conferences were held on September 26, 2013, and August 25, 2014, and one continuing medical education (CME) conference was held March 14-15, 2014. We collected information on training level, subspecialty, and gender from all study participants.

All participants were provided with a mixture of didactic lectures, hands-on instruction, and group ACLS simulation sessions (complete description of the curricula can be found in Appendices A and B). Didactic lectures described cardiac, abdominal, thoracic, vascular, and procedural applications of ultrasound. Hands-on training was conducted in small groups of no more than five participants. Under instructor guidance, participants obtained images from healthy human volunteers with ultrasound machines capable of 2D, M-mode, colour, and spectral Doppler imaging. All instructors were providers credentialed in the imaging applications they taught. Before group ACLS simulation, conference attendees received instruction regarding the algorithmic American Heart Association-compliant incorpo-

ration of ultrasound within ACLS.

Simulations

We created five ACLS scenarios for group simulation, each with a different aetiology of PEA arrest occurring in an intubated, mechanically ventilated, postoperative ICU patient, based on principles previously described (30). Scenarios were executed in identical sequence for all groups of participants: 1) hypovolemia, 2) cardiac tamponade, 3) myocardial infarction with severe left ventricular dysfunction, 4) right ventricular failure secondary to massive pulmonary embolism, and 5) tension pneumothorax. Participants were randomly assigned to groups of 3-6 members and rotated among roles of code team leader, chest compressor, and sonographer. The entire simulation session lasted 75 min per group.

Simulations were held in a secluded ICU simulation room with a Laerdal SimMan 3G mannequin instrumented for physical exam (programmable breath sounds, chest rise, and pulses), intubation, chest compressions, and defibrillation. Because mannequins were not instrumented for continuous ultrasound evaluation, participants were instructed to simulate probe placement and image capture. They then reviewed corresponding ultrasound clips on a nearby computer in near real time. Other equipment available included a portable ultrasound machine with a phased array cardiac probe pre-set to collect 10-s video clips; ultrasound gel and wipes for gel removal to allow safe defibrillation if required; a reference whiteboard of potential PEA arrest aetiologies; a fully stocked code cart with defibrillator and pads, CPR backboard, emergency medications, and procedure kits for emergent needle decompression or pericardiocentesis; a stethoscope; ventilator; and bag valve mask. In addition, continuous heart rate, blood pressure via arterial line, electrocardiogram, pulse oximetry, and end-tidal carbon dioxide waveforms and values were made available for viewing on a bedside monitor display.

A team of instructors coordinated all simulation scenarios. Each team consisted of a facilitator, an operator, and a sonographer coach. All instructors underwent training in simulated scenarios to ensure consistency in performing the three roles and to identify errors in the scenari-

os or mannequin programming. During live simulation, a facilitator oriented each group to the simulation, initiated each scenario with a verbal clinical prompt, and provided each group with closed-loop feedback regarding requested interventions, drug administration, or laboratory specimen collection. In addition, the facilitator was responsible for advancing scenarios, and often accelerated CPR cycles, except during NFIs, which were managed entirely by participants. Throughout the scenarios, an operator programmed the mannequin and vital-sign displays in real time and responded to verbalized or performed interventions. Finally, a sonographer coach assisted with ultrasound probe placement, determined whether simulated probe placement and image capture would have yielded a diagnostic-quality image, provided corresponding ultrasound images, and assisted with image interpretation.

The entire team of instructors facilitated a short debriefing and feedback session after each code scenario. Specifically, feedback addressed management of NFIs, team communication, performance of tasks, and achievement of education goals.

Outcome measures

All ACLS simulation sessions were videotaped with hidden cameras and automated data recording and subsequently reviewed for data extraction by one evaluator (SC), who adhered to criteria developed *a priori*, as described below.

The primary outcome evaluated was the average duration of NFI for each group of participants. Following initiation of CPR, NFI was measured as the time in seconds between cycles of CPR during which there were no ongoing chest compressions. The duration of NFI was measured separately for each cycle within the five scenarios.

In addition, an NFI score was determined for each NFI based on performance of pre-specified tasks. NFI score ranged from 0 to 6, with assignment of 1 point for successful completion of each of the following tasks:

- The code team leader either called for ultrasound use or instructed the team sonographer to begin positioning the ultrasound probe before the beginning of NFI.

- Any member of the code team provided a verbal countdown of 10 s during NFI.

- Any member of the code team performed a pulse check during NFI.

- Any member of the code team verbalized the electrocardiographic rhythm during NFI.

- The code team rotated chest compressors nearing the end of NFI.

- The code team leader called for a resumption of chest compressions at the cessation of NFI.

We additionally collected data on the following outcomes:

- Time from arrest to first chest compressions, in seconds. The time of arrest was defined as the time of arterial line flattening; however, if a code team member determined the absence of pulses, then the time of arrest was defined as the time “no pulse” was first verbalized.

- Time from arrest to defibrillation, if applicable. Measured in seconds as the time from the appearance of either monomorphic ventricular tachycardia or ventricular fibrillation to the time of actual defibrillation.

- Whether the team generated a list of differential diagnoses for arrest aetiology, determined by the verbalization of at least three possible causes.

- Whether the team verbalized the correct diagnosis prior to ultrasound.

- Whether the team performed definitive management before ultrasound.

- Whether the team chose to utilize ultrasound.

- The ultrasound view chosen, as determined by probe placement (e.g., lung, abdominal, parasternal short or long axis, subxiphoid, apical).

- Whether the ultrasound view would have likely yielded a diagnostic-quality image. The sonographer coach determined this measure, and if the image capture was deemed non-diagnostic, the result was verbalized as “unable to obtain a view” or presented as a poor-quality image to participants.

- Whether definitive management was performed given the aetiology of arrest.

Data analysis

Comparisons between groups by participant status (fellow vs. CME participant) were performed with a Pearson’s chi-square test for categorical variables and Student’s t-test for continuous variables.

We performed multilevel regression to evaluate for differences in duration of NFI during the sequence of scenarios, adjusting for participant status (fellow vs. CME participant). For the analysis, we considered an individual group as a unit of observation. We evaluated secondary outcomes of time from arrest to first chest compressions and NFI scores using multilevel regression. Significance at the $P \leq 0.05$ level is noted but interpreted conservatively, using the Bonferroni correction to account for multiple comparisons.

To calculate the sample size needed to detect a difference in duration of NFIs between the first and subsequent scenarios, with alpha 0.05 and power 80%, we made the following assumptions: the mean (SD) duration of NFI during the 1st scenario would be 20 (10) seconds, and the mean (SD) duration of NFI during the subsequent scenarios would be 10 (5) seconds. These assumptions were based on previously reported durations of NFIs (31). Based on these assumptions, we determined that we would require 12 groups to detect differences in NFI duration between the first and subsequent scenarios.

All analyses were performed with Stata software (version 13.1 for Mac, Stata, College Station, Tex., USA.).

RESULTS

In total, 56 participants underwent video recording of ACLS simulation, resulting in eight groups of fellows and four groups of CME participants. Participant characteristics are shown in Table 1. Subspecialty breakdown data were available only for fellow-level participants.

All code simulations were conducted according to the previously described methods. All simulation sessions were video-recorded, except for seven scenarios during which technical challenges occurred.

NFI

For all participants, the average duration of NFI was 22.2 s (95% CI, 19.1–25.2) during scenario 1 (Table 2). We found no differences between fellows and CME participants. However, the duration of NFIs declined after the 1st scenario ($P \leq 0.004$; Figure 1A). Although the average

duration of NFI remained relatively constant after the 1st scenario, the fraction of NFI ≤ 10 s continued to increase throughout the session ($P = 0.018$; Figure 1B).

Secondary outcomes

Fellows and CME course participants performed equally well in NFI management, as evidenced by NFI scores (Table 2). Deductions in score most commonly occurred because of a failure by the code team leader to keep time or conduct a countdown during NFI.

CME participants initiated CPR after the onset of simulated arrest sooner than fellow participants, but differences between groups disappeared as the simulation progressed (Table 2). Time from simulated arrest to initiation of CPR did not appear to improve over the course of the simulation ($P = 0.11$) but was considerably shorter during scenario 2 than during scenario 1 ($P = 0.002$). Fellows and CME participants did not differ in the average time to defibrillation after the appearance of unstable ventricular tachycardia in scenario 3. In most scenarios, simulation code teams could generate a differential for aetiology of arrest. However, we do not report these results because in most cases the facilitator prompted the team to generate a differential diagnosis, and a visual aid was present that listed possible aetiologies.

Ultrasonography was used in 94% of simulation scenarios and 84% of NFIs. The only scenario for which ultrasonography was not used was scenario 5 (tension pneumothorax). The most commonly used ultrasound view was the subxiphoid window, which accounted for 65% of all ultrasound attempts, followed by parasternal short axis (16%), parasternal long axis (10%), pleural view (8%), and deep venous thrombosis exam (1%). Diagnostic-quality images, as determined by the sonographer coach, were obtained in 79% of all ultrasound attempts. When diagnostic-quality images were obtained, they were judged to change management in 70% of cases. In 68% of scenarios, simulation code teams were unable to identify the correct diagnosis before the use of ultrasound. Prior to ultrasound use, simulation teams were unable to perform definitive management in 85% of scenarios; however, after using ultrasound,

Table 1. Characteristics of Study Participants.

Variable	Fellows (n=38)	CME participants (n=18)	P ^a
Male sex, n (%)	16 (42)	9 (50)	0.77
Physicians, n (%)	38 (100)	7 (39)	<0.0001
Physician specialty			
Anaesthesiology	10 (26)	-	
Surgery	3 (8)	-	
Internal medicine	8 (21)	-	
Paediatrics	9 (24)	-	
Neurology	8 (21)	-	
Non-physicians, n (%)	-	9 (50)	
Unspecified, n (%)	-	2 (11)	

CME, continuing medical education.

^aSignificance as determined by Fisher's exact test.

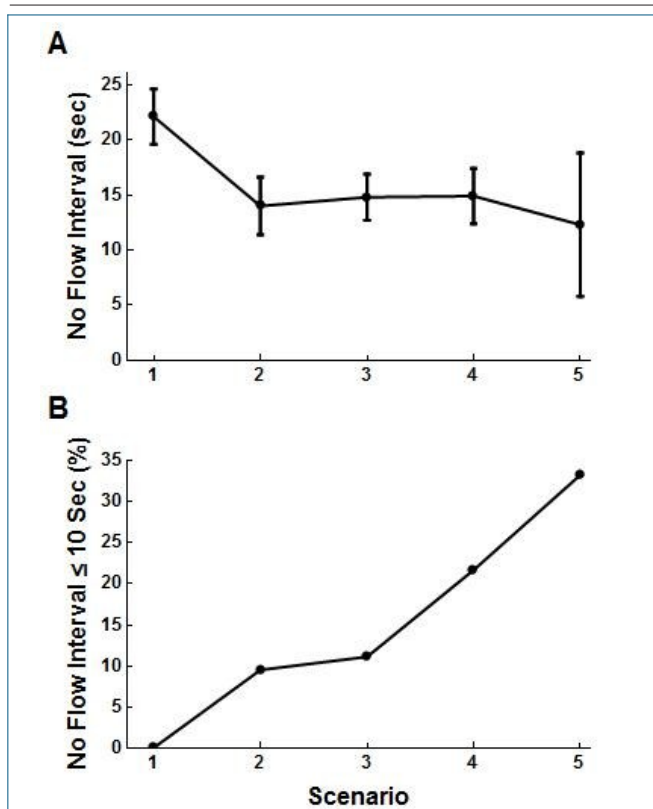


Figure 1. Changes in No-Flow Interval Over the Course of 5 Cardiac Arrest Simulation Scenarios.

(A) Duration of no-flow intervals shortened during the 2nd – 5th scenarios compared with that in scenario 1 ($P \leq 0.004$). Fellowship status was not contributory ($P = 0.93$). (B) The frequency of no-flow intervals of 10 s or less continued to increase throughout the simulation ($P = 0.018$) with no differences related to fellow participation ($P = 0.57$). Data are shown as mean \pm standard deviation.

Table 2. Major Outcomes in Management of Cardiopulmonary Arrest Using Ultrasound as Supportive Diagnostic Modality^a.

Variable	Fellows (n=38)	CME participants (n=18)	P ^b
Duration of NFI (sec)			
Scenario 1	20.4 (8.1)	24.8 (9.8)	0.32
Scenario 2	14.3 (3.2)	13.2 (2.9)	0.39
Scenario 3	14.6 (4.8)	15.3 (4.3)	0.77
Scenario 4	15.8 (6.2)	12.0 (5.6)	0.30
Scenario 5	16.0 (0.0)	10.5 (3.5)	0.028*
NFI score (n, 0-6)			
Scenario 1	5 [4, 5]	3.5 [2.5, 4]	0.27
Scenario 2	4.5 [4, 5]	4 [4, 5]	0.85
Scenario 3	4 [3, 5]	5 [3, 5]	0.86
Scenario 4	4 [4, 5]	3 [3, 3]	0.14
Scenario 5	4 [4, 4]	5 [5, 5]	0.28
Time from arrest to CPR (sec)			
Scenario 1	10.6 (7.9)	4.0 (1.3)	0.001*
Scenario 2	6.0 (3.5)	3.8 (0.4)	0.007*
Scenario 3	7.1 (5.5)	12.0 (9.1)	0.021
Scenario 4	6.6 (3.9)	6.7 (4.8)	0.96
Scenario 5	7.9 (4.1)	9.0 (2.1)	0.40
Time from unstable VT to defibrillation: scenario 3 (sec)			
	64.5 (38.8)	71.0 (46.2)	0.59

CME, continuing medical education; NFI, no-flow interval; CPR, cardiopulmonary resuscitation; VT, ventricular tachycardia.

^aData are presented as mean (SD) for continuous data and median [IQR] for count data.

^bSignificance between fellows and CME participants as determined by multilevel regression appropriate for continuous data or counts.

*Statistically significant.

simulation teams performed definitive management in 100% of scenarios.

DISCUSSION

In this study, novice ultrasound users underwent a program that combined didactics and simulation-based exercises for training in the use of CCUS, and subsequently demonstrated general adherence to ACLS principles during multiple sequential cardiac arrest simulation scenarios. After training, participants demonstrated minimal times to defibrillation and initiation of CPR following arrest, as well as general adherence to the recommended NFI duration. NFI duration

performance improved with continued simulation, emphasizing the importance of ongoing training to achieve ACLS-compliant use of ultrasonography. It is likely that other parameters related to CPR did not change, as, apart from ultrasound, participants were already familiar with the elements of CPR and ACLS. Our results are consistent with prior studies that have shown the potential for POC ultrasonography to enhance management during cardiac arrest through identification of cardiac motion and potentially reversible causes of arrest (8, 10, 33).

Specifically, we addressed whether an ACLS-compliant CCUS protocol can be taught effectively for use in an in-hospital setting using multiple sequential simulated cardiac arrest scenarios. We believe that patients who experience in-hospital arrest benefit the most from application of POC ultrasonography because these arrests are more commonly due to reversible underlying aetiologies. In addition, our simulation scenarios employed an important and realistic element of in-hospital arrests that differs from pre-hospital arrests — a resuscitation team composed of providers who are often not previously known to each other.

This study has several limitations. First, due to unavailability we did not use mannequin simulators instrumented to accommodate both CPR and continuous POC ultrasonography. We instead instructed participants to simulate probe placement during simulation scenarios, which often resulted in the subjective use of prompting. Specifically, the determination of diagnostic-quality imaging, accurate image interpretation, and ACLS management was susceptible to subjective assessment and prompting by both the simulation facilitator and sonographer coach, despite pre-simulation instruction to avoid prompting. We therefore selected management of NFI as our primary focus, which was by design unprompted, with exception of the signalling for NFI initiation (e.g., facilitator may state “you are approaching the end of this 2-minute cycle of CPR”). Second, all video data were extracted by one evaluator (SC). We attempted to minimize inconsistent evaluation of data by establishing rules and definitions prior to data extraction. In addition, the evaluator performed initial extraction together with another author (AP) to

ensure that developed definitions were unequivocal. Third, not all simulation scenarios and participants were recorded for subsequent data extraction because of technical issues with video recording, however, the exclusion of subjects was likely random. Fourth, scenarios were executed in non-random sequence, however, simulations occurred in secluded rooms, and participants were not informed that a diagnosis in one scenario excluded its potential occurrence in another. Finally, our study is underpowered to detect differences between the fellows and CME participants, which may account for the lack of differences observed in NFI, NFI score, and time from unstable VT to defibrillation during simulated scenarios.

Interestingly, we found that simulation teams universally performed definitive management of tension pneumothorax without the use of ultrasound. While POC ultrasonography may certainly aid diagnosis and treatment of unstable patients compared with other imaging modalities, there is no evidence to suggest that use of ultrasound is superior to clinical exam in cardiac arrest caused by tension pneumothorax (34). Our educational aim was to instruct participants to use POC ultrasonography during arrest scenarios to identify reversible causes for arrest, but we emphasized that doing so should not compromise the basic tenets of ACLS itself. Participants likely avoided certain ultrasound views they had been instructed on (e.g. lung and DVT exams) due to the low yield of new diagnostic information in the setting of convincing mannequin clinical exam and severe physiologic instability.

Minimization of NFI is essential for maximizing vital organ, and especially, coronary perfusion during cardiac arrest. However, the exact time frame to guide interruption from CPR and rhythm analysis is unknown. Nevertheless, several guidelines recommend a maximal NFI of 10

s, with perhaps the strongest basis found in the paediatric population (10, 32, 35). In our study, it is noteworthy that an NFI ≤ 10 seconds was not achieved consistently by any group. However, NFI duration improved significantly among all groups as simulation progressed, evidenced by a dramatic improvement occurring even after the first scenario and a continuing increase in fraction of NFI ≤ 10 seconds. Overall, our study suggests that within the context of POC ultrasonography, course training that involves multiple sequential simulated cardiac arrest scenarios and incorporation of ultrasonography results in rapid improvement in NFI duration among course participants. In addition, this effect is maintained through the rest of the scenarios.

CONCLUSIONS

In this study, we show that novice ultrasound users can be taught to perform POC ultrasonography effectively during simulated arrest in an ACLS-compliant manner. Moreover, training results in improved adherence to American Heart Association guidelines, as evidenced by increasing fraction of NFI ≤ 10 s. Additional investigation is required to evaluate whether acquired ultrasonography skills persist over time, and whether they translate into clinical practice.

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The authors have no other potential conflicts of interest for this work.

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