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Goal-directed transthoracic echocardiography during advanced cardiac life support: A pilot study using simulation to assess ability

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Abstract

Introduction—Goal-directed echocardiography (GDE) is used to answer specific clinical questions which provide invaluable information to physicians managing a hemodynamically unstable patient. We studied perception and ability of housestaff previously trained in GDE to accurately diagnose common causes of cardiac arrest during simulated advanced cardiac life support (ACLS); we compared their results to those of expert echocardiographers.

Methods—Eleven pulmonary and critical care medicine fellows, seven emergency medicine residents, and five cardiologists board-certified in echocardiography were enrolled. Baseline ability to acquire four transthoracic echocardiography views was assessed and participants were exposed to six simulated cardiac arrests and were asked to perform a GDE during ACLS. Housestaff performance was compared to the performance of five expert echocardiographers.

Results—Average baseline and scenario views by housestaff were of good or excellent quality 89% and 83% of the time, respectively. Expert average baseline and scenario views were always of good or excellent quality. Housestaff and experts made the correct diagnosis in 68% and 77% of cases, respectively. On average, participants required 1.5 pulse checks to make the correct diagnosis. 94% of housestaff perceived this study as an accurate assessment of ability.

Conclusions—In an ACLS compliant manner, housestaff are capable of diagnosing management altering pathologies the majority of the time and they reach similar diagnostic

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Supplemental Digital Content

Supplement Digital Content 1.mp4, video which demonstrates the four baseline views obtained on the simulator

Supplemental Digital Content 2.mp4, video which shows a participant attempting diagnosis during the cardiac tamponade and fine ventricular fibrillation scenarios

Supplemental Digital Content 3.mp4, video which demonstrates all six cardiac pathologies on the simulator

Supplemental Digital Content 4.mp4, video which demonstrates part of a debriefing session

conclusions in the same amount of time as expert echocardiographers in a simulated cardiac arrest scenario.

Keywords

echocardiography; simulation; sudden cardiac arrest; advanced cardiac life support; critical care; fellow

Introduction

It has been shown that a focused ultrasound exam performed in the emergency department on patients with nontraumatic hypotension can narrow the differential diagnosis in a timely manner¹. Goal-directed echocardiography (GDE) is used to answer specific clinical questions that can provide invaluable and timely information to the critical care physician managing an unstable patient. For example, does the patient have cardiac tamponade, right ventricular dilatation or failure suggestive of a massive pulmonary embolism (PE), or marked left ventricular systolic dysfunction?

The Accreditation Council of Graduate Medical Education now requires that critical care ultrasonography which includes GDE be a mandatory component of critical care medicine fellowship training, surgical critical care fellowship training, and emergency medicine residencies.²⁻⁴ Goal-directed echocardiography falls under the purview of basic critical care echocardiography as defined by The American College of Chest Physicians/Société de Réanimation de Langue Française (ACCP/SRLF) statement on competence in critical care ultrasonography.⁵ It is well established that this can be done successfully with a mixture of didactics, simulation, and hands on training.⁶⁻¹¹ The use of GDE to guide management during cardiac arrests is a relatively new frontier with little evidence based research to guide clinicians. Multiple groups have proposed basic algorithms for integration of GDE into Advanced Cardiac Life Support (ACLS),¹²⁻¹⁴ yet few studies assess feasibility and competency in GDE, leaving many questions unanswered.¹⁵⁻¹⁶

Since GDE is used by pulmonary and critical care medicine (PCCM) and emergency medicine (EM) physicians at our institution during cardiac arrests, we studied ability of housestaff previously trained in GDE to accurately diagnose common causes of pulseless electrical activity (PEA) or asystole during simulated scenarios and compared them to expert echocardiographers. We also sought to determine if GDE can be performed in an ACLS compliant manner, during pulse checks lasting no more than ten seconds, which minimizes interruptions of proven interventions such as the delivery of high quality chest compressions. Furthermore we studied housestaff perceptions of their ability to perform GDE before and after study commencement.

Methods

Participants included housestaff and experts for comparison. Housestaff were PCCM fellows (n = 11) and EM residents (n = 7) at New York University Medical Center (NYUMC) during 2012 with prior training in GDE. Pulmonary and critical care medicine fellows were enrolled at any stage of their fellowship, however, all had received GDE training at the

Cooperative Ultrasound Project course, a three day ultrasound course offered to first year fellows in the greater New York area. Emergency medicine residents were in their third or fourth year of residency and had received GDE training during mandated ultrasound rotations. Five cardiologists board certified in echocardiography were enrolled to serve as experts. This study was approved by the Institutional Review Board at New York University's School of Medicine (study # S12-00860), and all participants gave informed consent.

Housestaff answered a pre-study questionnaire (Appendix A). All participants were allotted five minutes to familiarize themselves with the high fidelity transthoracic echocardiography (TTE) simulator (Vimedix, CAE Healthcare, Saint-Laurent, Quebec, Canada, Figure 1) to minimize a potential learning curve effect. A baseline assessment was conducted in which participants were asked to obtain an image in each of four standard cardiac ultrasound windows: parasternal long axis (PSL), parasternal short axis (PSS), apical four chamber (AP4), and subcostal long axis (SCL). Participants were allowed thirty seconds per window (see Video, Supplemental Digital Content 1, which demonstrates the four baseline views obtained on the simulator).

After baseline data were obtained, participants were called into a total of six simulated PEA or asystolic arrest scenarios presented in a random order (Table 1). Upon entering the simulated cardiac arrest, participants were given a clinical vignette (Appendix B) from the patient's nurse and they were instructed that sole purpose during the ACLS resuscitation was to perform and interpret a GDE during pulse checks. Vignettes were designed to provide the pertinent information typically available to the clinician assessing an unstable patient and were not designed to mislead the participant. An actor stood on one side of the simulator and performed continuous chest compressions (CC), pausing for ten seconds during pulse checks. In the interest of time, CC were performed for 30 second intervals rather than the standard two minute intervals recommended by the American Heart Association; participants were made aware of this deviation ahead of time. It was during the ten second pulse checks that the participant was allowed to position the ultrasound probe and attempt to acquire and interpret an echocardiographic view of the heart (see Video, Supplemental Digital Content 2, which shows a participant attempting diagnosis during the cardiac tamponade and fine ventricular fibrillation scenarios). Participants were mandated during each scenario to start with the SCL view, but were subsequently free to use any other standard view if subsequent pulse checks were necessary. All six scenarios in this study could be readily diagnosed with the SCL view. The other standard views were not necessary for diagnosis, but could be useful for the clinician unsure of the SCL findings (see Video, Supplemental Digital Content 3, which demonstrates all six cardiac pathologies on the simulator). After each pulse check the participant was asked if they had a diagnosis. Three ACLS compliant GDE attempts were allowed and if the participant did not offer a diagnosis, a final twenty second non-ACLS compliant interval for GDE was allowed. Participants were debriefed on all scenarios (see Video, Supplemental Digital Content 4, which demonstrates part of a debriefing session) whereby an instructor walked them through the salient features of the case and ensured that they understood the GDE findings of the scenario. Participants filled out a post-study questionnaire (Appendix C). All echocardiography views were graded

for quality on a modified, but previously used scale of zero to three (Table 2).⁷ Housestaff performance was compared to the performance of the five expert echocardiographers.

For each participant, each baseline view was scored (Table 3) and the average quality of baseline views was determined for each of the four standard echocardiographic views. During the scenario phase, the best view achieved per scenario was scored and average quality of the six scenario views was calculated by participant. The accuracy of diagnosis and time to diagnosis (TTD) was recorded. Time to diagnosis was reported in ten second intervals with each interval corresponding to a single pulse check.

All echocardiography scans performed by each participant were recorded and were later reviewed independently by two experts in GDE (TM and YG). Inter-rater reliability was calculated using the Cohen's kappa statistic. Score discrepancies were reconciled by reviewing the scoring scale and reaching a consensus on the video at question.

Statistical Analysis and Sample Size Considerations

Primary outcome measure was diagnostic accuracy during the simulated cardiac arrest scenarios. Secondary outcome measures included perception of ability in GDE before and after study commencement, quality of GDE images obtained at baseline and during each scenario, TTD during each scenario, and diagnostic accuracy in an ACLS compliant time frame.

Our recruitment of participants was interrupted for several months in late 2012 and early 2013 due to suspension of operations and facility closure as a result of Superstorm Sandy. Sufficient statistical power for group comparison is lacking due to small samples sizes. Much of our results consist of descriptive summary data. Characteristics of the three groups and study results were summarized as means with standard deviations for continuous data and as percentages for categorical data. The relationship between the diagnostic accuracy and the quality of scenario views achieved was assessed with the nonparametric Spearman's rank order correlation coefficient. We tested for a learning effect using general linear models to perform repeated measure analyses to determine if subjects performed better as they progressed through the randomized scenarios.

Results

Inter-rater reliability

The two independent reviewers agreed on the quality of view score 85% of the time (Cohen's kappa 0.079). When disagreement existed it was within one point on the quality scale.

Primary Outcome Measure

Housestaff and experts made the correct diagnosis in 68% and 77% of simulated scenarios, respectively (Figure 3) and the rates of correct diagnosis for each scenario are reported (Table 1). Housestaff made the incorrect diagnosis for 23% of scenarios and they did not offer a diagnosis for 8% of scenarios. Experts made the incorrect diagnosis for 20% of scenarios and they did not offer a diagnosis for 3% of scenarios.

Secondary Outcome Measures

Housestaff and experts made the correct diagnosis in an ACLS compliant manner in 62% and 67% of the scenarios, respectively. Average baseline views obtained by housestaff were of good or excellent quality 89% of the time and all were able to acquire at least two different echocardiographic windows which met criteria for good or excellent quality. The experts' average baseline views were always of good or excellent quality and all experts were able to acquire at least two different echocardiographic windows which met criteria for good or excellent quality.

Average scenario views by housestaff were of good or excellent quality 83% of the time (Figure 2). 72% (13/18) of housestaff acquired at least good quality views during each scenario. 94% (17/18) of housestaff achieved at least good views during 50% of scenarios. During each scenario, experts acquired at least one view which met criteria for good quality or better.

There was a weak relationship between quality of scenario views achieved and the likelihood for a participant to give the correct diagnosis ($p=0.45$, $p=0.03$). When a correct diagnosis was made, the TTD was 18 seconds $\pm$ 8. When subjects made the incorrect diagnosis or offered no diagnosis, the TDD was 30 seconds $\pm$ 8 and 38 seconds $\pm$ 15, respectively. When an incorrect diagnosis was offered, two or more pulse checks were used and when no diagnosis was offered three or more pulse checks were used. Analysis of the data yielded no evidence of a learning effect; subjects were not more likely to improve TDD ($p=0.11$), accuracy ($p=0.20$), or quality of images ($p=0.37$) as they progressed through the randomly ordered scenarios.

The number of all-time GDEs performed in real clinical scenarios prior to study commencement by housestaff is reported (Table 4). There was no correlation between the number of GDEs performed prior to study enrollment and the quality of baseline or scenario views or the ability of the participant to make the correct diagnosis. The majority of housestaff perceived this study as an accurate assessment of their ability and enjoyed participating in the study (Table 4).

Discussion

At many institutions GDE is increasingly being used to guide management during cardiac arrest situations. This non-invasive window to the heart has the potential to quickly uncover reversible causes of cardiac arrest not apparent during the physical exam, and provide useful information to treating physicians. To our knowledge, this pilot study is the first which sought to determine if GDE can be successfully performed during cardiac arrests in an ACLS compliant manner. A study by Breitzkreutz et al.¹⁵ sought to answer this question by performing a GDE while ACLS was being conducted on pulseless patients in the emergency department. Whilst a high success rate was reported, images obtained were not stored and thus it is impossible to know the quality of the views obtained and if they were interpreted correctly. Additionally, the prevalence of relatively rare causes of cardiac arrest such as cardiac tamponade and right heart strain from a massive PE were low making it impossible

to draw conclusions about the capability of the physicians studied to make these crucial diagnoses.

Our study demonstrated that trained housestaff and expert participants were able to perform and interpret a GDE during simulated cardiac arrest scenarios in an ACLS compliant manner the majority of the time. Furthermore, trainees and experts achieved similar diagnostic accuracy in the same time frame. It may seem surprising that we did not identify a relationship between quality of baseline or scenario GDE views and diagnostic accuracy during the simulated scenarios. We believe this is the case because the majority of views obtained were at least of good quality which provides enough information for the participant to make a diagnosis. The skills demonstrated during the simulated scenarios are directly translatable to real world ACLS. With the growing ubiquity of portable ultrasonography in the hospital environment this study provides evidence for the feasibility of performing GDE during cardiac arrest situations.

Using a computerized TTE simulator is advantageous in that it allows evaluators to test participant ability to both acquire and interpret images which are typically only present during high risk, low frequency events. Beraud et al. recently demonstrated the utility of using a TTE simulator to assess participant skill after a novel GDE training curriculum.¹⁷ While participants were not placed under the same time constraints as those in our study, they reported comparable TTD.

At study conclusion, participants felt more comfortable in their abilities. They appreciated the debriefing period whereby they were able to spend more time acquiring images and interpreting the pathologies that they encountered. Such opportunity is seldom feasible with real patients and is another advantage of incorporating simulation into training and assessment. The ability to spend as much time as is needed getting hands on training to understand the echocardiographic features of different pathologies is invaluable.

Ventricular fibrillation (VF), which is often amenable to defibrillation, can be confused with asystole on cardiac monitors and/or electrocardiogram. The distinction between the two has a profound impact on patient management and prognosis given dismal outcomes in asystole compared to VF.¹⁸ Several studies report diagnosing VF using echocardiography.^{18–20} It is intuitive that distinguishing VF from asystole with echocardiography is more challenging than identifying more obvious causes of cardiopulmonary arrest such as cardiac tamponade, however, the sensitivity and specificity of TTE for diagnosing VF is unknown. In our study, only 9% of participants correctly identified fine VF. It is important to recognize that the low rate of correct diagnosis of VF in our study may be due to the performance of our participants and a lack of awareness of this diagnosis, however, it may also be a limitation of our simulator's ability to accurately portray VF on an echocardiogram. Although not formally assessed, our expert echocardiographers thought the VF simulation had good fidelity. Given the management altering implications of correctly identifying this rhythm, we believe that GDE training should include this diagnosis and efforts should be increased to improve its identification. GDE training should also focus on the echocardiographic findings of severe hypovolemia and right ventricular pressure overload.

Currently no standard exists to guide physicians performing GDE in reporting their findings. As GDE is performed in hope of having immediate treatment implications, findings should be reported immediately to the treating physicians. A GDE may show a clear cause of the cardiac arrest. Alternatively, a GDE may not elucidate the cause. In such a case, it is useful for the physician to report their findings to the treating physicians. For example a physician may report as follows: “GDE performed. No pericardial effusion present. Right and left ventricular size appears normal. There is no end-systolic effacement of the left ventricular cavity. There is cardiac contractile activity. I do not suspect cardiac tamponade, right heart failure from a massive pulmonary embolism, or hypovolemic shock to be the cause of this patient’s cardiac arrest. I do not see evidence of asystole or ventricular fibrillation.” Finally, the GDE images may be of poor quality and thus an accurate assessment cannot be made. It is important that the physician performing the study relay this information to the treating team.

One might interpret our data more cautiously noting that a diagnosis was made in 93% of the scenarios and in 22% of those the diagnosis was wrong. There is clearly room for improvement, however, we urge readers to consider the following: it is possible that participants were unsure of the diagnosis in some of those cases, but due to our study design felt compelled to offer one. While this could occur in a real patient scenario, such a hypothesis needs to be confirmed in future studies. Misdiagnoses compared to correct diagnoses took longer on average to make. Physicians should keep this in mind when performing GDE, and this should be studied in the future. Additionally, GDE is useful in cardiac arrest situations where the cause of the arrest is unknown. At that point, physicians are only able to treat algorithmically and to offer empiric therapies. Mortality remains unacceptably high in such cases. Housestaff and expert correct diagnosis rates of 68% and 77%, while imperfect, do have potential to save many lives. Furthermore, analysis of accuracy with the elimination of the fine ventricular fibrillation scenario, which was diagnosed correctly in only 9% of cases, shows that housestaff and experts correctly diagnosed the cause of the cardiac arrest in 80% and 92% of cases, respectively. Nonetheless, future GDE training should focus on the time-constrained setting of an ACLS resuscitation and should emphasize that it is okay to notify the treating team that GDE was unable to yield a diagnosis. Another measure which would likely improve accuracy would be for the GDE to be recorded and quickly reviewed at the bedside. In this way, the physician acquiring the images can take a few extra moments to process the data and other treating clinicians with knowledge of GDE can be involved in the interpretation. In this study, participants did not have such an opportunity.

Limitations

Our study has several limitations. The sample size was limited as a result of operational interruptions due to Superstorm Sandy. Nonetheless, we believe that our data provides a strong foundation to inform future research in this area. Simulation has inherent advantages and disadvantages which have been well described in the literature. We attempted to create a realistically stressful environment to simulate an in-hospital cardiac arrest and believe that we observed good buy-in from our participants.

Computerized echocardiography simulators are a new technology and the device we used closely simulated real world echocardiography. We included ribs shadows in the simulation so as to create realistic difficulties in finding an adequate cardiac window. In this study, participants were naïve to the simulator, thus decreasing the chance that a participant could have a familiarity advantage with the simulator. Goal-directed echocardiography on hospitalized patients is notoriously challenging as optimal patient positioning and lighting is rarely encountered and electrodes and wires are often in the way of the ultrasound beam. With that in mind, the level of difficulty of image acquisition on this simulator closely mimics that of our patients, however, the reader may wish to consider our results to represent the upper bounds on expected real world performance. To date, no studies exist which validate the use of a particular echocardiography simulator.

We chose to use cardiologists board certified in echocardiography as our expert group. While they do serve as a good comparison group, it's important to note that they actually perform relatively few echocardiograms and rather spend the majority of their time interpreting echocardiograms obtained by a trained technician. Future studies should consider using expert level EM physicians and intensivists in addition to cardiologists.

Since our study did not account for duration of elapsed time between GDE training and enrollment, we cannot comment on the presence or absence of skill decay. This should be accounted for in future studies.

Conclusions

As GDE becomes integrated into ACLS, institutions will need to ensure that physicians performing GDE are sufficiently skilled to do so. Utilization of computerized echocardiography simulators provides a practical way to expose clinicians to both common and rare management-altering pathology in an environment which closely simulates the intensity and time constraints of an ACLS resuscitation.

Use of a high fidelity transthoracic echocardiography simulator is a novel and practical method of assessing skill and training housestaff in GDE. This study provides data to suggest that housestaff with prior GDE training reach similar diagnostic conclusions in the same amount of time as expert echocardiographers in a simulated cardiac arrest scenario. Using GDE in an ACLS compliant manner, housestaff are capable of diagnosing management altering pathologies the majority of the time. A larger study is needed to confirm the observations of this pilot study.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

GDE	Goal-directed echocardiography
ACLS	Advanced cardiac life support
PE	Pulmonary embolism
ACCP/SRLF	American College of Chest Physicians / Société de Réanimation de Langue Française
PCCM	Pulmonary and critical care medicine
EM	Emergency medicine
PEA	Pulseless electrical activity
NYUMC	New York University Medical Center
TTE	Transthoracic echocardiography
PSL	Parasternal long axis
PSS	Parasternal short axis
AP4	Apical four chamber
SCL	Subcostal long axis
CC	Chest compressions
TTD	Time to diagnosis
VF	Ventricular fibrillation

Appendices

Appendix A – Pre-study Questionnaire

Appendix B – Clinical Vignettes

Appendix C – Post-study Questionnaire

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Figure 1.
Photograph of the high fidelity transthoracic echocardiography simulator used in the study.

Figure 2.

Average quality of goal-directed echocardiography views during baseline assessment and scenario simulation by subject. Housestaff (n = 18); Experts (n = 5).

Figure 3.
Box plot showing overall scenario accuracy. Housestaff (n = 18); Experts (n = 5).

Table 1

Cardiac arrest / pulseless electrical activity pathologies and accuracy

<i>Scenario</i>	<i>Pathology</i>	<i>Overall Accuracy (n = 23)</i>	<i>Housestaff Accuracy (n = 18)</i>	<i>Expert Accuracy (n = 5)</i>
A	Fine ventricular fibrillation	9%	11%	0%
B	Asystole	96%	94%	100%
C	Decreased left-ventricular function	91%	89%	100%
D	Cardiac tamponade	100%	100%	100%
E	Hyperdynamic left-ventricular function	52%	44%	80%
F	Right ventricular dilatation	74%	72%	80%

Table 2

Echocardiogram scoring paradigm

<i>Score</i>	<i>Quality of view</i>	<i>Description of echocardiogram image</i>
0	Poor	No image
1	Poor	< 50% of total expected chambers and vessels visualized
2	Good	> 50% of total expected chambers and vessels visualized
3	Excellent	100% of total expected chambers and vessels visualized

Table 3

Quality of baseline views obtained by participants (n = 23)

The last five participants, numbers 15, 16, 17, 19, & 20, are the expert group and the rest are housestaff.

Participant	Parasternal Long Axis	Parasternal Short Axis	Apical 4-Chamber View	Subcostal View	Participant Average
1	3	1	3	1	2
2	2	1	3	2	2
3	3	3	3	2	2.75
4	2	2	1	3	2
5	3	2	3	3	2.75
6	1	1	3	2	1.75
7	2	1	3	2	2
8	2	3	3	2	2.5
9	3	3	3	2	2.75
10	2	2	3	2	2.25
11	3	3	2	2	2.5
12	3	1	3	3	2.5
13	3	3	2	3	2.75
14	3	1	2	3	2.25
18	2	3	3	2	2.5
21	3	3	3	2	2.75
23	2	2	1	1	1.5
24	2	2	3	2	2.25
15	1	3	2	2	2
16	2	2	2	3	2.25
17	3	2	2	3	2.5
19	2	2	3	2	2.25
20	1	2	3	3	2.25
Baseline Average	2.44	2.06	2.61	2.17	2.34

Table 4

Housestaff pre- and post-study questionnaire data (n = 18)

Prior to Study Commencement	
Number of GDEs performed:	
1–5	17%
6–15	17%
16–30	50%
>30	17%
Post-study Perceptions	
Study perceived as accurate assessment of ability	
Strongly disagree / disagree	0%
Neutral	6%
Agree	50%
Strongly agree	44%
Increased comfort with GDE after study	
Strongly disagree	0%
Disagree	6%
Neutral	11%
Agree	61%
Strongly Agree	22%
Housestaff enjoyment in participation	
Agree	33%
Strongly agree	67%