Guiding Cardiopulmonary Resuscitation with Focused Echocardiography: A Report of Five Cases


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GUIDING CARDIOPULMONARY RESUSCITATION WITH FOCUSED ECHOCARDIOGRAPHY: A REPORT OF FIVE CASES

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ABSTRACT

Background: Focused transthoracic echocardiography has been used to determine etiologies of cardiac arrest and evaluate utility of continuing resuscitation after cardiac arrest. Few guidelines exist advising ultrasound timing within the advanced cardiac life support algorithm. Natural timing of echocardiography occurs during the pulse check, when views are unencumbered by stabilization equipment or vigorous movements. However, recent studies suggest that ultrasound performance during pulse checks prolongs the pause duration of cardiopulmonary resuscitation. Transesophageal echocardiography studies have demonstrated benefits in this regard, but there have been no transthoracic echocardiography studies assessing the physical performance of compressions during cardiopulmonary resuscitation. Objective: The purpose of this study was to describe cases where echocardiography performed at the beginning of the cardiac arrest algorithm offers actionable information to cardiopulmonary resuscitation itself without delaying provision of compressions. Conclusion: Providers using focused echocardiography to evaluate cardiac arrest patients should consider initiating scans at the start of compressions to identify the optimal location for compression delivery and to detect inadequate compressions. Subsequent visualization of full left ventricular compression may be seen after a location change, and combined with end tidal carbon dioxide values, gives indication for improved forward circulatory flow. Although it is not possible in all patients, doing so hastens provision of quality compressions that affect hemodynamic parameters without causing prolongations to the pulse check pause. Further research is needed to determine patient outcomes from both out-of-hospital and in-hospital cardiac arrest when cardiopulmonary resuscitation is visually guided by focused echocardiography. Key words: point-of-care ultrasound; echocardiography; cardiac arrest; cardiopulmonary resuscitation; emergency medicine

INTRODUCTION

Focused transthoracic cardiac ultrasound (FOCUS) is an influential tool used by a majority of emergency physicians during cardiac arrest (1). Its benefits include identifying reversible causes of cardiac arrest and determining presence of meaningful cardiac activity. Ultrasound protocols have been created to help guide echocardiography during cardiac arrest (2–5), including emergency medical technician-driven algorithms such as the Prehospital Assessment with Ultrasound for Emergencies (PAUSE) protocol and the Cardiac Ultrasound Structural Assessment Scale (CUSAS) (6, 7). They focus on obtaining treatable diagnoses or prognosticating survival and incorporate ultrasound assessments during the pulse check, rhythm analysis, or ventilation phases of the advanced cardiac life support (ACLS) algorithm during a time that chest compressions are typically withheld (8–11). However, recent studies suggest that performing ultrasound during the rhythm check prolongs the duration of pause in cardiopulmonary resuscitation (CPR) in both the ED setting and paramedic-led field resuscitation (12–14). Since delivery of high-quality chest compressions is most crucial to improving chances of survival, prolonged interruptions compromise forward blood flow, tissue perfusion, and ultimate neurologic recovery (15).

Several radiographic studies suggest that the current standard location for CPR performance may not promote compression of the left ventricle (LV) but instead forces pressure onto non-optimal areas.
which prohibit forward circulation (16, 17). While CPR mainly focuses on the vertical compression of the heart, Jung et al. showed that LV position varies widely among individuals and its transverse position changes during both basic life support (BLS) and ACLS resuscitation (18). Transesophageal studies substantiate this (19), with Anderson et al. finding that return of spontaneous circulation (ROSC) and other hemodynamic parameters were higher in swine that received compressions directly over the center of the left ventricle instead of at the standard sternal site (20).

To our knowledge, there have been no descriptions of focused transthoracic echocardiography addressing the physical performance of CPR in a human population, either in the field or in-hospital. Emphasis on applying it before the pulse check stage may have benefits in cardiac resuscitation without affecting interruptions to CPR. Our case series highlights this application and provides suggestions to optimizing real-time CPR monitoring using bedside or field echocardiography as early as possible in the resuscitation.

**Case 1**

A 45-year-old male was found unresponsive by his mother 30 minutes after she last conversed with him. Paramedics responded within 6 minutes and commenced resuscitation using a mechanical compression device (MCD) and bag-valve-mask ventilation. No prior bystander interventions occurred. The initial rhythm during the 45-minute prehospital interval was pulseless electrical activity (PEA), and he received IV naloxone as well as epinephrine without effect. On emergency department (ED) arrival, he was immediately intubated while MCD compressions were ongoing. His initial oxygen saturation value (SaO2) was 55% with an EtCO2 value of 18 mmHg. His cardiac rhythm remained PEA.

Using a parasternal long axis (PSLA) view, chest compressions were evaluated by the attending ED physician. It was found that even with appropriate MCD positioning over the sternum, compressive force was directed over the aorta and right heart (Supplementary Video 1). The LV had not been receiving compressions and was instead rocked from side to side. The MCD was disconnected and manual compressions were started at the left sternal border and left chest. Adequate compressions and recoil of the LV walls were seen using real-time echocardiography, with immediate improvement in both SaO2 to 90% and EtCO2 to 68 mmHg. Subsequent FOCUS performed by the same ED physician during pulse checks revealed fine refractory ventricular fibrillation (Vfib). Double sequential defibrillation was performed twice, with ROSC achieved and a sinus rhythm maintained by IV amiodarone, sodium bicarbonate, norepinephrine and epinephrine drips. As ROSC continued, his SaO2 further improved to 100%. He survived several days through hospital admission, but due to global hypoxic encephalopathy with grim neurological prognosis, his family decided not to pursue further life sustaining care.

**Case 2**

An 84-year-old female was found unresponsive at home after family heard a fall, which was unwitnessed. She did not receive bystander CPR. Responding paramedics discovered Vfib and delivered a defibrillating shock. They administered IV epinephrine, calcium chloride, sodium bicarbonate, endotracheal intubation and MCD compressions. On arrival to the ED 20 minutes later, she was in asystole. Her SaO2 was 65% and EtCO2 was 13 mmHg.

During the initial ED evaluation, MCD compressions were maintained. She had a right mainstem intubation which was corrected. However, this resulted in only mild improvement of her SaO2 to 80%. A bedside PSLA view performed by the ED physician was used to evaluate cardiac arrest etiology and her persistent hypoxia. The MCD was correctly positioned over her sternum, but the LV was not compressed at all. Instead, the right heart and aorta received all compressive force, likely due to anatomical variance positioning her heart towards the lateral left side of her body (Supplementary Video 2).

The MCD was removed and manual compressions were started over the patient’s left breast. Using real-time ultrasound guidance with continuous probe placement in the subxiphoid view, the LV was seen to fully compress with adequate depth and recoil. Within seconds of changing the location of CPR delivery, her SaO2 improved to 100% and her EtCO2 increased to 42 mmHg. Subsequent organized cardiac activity was briefly appreciated but could not be maintained despite maximal therapies. Her family requested termination of CPR.

**Case 3**

A 54-year-old male with chronic obstructive pulmonary disease (COPD) called emergency medical services complaining of shortness of breath, 25 minutes prior to ED arrival. Responding paramedics found him alone, in PEA. They established a supraglottic airway and started manual compressions. He received IV epinephrine, calcium chloride, and sodium
bicarbonate, with resuscitation ongoing for 20 minutes en route to the ED. His SaO2 was 40% and EtCO2 8 mmHg throughout transport. During hand-off to ED personnel, a PSLA view was performed by the ED physician as paramedics carried out CPR. Image quality was limited by the patient’s obesity and COPD status, but no actual compression activity was seen within the LV. Instead, his whole heart was pushed in a horizontal to-and-fro pattern. Additionally, compressions were too fast and shallow. The overseeing physician instructed paramedics to move compressions over to the left chest, increase compression depth, and slow rate of compression delivery. With real-time visual feedback, paramedics watched the ultrasound screen as their changes achieved full LV compressions and adequate CPR in less than 30 seconds (Supplementary Video 3). His SaO2 improved to 90% and EtCO2 to 40 mmHg. Intermittent ventricular tachycardia was seen throughout the continued resuscitation, but a definitive rhythm could not be sustained.

CASE 4

A 74-year-old female with hypertension, diabetes and coronary artery disease complained of headache, dizziness, and shortness of breath the morning of her arrest. She had witnessed unresponsiveness in the afternoon and was found by responding paramedics in PEA. She did not receive any bystander interventions. EMS administered manual CPR and IV epinephrine, calcium chloride, sodium bicarbonate, and amiodarone. This initially enabled ROSC with an electrocardiogram showing anterior ST elevations and an EtCO2 of 33 mmHg. However, 15 minutes after ED arrival she lost pulses and CPR was resumed. At this time, the EtCO2 was 16 mmHg. An immediate parasural short axis view obtained during CPR by the ED physician demonstrated misdirected manual compression location, and inadequate compression depth (Supplementary Video 4). Real-time directed feedback using continuous echocardiographic monitoring in a PSLA view resulted in improved CPR within 45 seconds and she achieved ROSC 2 minutes later with an EtCO2 of 57 mmHg. However, she was not able to maintain a perfusing rhythm after 34 minutes elapsed and she arrested 3 more times, with EtCO2 decreasing below 20 mmHg prior to each arrest. With adequate compressions modeled from CPR under FOCUS guidance, she obtained ROSC with each CPR resumption, but was ultimately not able to maintain it despite maximal treatments. Her family requested termination of resuscitation efforts. During this patient’s encounter, SaO2 values were not documented.

CASE 5

A 72-year-old female with hypertension suddenly clutched her chest, complaining of chest pain and shortness of breath before sustaining a witnessed collapse. There were no bystander interventions performed, and the initial rhythm obtained by paramedics while on scene and en route to the hospital was Vfib. She received MCD CPR, endotracheal intubation, IV epinephrine, and one defibrillation. On arrival, immediate FOCUS performed by the ED physician using a subxiphoid view with the EMS MCD in place showed adequate compression delivery; as a result, the MCD was maintained in place to continue resuscitation (Supplementary Video 5). A large pericardial clot was noted, and subsequent pulse check imaging revealed Vfib with tamponade. Pericardiocentesis retrieved 60 cc of fluid, after which ROSC was obtained. A PSLA view showed a dilated aortic outflow tract indicating thoracic aneurysm or dissection. A ruptured ascending aorta with hemopericardium was confirmed on a subsequent CT, and due to her poor prognosis she was not a surgical candidate. Her family withdrew resuscitation care upon discussion with cardiothoracic surgeons. FOCUS allowed simultaneous compression assessment while facilitating diagnosis of her cardiac arrest etiology.

DISCUSSION

The use of FOCUS to elucidate origins for shock and cardiac arrest has been described in both clinical evaluations and societal consensus statements (5, 21–23). Echocardiography timing has been largely performed within the integrated pulse checks of the ACLS algorithm. However, the above cases demonstrate the value of performing ultrasound earlier in resuscitation, preferably at the initiation of chest compressions, to optimize location of compressions, identify inadequate compressions, and find the area of maximum ultrasound visibility before the pulse check occurs. Doing so may prevent inadvertent prolongations of the CPR pause, offers feedback regarding CPR provision, aids discovery of anatomic variants, and facilitates investigation of cardiac arrest etiology. Ultrasound provides information not obtainable from impedance devices or direct observation alone.

Implementation of FOCUS-guided compression monitoring may be a challenge due to crowding of personnel and equipment, the patient’s body habitus, comorbidities like COPD, environmental factors leading to skin and muscle noncompliance, and vigorous movement of the thorax impeding the ability
to obtain views. A main goal is to visualize the left heart and assess compression adequacy by appreciating full constriction of the LV walls followed by full recoil, which is marked by LV luminal expansion. When compressions are poorly located, the heart may be visualized on the screen as pushed in a horizontal or circular fashion, tilting from side-to-side without anterior to posterior LV wall constriction or disappearance of the LV lumen. The subxiphoid view provides a window that is unencumbered by defibrillator pads, ECG electrodes, cervical collars, or other devices. However, obesity and gaseous distension from bag-valve-mask ventilation may hinder use of this view.

To obtain an appropriate image of the left heart, nontraditional views may be required (Figures 1–2). Modified or “hybrid” parastral long and parastrernal short approaches with the probe placed atypically, such as at a higher or lower rib space than usual or a non-sternal lateral location, may be needed. In these positions, the probe angulation may have to change. For instance, if the probe is placed in a high intercostal space, the probe may need to be fanned caudally for the sound beam to intersect the heart or avoid air interference from lung parenchyma. Accommodation of these views should place the probe as close as possible to the anterior defibrillation pad, compression piston, or CPR provider’s hands without causing compression interference. Similarly, a modified apical 4-chamber view with the septum directed obliquely instead of vertically may be the only image obtainable.

Scanning personnel need to be mindful of the limitations of their views, including the appearance of atypical rotations and planes that over- or underestimate the size of the LV lumen due to inability to achieve the optimal angle of tilt.

The operator may need to be comfortable with ambidextrous probe-handling and be resourceful regarding acquisition of views. In certain environments, personnel provide compressions from the right side of the patient, so obtaining good views without hindering staff requires left-handed scanning on the patient’s left side. Positioning the FOCUS operator at the patient’s shoulder avoids obstructing staff who are delivering respirations or obtaining peripheral intravenous lines. This means that the ultrasound operator may be performing a scan in an atypical ergonomic position. Placing cloth towels over the area of chest compressions and over the ultrasound operator’s hands avoids compression providers from slipping in ultrasound gel.

In the hospital setting, limitations with transthoracic imaging are the reasons emergency and critical care physicians are exploring the use of transesophageal echo in resuscitation (24, 25). However, it has not become a standard yet due to costs and challenges of program implementation. Meanwhile, transthoracic echocardiography training of EMS physicians and paramedics specifically regarding cardiac arrest has shown feasible with sessions ranging from 20 minutes to 3 hours, along with other longitudinal programs described (6, 7, 10, 14, 26, 27). Technological advances allowing miniaturization of ultrasound to pocket devices expands the use of transthoracic echocardiography to more front-line providers and may allow easier performance of FOCUS-guided CPR compression monitoring.

The standard location for CPR may not allow effective compression of the left ventricle in a substantial subset of the cardiac arrest population, possibly contributing to poor survival rates observed when evaluating mechanical CPR devices (28, 29). The aforementioned cases suggest that the concept
of intra-arrest cardiac ultrasound holds merit for investigation, and there may be benefits to initiating field echocardiography to guide CPR and resuscitation efforts. Studies are beginning to show positive impact of physician and paramedic-performed field echocardiography in cardiac arrest management, which still largely focuses on cessation or continuation of resuscitation (27, 30–32). Future prospective trials involving FOCUS-guided compression monitoring that review prevalence of changes to mechanical or manual CPR performance, determine resultant patient outcomes, examine intrathoracic and musculoskeletal injury, and evaluate the overall impact of training in prehospital ultrasound are needed.

**CONCLUSION**

We advocate for focused transthoracic echocardiography to commence prior to the pulse check phase of the ACLS algorithm, allowing the ideal window for probe placement to be visualized prior to holding compressions. An aspirational goal would be to advise chest compression adequacy as soon as resuscitation begins, whether administering mechanical or manual CPR in the field or in-hospital. In this way, resuscitation efforts could be tailored towards each individual patient’s cardiac anatomy regarding optimal compression location and compression quality. Technical and environmental challenges exist that limit image acquisition, and allowing modifications to traditional echocardiographic views may help. Further research is required to clarify patient outcomes and assess operational feasibility when adopting these concepts, as well as continued study of the best methods for achieving high quality compression delivery.

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