CLINICAL PAPER

C.A.U.S.E.: Cardiac arrest ultra-sound exam—A better approach to managing patients in primary non-arrhythmogenic cardiac arrest

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Summary Cardiac arrest is a condition frequently encountered by physicians in the hospital setting including the Emergency Department, Intensive Care Unit and medical/surgical wards. This paper reviews the current literature involving the use of ultrasound in resuscitation and proposes an algorithmic approach for the use of ultrasound during cardiac arrest. At present there is the need for a means of differentiating between various causes of cardiac arrest, which are not a direct result of a primary ventricular arrhythmia. Identifying the cause of pulseless electrical activity or asystole is important as the underlying cause is what guides management in such cases. This approach, incorporating ultrasound to manage cardiac arrest aids in the diagnosis of the most common and easily reversible causes of cardiac arrest not caused by primary ventricular arrhythmia, namely; severe hypovolemia, tension pneumothorax, cardiac tamponade, and massive pulmonary embolus. These four conditions are addressed in this paper using four accepted emergency ultrasound applications to be performed during resuscitation of a cardiac arrest patient with the aim of determining the underlying cause of a cardiac arrest. Identifying the underlying cause of cardiac arrest represents the one of the greatest challenges of managing patients with asystole or PEA and accurate determination has the potential to improve management by guiding therapeutic decisions.

We include several clinical images demonstrating examples of cardiac tamponade, massive pulmonary embolus, and severe hypovolemia secondary to abdominal aortic aneurysm.

In conclusion, this protocol has the potential to reduce the time required to determine the etiology of a cardiac arrest and thus decrease the time between arrest and appropriate therapy.

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Cardiac arrest is a condition frequently encountered by physicians in the hospital setting including the Emergency Department, Intensive Care Unit and medical/surgical wards. Since the implementation of preventative health policy and ACLS, deaths from ventricular fibrillation and ventricular tachycardia have decreased significantly, however the prevalence of pulseless electrical activity (PEA) and asystole have increased. Unlike ventricular fibrillation and pulseless ventricular tachycardia where the pattern/rhythm of electrical activity is the focus of treatment rather than the underlying cause, PEA and asystole are corrected by addressing the underlying cause. The importance of identifying a reversible underlying cause in these forms of cardiac arrest is of such importance that almost half of the ACLS for experienced practitioners manual is dedicated to this topic and its practical application. Hughes et al. provided a list of the etiologies of PEA in the order of frequency and ease of reversal. He lists the top five conditions as hypoxia, hypovolemia, tension pneumothorax, pericardial tamponade, and pulmonary emboli. These conditions are potentially reversible, but the treatment is often invasive and may be deadly if mistakenly applied to the wrong etiology. This is crucial. Currently the AHA recommends using physical signs and the patient’s history to guide the management of PEA and asystole. However, physical examination can be unreliable and many physicians may withhold therapy for a fear of causing harm if uncertain of the cause of cardiac arrest.

Ultrasound is a diagnostic tool with increasing applications and use in emergency situations. Levitt et al. have observed that emergency physicians had increased confidence in clinical decision-making when presented with diagnostic ultrasonographic images of medical conditions versus clinical impression and physical examination alone. Ultrasound examination has the potential to bring increased diagnostic clarity to clinical decision-making and aid in the identification of a reversible cause for PEA or asystole. Many of these investigators have studied the application of ultrasound to one, or a few, causes of PEA and cardiac arrest; however a protocol that addresses the most common cardiac and pulmonary causes of PEA has not been developed. There remains a need for an organized and structured approach to non-arrhythmogenic cardiac arrest with sufficient diagnostic accuracy to justify appropriate aggressive life-saving therapy. An effective protocol for emergency ultrasound evaluation in cardiac arrest patients would address the most likely and reversible causes; severe hypovolemia, tension pneumothorax, cardiac tamponade, and pulmonary embolus. There is a body of literature supporting the use of ultrasound as an accurate diagnostic aid in the four above-mentioned conditions. The purpose of this paper is twofold; first, to review the literature involving ultrasound and resuscitative conditions. Second, to propose a goal oriented approach to the cardiac arrest patient that incorporates the use of ultrasound to address the most common reversible causes of non-arrhythmia cardiac arrest. The name of this new test is C.A.U.S.E., an acronym for cardiac arrest ultra sound examination, and whose name has the added benefit of reminding the practitioner that the primary goal of their effort in PEA or asystole should be to identify and address the underlying cause. The protocol also serves to organize a process that can at times be chaotic and disorganized. Past studies have shown that increased organization during resuscitation increases the likelihood of survival. A similar organizational protocol has been used for the treatment of ventricular arrhythmias using three-lead electrocardiogram as a diagnostic tool with great success.

Sonographic applications for cardiac arrest

Ultrasound has been used as an effective diagnostic tool during cardiac arrest and has identified causes of PEA. These include cardiac tamponade, severe hypovolemia, pulmonary embolus, tension pneumothorax, and true asystole.

Cardiac tamponade

The use of ultrasound is widely accepted in the diagnosis of cardiac tamponade in the form of identifying a pericardial effusion during the FAST screening examination for trauma. Cardiac tamponade is more accurately identified by visualizing pericardial effusion and right chamber collapse with either of the parasternal views or the subxyphoid/costal view. Ultrasound is also highly accurate in diagnosing this condition. Mandavia et al., demonstrated that emergency physicians could diagnose the presence of pericardial effusion accurately when compared to a cardiologist with an overall sensitivity of 96%, specificity of 98% and overall accuracy of 97.5%.

Currently the AHA recommends identifying neck vein distention and absence of pulse with CPR as diagnostic criteria for tamponade. However these features are shared by tension pneumothorax as well. During cardiac arrest situations it could be difficult to differentiate between the two conditions, as unequal breath sounds are difficult to appreciate in noisy or chaotic environments (i.e. emergency departments). Regularly using ultrasound to identify cardiac tamponade would add a greater level of accuracy to the determination of this cause for cardiac arrest and may prevent the use of inappropriate therapy. Therapy for cardiac tamponade is invasive (i.e. pericardiocentesis or open thoracotomy). Having a test that is available in real time with greater accuracy than a physical examination would be useful to physicians managing a patient in cardiac arrest and reduce concerns of making a diagnostic and therapeutic error. Physical examination and history remain important factors in medical decision-making, and their importance should not be neglected. There are caveats that should always be remembered when interpreting sonographic findings. For example patients in chronic renal
failure may have long standing pericardial effusions that may be unrelated to the cause of cardiac arrest (i.e. hyperkalemia), or patients who have trauma to the chest may have minimal pericardial effusion but demonstrate clinical signs of tamponade. The characteristic emergency ultrasound image of cardiac tamponade is depicted above (Figure 1).

### Hypovolemia

Hypovolemia is suggested by flattened right and left ventricles in the subxyphoid or long axis views of the heart, or by measuring left ventricular end-diastolic area from the short axis parasternal view. Brown et al. reviewed literature on the use of sonography to monitor hemodynamic status. He observed that left ventricular end-diastolic volume correlated extremely well with blood loss ($r = 0.96$) and could significantly detect small changes in intravascular volume by as little as 1.75 mL/kg in human subjects and 5 mL/kg in pigs demonstrating that ultrasounds are useful as an accurate tool to determine volume status noninvasively. Hendrickson et al. reports a case where ultrasound was used to diagnose hypotension as the cause of PEA. He describes a patient with the characteristic signs of hypovolemia on cardiac sonogram and was found to have a ruptured abdominal aortic aneurysm. The use of ultrasound in this case affected the patient’s care significantly.

Ultrasound of the inferior vena cava (IVC) can be a valuable adjunct to cardiac imaging in the setting of cardiac arrest. IVC is measured in the sub-xiphoid space in the long axis, using the liver as an acoustic window. There have been some studies that have linked the IVC diameter to volume status and right ventricular pressure, demonstrating a sensitivity and specificity of 88 and 81%, respectively, and a high degree of correlation between blood loss and IVC diameter at $r = 0.83$. However, most of these studies were performed on patients with spontaneous respiration which is not likely to be the case in the setting of cardiac arrest where positive pressure ventilation is routine. The authors recommend that in the setting of cardiac arrest a flat (IVC diameter <5 mm) or collapsed IVC represents hypovolemia and should prompt aggressive fluid resuscitation. On the other hand, a dilated IVC (IVC diameter >20 mm) in the setting of a cardiac arrest would be more consistent with pump failure from congestive heart failure, cardiac tamponade or pulmonary embolism or may be as a result of cardiac arrest itself. In any case echocardiographic findings should be correlated with clinical impression for a more educated resuscitative plan.

Ultrasound to diagnose hypovolemia in the presence of PEA adds increased diagnostic clarity, speed and accuracy, and may decrease the use of unnecessary, time-wasting and potentially harmful empiric therapy (i.e. thrombolytics for suspected massive PE in the setting of true aortic aneurysm rupture). A characteristic emergency ultrasound image of the heart in hypovolemia may be viewed below (Figure 2). There is also an ultrasound of image demonstrating the cause of this hypovolemia in the same patient as Picture 2, a ruptured abdominal aortic aneurysm (Figure 3).

![Figure 1](image1.png) **Figure 1** Subxyphoid emergency ultrasound image of a patient with cardiac tamponade as a cause of PEA. Notice the pericardial effusion and right atrial collapse.

![Figure 2](image2.png) **Figure 2** Subxyphoid emergency ultrasound image of a patient with hypovolemia as the cause of PEA. Patient was actively being resuscitated with two large bore central venous catheters at time of image acquisition.
Pulmonary embolus

Pulmonary embolus has been observed to be the direct cause of almost 5% of cardiac arrests, with PEA being the initial diagnostic rhythm in 63% and asystole in another 32% of these cases.\textsuperscript{12} It has also been observed that in patients presenting with cardiac arrest as a consequence of acute pulmonary emboli, thrombolytic therapy resulted in a significantly higher return of spontaneous circulation when compared to similar patients who did not receive thrombolytic therapy, 81% versus 43%, respectively.\textsuperscript{22} Therefore having a diagnostic tool with the potential of directing thrombolytic therapy in patients in cardiac arrest as a consequence of pulmonary emboli has the potential to greatly impact outcomes in this patient population.

Pulmonary embolus is identified sonographically by the finding of an engorged right ventricle with a flattened left ventricle.\textsuperscript{4,7,15} There are a few reports of the use of cardiac ultrasound in the setting of cardiac arrest. MacCarthy et al. described a case where a 25-year-old woman experienced cardiac arrest due to massive pulmonary embolus.\textsuperscript{4} The above findings were recognized on cardiac ultrasound and the patient was given appropriate management, leading to the eventual discharge of the patient from the hospital. Similarly Tovar et al. describes a similar case where transthoracic ultrasound was used to diagnose pulmonary embolism in a 61-year-old man.\textsuperscript{7} In this case embolectomy was performed and the patient was discharged form the hospital to live a normal life. Both of these case reports illustrate that sonographic diagnosis of massive pulmonary emboli allow physicians the confidence to employ aggressive life-saving therapy that may have not been used or reluctantly used in the face of diagnostic uncertainty, due to the fear of potential catastrophic negative outcome.

The use of transthoracic ultrasound to diagnose pulmonary emboli has been studied as well in patients not experiencing cardiac arrest. Nazeyrollas et al. performed a prospective study in 70 patients with suspected acute pulmonary emboli, he found that right sided enlargement in this patient population demonstrated a sensitivity of 0.70 and a specificity of 0.86 for diagnosing acute pulmonary emboli when a threshold of 25 mm was used.\textsuperscript{23} Miniati et al. performed a prospective study in 110 consecutive patients with suspected pulmonary emboli; he found that echocardiographic criteria for PE demonstrated a sensitivity of 56% and specificity of 90%.\textsuperscript{24} Similarly Jackson et al. evaluated patients prospectively with suspected pulmonary emboli and found that ultrasound had a sensitivity of 0.41 and specificity of 0.91.\textsuperscript{25} Torbicki and Pruszczyk reviewed the available literature on the use of ultrasound to diagnose acute pulmonary emboli and found that cardiac ultrasound has specificity between 81 and 94%, with a positive predictive value of 71—86%.\textsuperscript{26} These data all indicate that ultrasound has poor to moderate sensitivity as a routine screening test in all patients with suspected pulmonary emboli. However cardiac ultrasound has demonstrated good to excellent specificity at detecting acute pulmonary emboli, which may be more important and appropriate in the setting of cardiac arrest, where the need for specific therapy must be justified.

After reviewing the available literature on the use of echocardiography in the diagnosis of acute pulmonary emboli Lebowitz recommended that ultrasound had the potential to make the greatest clinical impact in patients with central hemodynamically significant pulmonary emboli (i.e. those capable of causing cardiac arrest) versus the majority of patients with small peripheral pulmonary emboli.\textsuperscript{27} This recommendation is logical as echocardiographic findings of pulmonary embolus begin to be evident after acute obstruction of more than 30% of the pulmonary arterial bed.\textsuperscript{26} Ultrasound therefore appears to be an excellent bedside test for detecting the presence of large pulmonary emboli capable of causing cardiac arrest.

A characteristic four-chamber apical view of the heart of a patient with massive pulmonary embolus is demonstrated below (Figure 4). A CT-scan image of the same patient demonstrating a large saddle pulmonary embolus is presented as well (Figure 5).

**Tension pneumothorax**

Tension pneumothorax is identified sonographically by absence of "sliding sign" between the visceral and parietal pleura when viewed anteromedially at the level of the second intercostal interspace and the mid clavicular line. This approach was used by Knudtsen et al. in trauma patients\textsuperscript{28} and provides the ability to diagnose pneumothorax in as little as 30s with a sensitivity of 92.3%, specificity of 99.6%, and positive predictive value of 92.3% and accuracy of 99.3%.\textsuperscript{28} Other studies have achieved equally impressive accuracies using ultrasound for the detection of pneumothorax.\textsuperscript{29,30} This high level of accuracy in both ruling pneumothorax in or out could greatly aid physicians in managing cardiac arrest. A protocol addressing the pulseless patient should address pneumothorax, as it
Figure 4  Four-chamber apical view of the heart in patient with suspected pulmonary embolus. Notice the massive enlargement of both right chambers when compared to the left side of the heart.

Figure 5  CT angiogram of the chest in a patient from Figure 4, obtained 1 h after initial ultrasound image. Notice the large saddle pulmonary embolus. As a result of interventions started after initial emergency ultrasound patient survived and was discharged from the hospital.

Figure 6  Diagram comparing relative sizes of the cardiac chambers (apical four-chamber view) in cardiac tamponade, pulmonary embolus, and hypovolemia to that of a normal heart. Please note that this diagram represents images obtained with normal emergency room probe setting, if using cardiac setting the diagram is flipped to its mirror image. Please see Figure 4 for an example.
is a common problem and readily reversible. Ultrasound has been demonstrated to be a highly accurate diagnostic aid for pneumothorax, and could be of great use in a cardiac arrest situation where ambient noise may affect the accuracy of auscultation via stethoscope. Furthermore the high degree of accuracy afforded by ultrasound assists in differentiating between cardiac tamponade and tension pneumothorax, both of which present with similar clinical features.

**True asystole**

Ultrasound has also been useful in distinguishing true asystole from other types of cardiac arrest. Cardiac standstill or true asystole is identified by complete absence of any motion in the heart including the valves, atria or ventricles and is often seen in association with severe spontaneous echo contrast. Blaivas et al. observed that cardiac standstill in the emergency department had a positive predictive value of 100% for death in the emergency department. Salen et al. made similar observations in his study. Salen observed that none of the patients with absence of cardiac kinetic activity on sonogram had spontaneous return of circulation. However, evidence of kinetic activity on sonographic evaluation of the heart was associated with return of spontaneous circulation. This knowledge may be useful for physicians, allowing them to make decisions regarding the value of continued resuscitative efforts. There appears to be justification for terminating resuscitative efforts if no cardiac motion is detected on cardiac ultrasound after adequate resuscitative efforts were employed.

**C.A.U.S.E.**

C.A.U.S.E. is a new approach developed by the authors. The C.A.U.S.E. protocol addresses four leading causes of cardiac arrest and achieves this by using two sonographic perspectives of the thorax; a four-chamber view of the heart and pericardium and anteromedial views of the lung and pleura at the level of the second intercostal space at the midclavicular line bilaterally. The four-chamber view of the heart and pericardium is attained using either the subcostal, parasternal or apical thoracic windows. This allows the individual performing the examination to select the most adequate view depending on the patients’ anatomy. The authors recommend beginning with the subcostal view first as this view makes it possible for the practitioner to evaluate the heart without interrupting chest compression. If this view is not possible then the apical or parasternal approaches may be used during coordinated pulse checks lead by the resuscitation team leader. A four-chamber view is used in this protocol as it allows for ease of comparison between the different chambers in the heart, facilitating the diagnosis of hypovolemia, massive PE, and cardiac tamponade. Pneumothorax is diagnosed by identifying the lack of sliding sign and comet-tail artifact while looking in the sagittal plane at the second intercostal space of the midclavicular line. For both the cardiac and lung views it is recommended to use a 2.5—5.0 phased array transducer probe. This allows the examiner to use the same probe for both lung, heart and if needed abdominal exam. This type of probe was used by Knudtson in his study involving ultrasound for the use of identifying pneumothorax as an addition to the FAST exam, and it yielded very a high accuracy in detecting pneumothorax, yet still remained useful in identifying the heart and abdominal organs. The protocol is best described in diagram form (Figure 8). Pulseless patients are treated with standard resuscitative protocol. After the monitor is attached patients are divided into two groups: arrhythmogenic (i.e. ventricular fibrillation and ventricular tachycardia) and non-arrhythmogenic (i.e. massive PE, hypovolemia, tension pneumothorax, etc.) cardiac arrest. Arrhythmogenic patients are treated with electrical cardioversion, but non-arrhythmogenic patients are then examined with the C.A.U.S.E. protocol to exclude readily reversible causes for the cessation of the circulation. The cardiac view is the first performed as this gives the potential to diagnose one of the three conditions in a single view (massive PE, cardiac tamponade, and hypovolemia), and this view takes the least time, meaning less interference with resuscitation as possible. If the results of the cardiac view are inconclusive the pulmonary views are attempted as these use approximately 30 s per side and diagnose only one condition, pneumothorax. If these studies are negative alternate causes of the arrest are considered as described by

![Diagram demonstrating ultrasound findings observed in pneumothorax and comparing these to findings of normal lung.](image-url)
Figure 8  Flow diagram demonstrating use of C.A.U.S.E. protocol in patients with cardiac arrest.

Figure 9  Characteristic image of IVC diameter in a patient without hypovolemia.

Figure 10  Characteristic image of IVC diameter in a patient with hypovolemia.
Hughes in order of frequency and ease of reversibility (i.e. electrolyte and metabolic disturbance, massive hypothermia, massive myocardial infarction, and drugs or toxins). 3 If one encounters an abnormal image on examination of the four chambers of the heart, one may attempt further confirmatory views with the ultrasound to make the diagnosis more clear (i.e. the finding of collapsed right and left ventricles should be followed by sonographic evaluation of the IVC and abdominal aorta) (Figures 9 and 10).

Conclusion

Ultrasound is currently the only radiographic modality with the potential to guide management in real time, at the bedside, during cardiac arrest without interfering with resuscitation. This literature review justifies the need for further study of ultrasound in the setting of cardiac arrest and also demonstrates that implementation of sonography into patient-care provides substantial potential benefits to patients and clinicians alike. As technology and training improve it will become easier to incorporate ultrasound into the care of patients in need of resuscitation (Figure 11). The reviewers included a proposed protocol to add organization and structure to a clinical scenario that has the potential for chaos. The protocol is an attempt to incorporate the most clinically relevant information in the literature on the applications of ultrasound use for cardiac arrest in an organized manner for clinical application. The hope is that this protocol will foster future study in the area of sonographic diagnosis during cardiac arrest, and eventually reduce the time required for emergency providers to determine the etiology of a cardiac arrest and thus decrease the time between arrest and appropriate therapy.

Conflict of interest

None.

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