American Journal of Emergency Medicine 99 (2026) 176–187

Contents lists available at ScienceDirect

American Journal of Emergency Medicine

journal homepage: www.elsevier.com/locate/ajem

Emergency medicine updates: Point-of-care ultrasound in cardiac arrest

Brit Long, MD [a,*], Robert James Adrian, MD [b], Michael Gottlieb, MD [c]

[a] Department of Emergency Medicine, University of Virginia Medical Center, Charlottesville, VA, USA
[b] Department of Emergency Medicine, Harvard Medical School, Massachusetts General Hospital, Brigham and Women's Hospital, Boston, MA, USA
[c] Department of Emergency Medicine, Rush University Medical Center, Chicago, IL, USA

ARTICLE INFO

Article history:
Received 29 July 2025
Received in revised form 9 September 2025
Accepted 11 September 2025

Keywords:
Cardiac arrest
Return of spontaneous circulation
Resuscitation
Cardiopulmonary resuscitation
Compressions
POCUS
Ultrasonography
Ultrasound
Point-of-care

ABSTRACT

Introduction: Cardiac arrest is a commonly managed condition in the emergency department (ED). Point-of-care ultrasound (POCUS) has demonstrated utility in multiple components of cardiac arrest.
Objective: This paper summarizes evidence-based updates concerning the use of POCUS in cardiac arrest.
Discussion: POCUS can be used for both cardiac and non-cardiac applications. Common cardiac assessments include the evaluation of pericardial effusion and tamponade physiology, right ventricular dilation, occult ventricular fibrillation, and optimizing chest compressions. Non-cardiac applications include the assessment of intraperitoneal free fluid, aortic pathology, hypovolemia, endotracheal tube position, and pneumothorax. In addition, POCUS can evaluate for the presence or absence of a pulse more quickly and accurately than manual palpation. POCUS can also guide prognosis by assessing cardiac activity.
Conclusions: An understanding of literature updates focused on POCUS can improve the ED care of patients in cardiac arrest.

1. Introduction

Out-of-hospital cardiac arrest (OHCA) is a significant cause of morbidity and mortality, accounting for over 400,000 deaths in adults per year in the United States and a survival to discharge rate of less than 10 % [1-4]. The management of cardiac arrest requires rapid and focused interventions, including high-quality cardiopulmonary resuscitation (CPR) and defibrillation in those with shockable rhythms [4-7]. Often, diagnosis of an underlying etiology can be challenging due to the limited history and examination, limiting the ability to perform tailored therapy. Point-of-care ultrasound (POCUS) is commonly used in the emergency department for a variety of applications. While the first reported use of POCUS in cardiac arrest by emergency medicine was in 1988 [8], the expansion of POCUS in this setting has rapidly expanded over time [9]. Despite this, uptake has been variable in practice [10], and there is a critical need to summarize and review the current role of POCUS in cardiac arrest.

This review is part of a series evaluating components of cardiac arrest management [11-15]. This manuscript will focus on the use of POCUS in patients with cardiac arrest.

* Corresponding author at: Department of Emergency Medicine, University of Virginia, 200 Jeanette Lancaster Way, Charlottesville, VA 22903, USA.
E-mail address: Brit.long@yahoo.com (B. Long).

2. Discussion

2.1. What are the major cardiac applications of POCUS in cardiac arrest?

There are several diagnostic applications for POCUS in cardiac arrest. Cardiac applications are typically performed during pauses in compressions (unless using a transesophageal echocardiography [TEE] probe) [16]. One of the most common applications of POCUS in cardiac arrest is the echocardiographic assessment. This can include assessment for cardiac tamponade, right ventricular (RV) dysfunction, and occult ventricular fibrillation.

2.1.1. Pericardial effusion and cardiac tamponade

A 2016 multicenter study reported pericardial effusion was present in up to 4 % of cardiac arrest patients [17]. In trauma patients, another study found 10 % of cardiac arrest cases may be due to cardiac tamponade [18]. Clinicians performing echocardiography in cardiac arrest should first evaluate for effusion. While larger effusions are more commonly associated with right side chamber collapse (i.e., ultrasonographic cardiac tamponade), the rate at which the effusion develops and the pericardial compliance significantly impact the development of tamponade physiology [19-22]. For example, a 50-mL effusion that rapidly accumulates may overcome the stretch limit of the visceral pericardium and lead to tamponade [23,24]. Due to the steep pericardial pressure-volume relationship in this setting, drainage of even a few milliliters of the pericardial

https://doi.org/10.1016/j.ajem.2025.09.021
0735-6757/

effusion can relieve the tamponade [19,25]. One study of cardiac arrest patients undergoing pericardiocentesis for suspected tamponade demonstrated a 15 % survival rate, compared to 1 % of all other patients in cardiac arrest [17].

If cardiac POCUS can be performed just prior to arrest, clinicians should evaluate for diastolic RV collapse (sensitivity 48–60 %, specificity 75–90 %), systolic right atrial collapse (50–100 % sensitive, 33–100 % specific), plethoric IVC (95–97 % sensitive),or sonographic pulsus paradoxus [26-41]. The lack of right side chamber collapse on transthoracic ultrasound is associated with over a 90 % negative predictive value for tamponade [42]. However, right side chamber collapse is unreliable in determining whether an effusion is responsible for the hemodynamic compromise when the patient is already in cardiac arrest [16].

2.1.2. Pulmonary embolism and right ventricular dysfunction

Pulmonary embolism (PE) may be the cause of 2–13 % of cardiac arrest cases [17,30,43-46]. Transthoracic echocardiography findings that are associated with PE include RV dysfunction (enlarged RV, septal dyskinesia, 'D sign') and right-sided clot-in-transit [31,47-50]. However, RV dilation found on POCUS is common in cardiac arrest due to other conditions such as hyperkalemia, hypoxemia, hypovolemia, myocardial infarction, and arrhythmia [48-53]. A 2000 prospective observational study of 25 patients with cardiac arrest undergoing TEE found 14 patients had enlarged RV, but only 9 had PE confirmed by TEE or autopsy [53]. A 2005 study evaluated ventricular dimension with magnetic resonance imaging among six swine receiving 30 min of untreated VF. Researchers found that mean RV volume increased by 29 % within the first minute of untreated VF [52]. A 2016 animal study evaluating 19 swine found early acute dilation of the RV (within 1.5 min) when the swine were subjected to hypoxia [50]. A 2017 study evaluating 24 swine with cardiac arrest due to PE, hypoxia, or arrhythmia found RV dilation was greatest in PE (32 mm; 95 % CI 29 to 36), but it was also present in hypoxia (23 mm; 95 % CI 20 to 27) and primary arrhythmia (25 mm; 95 % CI 22 to 28) [49]. A further study of 30 swine with cardiac arrest from hypovolemia, hyperkalemia, and arrhythmia found RV dilation was present no matter the cause of arrest [48]. In patients with massive PE, the greatest severity of septal dyskinesia typically occurs early in the cardiac arrest, but it may decrease over time as the arrest progresses [48-50]. These findings may also be found in patients with chronic RV dysfunction (e.g., pulmonary hypertension), though these patients usually have a significantly thickened RV free wall (> 5 mm diameter) from hypertrophy [31,54,55]. Therefore, while POCUS may reveal RV dysfunction and enlargement, this is a non-specific finding and should not be relied upon to diagnose PE in cardiac arrest or the initial post-return of spontaneous circulation (ROSC) period [16,47-49].

A right-sided clot-in-transit is another commonly discussed finding for suspected PE. However, intracardiac thrombi can occur in cardiac arrest due to the low-flow state, with literature suggesting thrombus formation can occur within 6 min following the onset of cardiac arrest [56,57]. Thus, if RV dysfunction or right-sided clot-in-transit is found on POCUS early in cardiac arrest with a suggestive history of PE such as dyspnea or pleuritic chest pain prior to the development of the cardiac arrest or if a deep vein thrombosis (DVT) is present, then PE may be the cause of arrest [58-61]. However, POCUS findings of RV dilation or thrombus alone are insufficient for the diagnosis of PE.

2.1.3. Ventricular fibrillation

Ventricular fibrillation (VF) has been reported to be present in 23–80 % of out-of-hospital cardiac arrests (OHCA) [62-66]. While VF is typically diagnosed on the cardiac monitor during cardiac arrest, fine or occult VF may be difficult to diagnose if pads are not in appropriate position or if there is increased soft tissue between the pads and the heart [16]. POCUS can evaluate for occult VF which may be mistaken for asystole or pulseless electrical activity (PEA).

VF present on ultrasound but not present on ECG is termed occult VF, and literature suggests that patients with occult VF may have similar outcomes including survival when compared to patients with VF present on ECG [67-72]. A 2025 multicenter prospective study including 811 patients found 5.3 % had occult VF only visible on echocardiography. On ECG, 81.4 % demonstrated PEA and 18.6 % asystole, and occult VF was less likely to be defibrillated. However, ROSC was not statistically different for occult VF compared with ECG VF (39.5 % vs 24.8 %; OR, 2.26; 95 % CI 0.87 to 5.9), and survival to hospital discharge was also no different (7.0 % vs 5.4 %; OR, 3.6; 95 % CI 0.63 to 19.2) [70]. Another 2025 study evaluating occult VF versus ECG VF found occult VF was present in 3.2 % (22 of 685) of patients during the first pause in compressions, but none of these patients were immediately defibrillated. On an ensuing pause in compressions, 50 % (11 of 22) of patients with occult VF were defibrillated. There was no difference in survival to hospital admission in occult VF versus ECG VF [71]. Based on the available data, POCUS may be able to diagnose occult VF requiring defibrillation, and VF is associated with higher survival compared to patients with nonshockable rhythms [69].

2.1.4. Evaluating cardiac movement

POCUS has demonstrated utility in evaluating for organized cardiac contractions in cardiac arrest. One study found PEA was reported in 22 % of OHCA and 11 % of in-hospital cardiac arrests (IHCA) [1]. Several studies report that 6–58 % of patients in electrocardiographic (ECG) PEA actually have cardiac movement on POCUS [67,73-75]. In patients with asystole on ECG, 4–12 % of patients have cardiac movement on POCUS [67,74,76-78]. During PEA or asystole, identifying organized cardiac contraction on POCUS is a favorable sign for prognosis and survival, but may not indicate adequate brain perfusion [79,80]. Cardiac movement should prompt the physician to evaluate for other signs of ROSC, such as an increase in end-tidal CO_2 ($ETCO_2$) to >20 mmHg [81,82], a persistent high-quality waveform on SpO_2 [83], presence of a pulse visible in the carotid or femoral arteries on POCUS [79,80,84-88], or a peak systolic velocity > 20 cm/s which was correlated to a systolic blood pressure (SBP) ≥ 60 mmHg [89] (Section 2.3). For the advanced sonographer evaluating the quality of the cardiac movement may be worth considering. Arterial line placement may be considered if not already done. If the clinician considers this ROSC, the patient is likely in a profound shock state and may necessitate vasopressors [79,80]. For the advanced sonographer evaluating the quality of the cardiac movement may provide additional information. Ultimately, early defibrillation and high-quality chest compressions are the most critical factors to cardiac arrest survival so continuing with chest compressions would not be unreasonable and may be the safest option.

2.2. What are the major non-cardiac applications of POCUS in cardiac arrest?

Non-cardiac applications of POCUS in cardiac arrest can frequently be performed during compressions. There are several protocols available for use in cardiac arrest or decompensating patients (Table 1) [90-105]. While the specific elements of the protocols can differ, they all share the common theme of utilizing a systematic approach to evaluate for an underlying etiology of the cardiac arrest. (See Figs. 1–11.)

2.2.1. Abdominal pathology

POCUS can also be used in the evaluation for abdominal free fluid and other intra-abdominal pathology. Emergency clinician-performed POCUS demonstrates sensitivity ranging between 27 and 100 % and specificity 55–100 % for significant free abdominal fluid, though this is higher when performed by emergency clinicians with POCUS experience [104,105]. Evaluation for fluid in the hepatorenal recess (Morison's pouch), perisplenic space, and pelvis can change management if return of spontaneous circulation is obtained, particularly in those with history of trauma or concern for ruptured ectopic pregnancy [106-108]. POCUS

Table 1
POCUS Protocols [90-105].

Protocol Name	Components
Cardiac Arrest Sonographic Assessment (CASA)	- Cardiac (cardiac tamponade, right heart strain, cardiac activity) - Lung (pneumothorax) - FAST
Cardiac Arrest Ultrasound Examination (CAUSE)	- Cardiac (cardiac tamponade, hypovolemia, massive PE) - Lung (pneumothorax)
Core Ultrasound in Resuscitation (CURE)	- Noncardiac (FAST, AAA, DVT, confirm ETT position, pneumothorax) - Cardiac TTE (cardiac contractility, ventricular arrhythmia, aortic emergency, intracardiac thrombus, maximal compression site, hypovolemia) - Post-ROSC TEE (preload, cardiac and valvular function, procedural guidance)
Focused Echocardiographic Evaluation in Life Support (FEEL)	- Cardiac (cardiac activity, ventricular function, right ventricular dilatation, and pericardial effusion)
Focused Echocardiographic Evaluation in Resuscitation (FEER)	- Cardiac (cardiac activity, pericardial effusion/cardiac tamponade, hypovolemia, and massive PE)
Pulseless Electrical Activity or Pulmonary-Epigastric-Abdominal	- Cardiac (pericardial effusion, cardiac activity, left ventricular size/hypertrophy/contractility, right ventricular size/contractility, IVC filling) - Lung (pneumothorax, pleural effusion, pulmonary edema) - Abdomen and other (thoracic and abdominal aortic aneurysm or dissection, peritoneal effusion, bowel obstruction or perforation, DVT)
Point-of-Care Ultrasound in Cardiopulmonary Arrest (POCUS-CA)	- Cardiac (cardiac activity, chest compression efficacy, pericardial effusion/cardiac tamponade, PE) - Lung (pneumothorax) - Abdominal (peritoneal effusion, AAA) - Femoral (DVT)
Rapid Cardiac POCUS in Pulmonary-Epigastric-Abdominal Arrest	- Cardiac (contractility, pericardial effusion, right ventricular dilation with small dynamic left ventricle, underfilled right ventricle with the small dynamic left ventricle)
Rapid Ultrasound for Shock and Hypotension (RUSH)	- Heart (ejection fraction, pericardial effusion, RV distension) - IVC (diameter and respiratory variation) - Morrison's Pouch/FAST (free intra-adominal fluid) - Aorta (aneurysm, dissection) - Pneumothorax
Reversible Causes in Cardiovascular Collapse at the Emergency Department Using Ultrasonography (REVIVE-US)	- Cardiac (cardiac activity, cardiac tamponade) - FAST - Aorta (dissection, aneurysm) - DVT - Lung (pneumothorax) - Post-ROSC Cardiac (contractility, right ventricular dilation, regional wall motion abnormalities)
Sequential Emergency Scanning Assessing Mechanism or Origin of Shock of Indistinct Cause (SESAME)	- Lung (pulmonary edema, pneumothorax) - DVT - Abdomen (peritoneal effusion) - Cardiac (cardiac tamponade, contractility, right ventricular dilatation, ventricular fibrillation)
Sonography in Hypotension and Cardiac Arrest (SHoC)	- Cardiac (cardiac tamponade, right ventricular dysfunction, cardiac activity, ventricular size) - Lung (pneumothorax, pleural effusion) - IVC (diameter and respiratory variation) - Airway (ETT confirmation) - DVT - Abdomen (AAA, peritoneal effusion)
Ultrasound Circulation-Airway-Breathing (US-CAB)	- Cardiac (contractility, cardiac tamponade, right ventricular dilatation, septal dyskinesia, right-sided chamber flattening suggestive of hypovolemia) - IVC (diameter and respirophasic collapsibility) - Trachea (ETT confirmation) - Lung (pneumothorax, single lung intubation)

can also evaluate for ruptured abdominal aortic aneurysm (AAA) and aortic dissection. One systematic review reported preoperative cardiac arrest in 13 % of patients with ruptured AAA [109]. An intimal flap of the aorta is diagnostic of dissection [107,108]. Systematic review and meta-analysis data report an incidence of acute aortic dissection causing OHCA in 4 % of patients [110], and POCUS may demonstrate a positive predictive value approaching 100 % of POCUS for diagnosing aortic dissection in cardiac arrest [108-110].

2.2.2. Endotracheal tube placement

POCUS can confirm placement of an endotracheal tube following intubation, which is of particular importance in cardiac arrest patients, in whom end-tidal capnography is less accurate due to reduced cardiac output and pulmonary blood flow [111-116]. Absent or low end-tidal capnography can be due to poor circulation, hypothermia, ventilation/perfusion mismatch, or prolonged arrest time [117]. POCUS is 99 % sensitive and 97 % specific for ETT confirmation, and evaluation can be performed during chest compressions [118]. POCUS findings have shown consistently high accuracy regardless of ETT size, transducer type, and technique [118-125]. POCUS can also be used to assess for appropriate ETT depth, as well as evaluate for mainstem intubation [16,126].

2.2.3. Pneumothorax

Pneumothorax has been reported in 1–4 % of cardiac arrests in the intensive care unit and as high as 13 % of cardiac arrest cases in a single trauma center [18,127]. POCUS can rapidly diagnose pneumothorax in the supine patient by placing the probe along the midclavicular line in the third intercostal space [128-131]. It can also determine the pleural interface depth to ensure a needle used for decompression can reach the pleural cavity [128-131]. POCUS demonstrates a sensitivity over 91 % and specificity of 99 % for identifying pneumothorax in non-cardiac arrest patients [128]. Importantly, in the recently intubated cardiac arrest patient (in whom lung pulse is not present), right mainstem intubation can create a false positive finding.

2.2.4. Deep vein thrombosis

POCUS can diagnose DVT with 2-point, 3-point, or whole leg compression, with sensitivities over 88 % and specificities over 92 % in non-cardiac arrest patients [60,132-135]. This examination can be

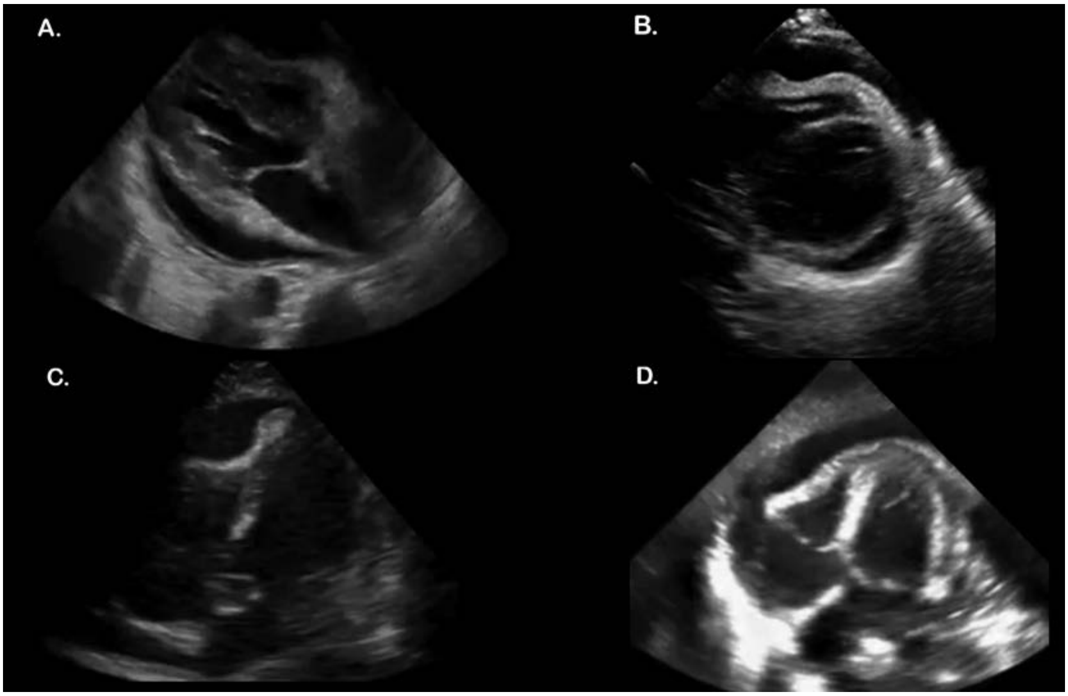

Fig. 1. Pericardial effusion and cardiac tamponade. A. Parasternal long-axis; B. Parasternal short-axis; C. Apical 4-chamber; D. Subxiphoid long-axis. *Images courtesy of Stephen Alerhand, MD (A, C, D) and Lauren Ann J. Selame, MD (B).*

rapidly performed with the knee in mild flexion and the hip slightly rotated laterally, and it does not require the cessation of compressions [60,132-135]. POCUS diagnosis of DVT in the setting of cardiac arrest may reflect PE as the underlying etiology of cardiac arrest, which can change management (e.g., thrombolytic administration).

2.2.5. Volume status

POCUS can suggest hypovolemia with underfilled, easily collapsible ventricles and a small and significantly collapsible inferior vena cava (IVC) [16,101]. IVC diameter and variability with respiration demonstrates moderate accuracy in predicting central venous pressure in

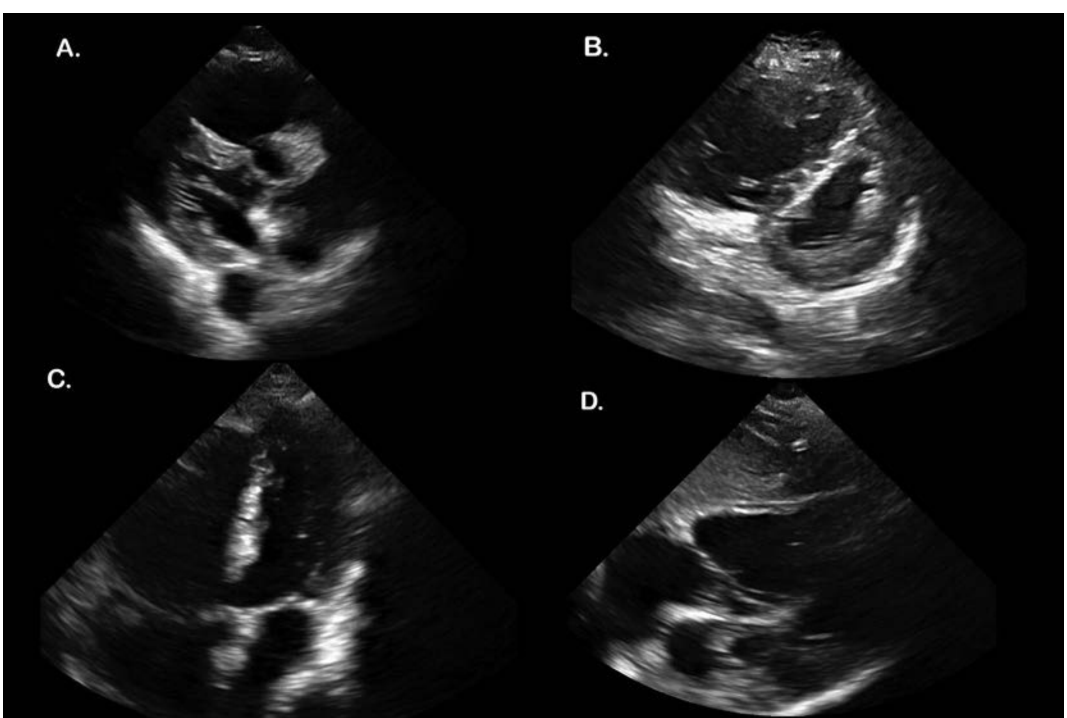

Fig. 2. Right ventricular dilation and pulmonary embolism. A. Parasternal long-axis; B. Parasternal short-axis; C. Apical 4-chamber; D. Subxiphoid long-axis. *Images courtesy of Peter Alsharif, MD (A, C, D) and Robert James Adrian, MD (B).*

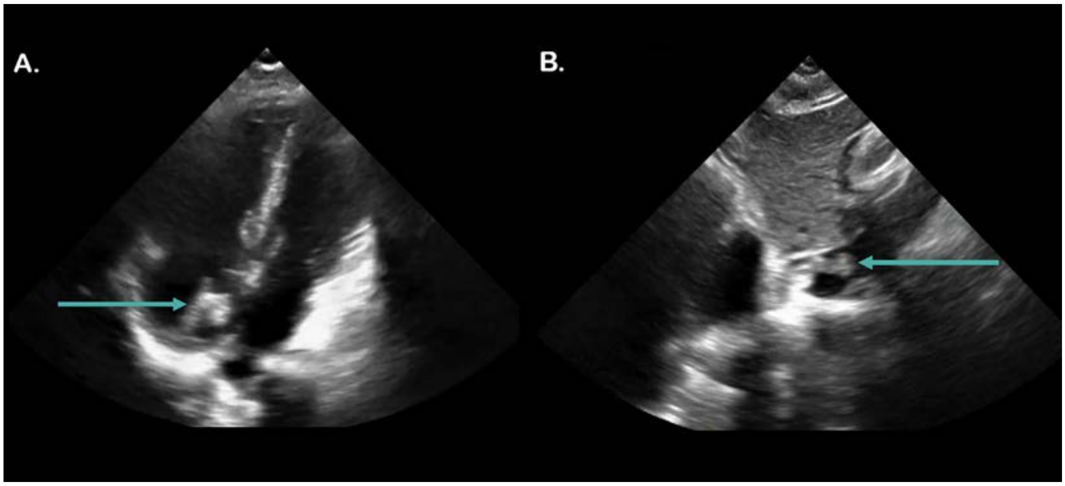

Fig. 3. Clot-in-transit. A. Arrow indicates mobile clot in the right atrium shown in apical 4-chamber; B. Arrow indicates mobile clot in the inferior vena cava and right atrium. *Images courtesy of Stephen Alerhand, MD.*

non-arrest situations; however, in patients in cardiac arrest undergoing positive pressure ventilation, the IVC is likely to be dilated [16,101]. Thus, there is limited diagnostic utility in evaluating the IVC during cardiac arrest, though if the IVC is small (i.e., < 1 cm) and has a high degree of collapsibility, volume resuscitation may be warranted [16,101].

2.3. How does ultrasound compare to manual palpation for pulse checks?

During cardiac arrest, a pulse and rhythm check is performed every two minutes [11,14]. Assessment for a pulse typically involves manual palpation [2-5,89]. However, literature suggests that manual pulse checks during cardiac arrest demonstrate limited accuracy (as low as 40 %) and sensitivity (54–85.6 %), has poor inter-rater reliability, and takes time to perform, potentially delaying compressions [89,136-144].

In contrast, POCUS can rapidly evaluate for the presence of a pulse with B-mode or color Doppler, as well as assess the strength of a pulse with peak systolic velocity (PSV) using pulsed-wave Doppler [87,89,143,144]. Pulse detection is generally performed via the central vessels, typically the carotid or femoral arteries, with multiple studies suggesting this is fast, reliable, accurate, and easily learned by emergency clinicians [87,89,136,145-150]. To minimize delays in chest compressions, the clinician should locate the carotid or femoral artery with POCUS while compressions are ongoing. During the pause, apply compression to enhance pulsatility. This can also be augmented by adding color or pulsed-wave Doppler.

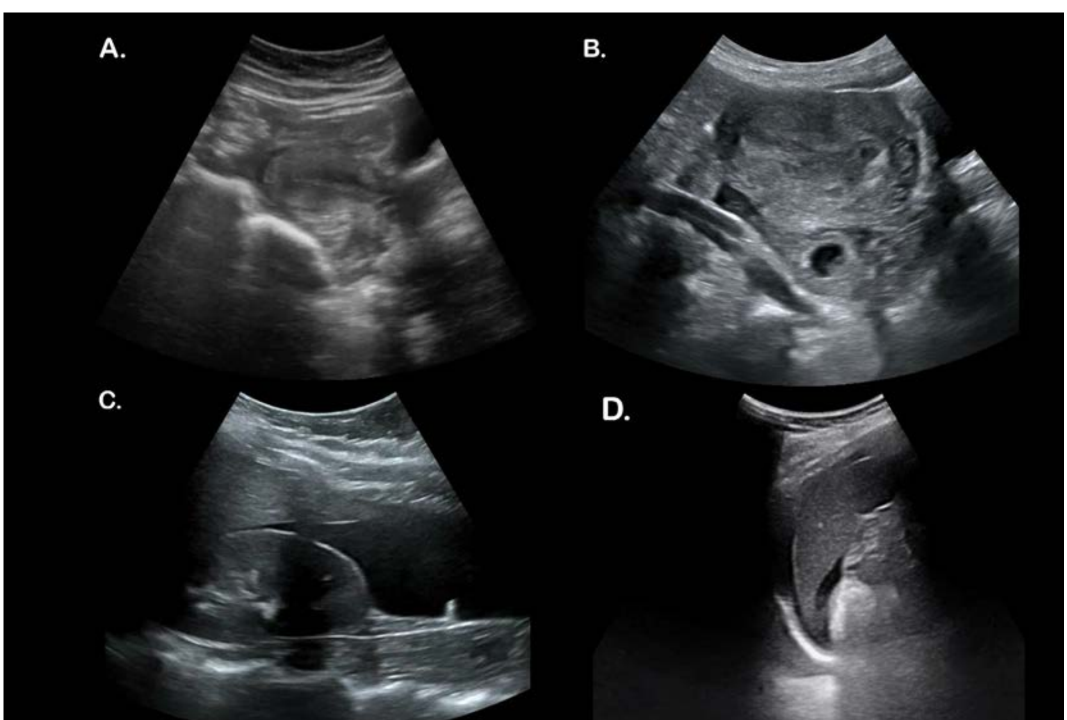

Fig. 4. Peritoneal free fluid in ruptured ectopic pregnancy. A. Transverse pelvis; B. Sagittal pelvis; C. Right upper quadrant; D. Left upper quadrant. *Images courtesy of Stephen Alerhand, MD (A), Megana Gupta, MD (C), Robert James Adrian, MD (B, D).*

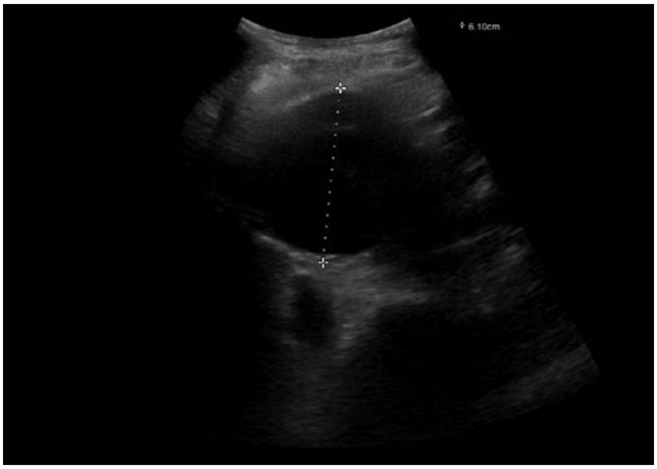

Fig. 5. Cardiac arrest with ruptured abdominal aortic aneurysm. *Image courtesy of Kris Walpot, MD.*

One study evaluating POCUS during chest compressions in cardiac arrest found pulse checks never exceeded 10 s, with an average POCUS pulse check time of 1.62 s (95 % CI 1.14 to 2.14 s) [146]. One challenge of this qualitative assessment is that it does not provide information concerning systemic perfusion. A 2022 prospective cross-sectional study evaluated Doppler ultrasound versus manual palpation to detect any pulse in patients in cardiac arrest with an arterial line [89]. Of the 54 patients and 213 pulse checks, Doppler ultrasound demonstrated higher accuracy for detection of any pulse (95.3 % vs. 54.0 %; $p < 0.001$) [89]. An emerging qualitative and quantitative strategy for assessing perfusion is using pulsed-wave Doppler to detect PSV. PSV has been demonstrated to correlate with SBP, and thus it may have a role in detecting ROSC during rhythm checks in patients without an arterial line. A 2022 prospective cross-sectional study evaluated PSV compared with manual pulse detection [89]. Authors found that there was a strong correlation between PSV and SBP (Spearman correlation coefficient = 0.89; $p < 0.001$), and the optimal cut-off for PSV associated with an SBP ≥ 60 mmHg was 20 cm/s. The accuracy of this PSV threshold to detect an SBP ≥ 60 mmHg was also higher than manual palpation (91.4 % vs. 66.2 %; $p < 0.001$) [89]. A 2023 study of 35 studies with 111 pulse checks found a higher correlation between PSV and SBP compared to $ETCO_2$ and SBP (0.71 vs 0.31; $p < 0.001$), and the diagnostic accuracy of PSV ≥ 20 cm/s for detecting SBP > 60 mmHg was 89 % (95 % CI 82 % to 94 %) versus 59 % (95 % CI 49 % to 68 %) and 58 % (95 % CI 48 % to 67 %) for $ETCO_2$ ≥ 20 and ≥ 25 mmHg, respectively [151]. To perform this evaluation, the clinician centers the sampling gate within the artery in the short or long axis and measures velocity.

2.4. Can ultrasound confirm the effectiveness of chest compressions?

Cardiopulmonary resuscitation with high-quality chest compressions is essential in patients with cardiac arrest. This involves placing the heel of the compressor's hand over the lower portion of the sternum and the other heel of the hand over the first [2,3,11,14]. A compression depth of 5–6 cm is recommended. This positioning and depth target the left ventricle [2,3,11,14]. However, despite placement in the typical recommended location, individual anatomy can vary resulting in the area of maximal compression including either the aortic root or left ventricular outflow tract (LVOT) as opposed to the left ventricle, which may impede forward blood flow and reduce the likelihood of obtaining ROSC. A retrospective study of cardiac arrest patients found the most common area of maximal compression was the left atrium (50.7 %), followed by the ascending aorta (16.7 %) [152]. Another study of 84 patients with cardiac arrest undergoing CPR found that the area of maximal compression was over the aortic root or LVOT in one-third of patients, while a third study of 33 patients found the area of maximal compression was over the aortic root or LVOT in 53 % of cases [153]. A 2009 study evaluating transesophageal echocardiography (TEE) in 34 cardiac arrest patients undergoing CPR found the area of maximal compression was the aorta in 20 patients (59 %), followed by the LVOT in 14 patients (41 %) [154]. Closure of the LVOT is associated with decreased

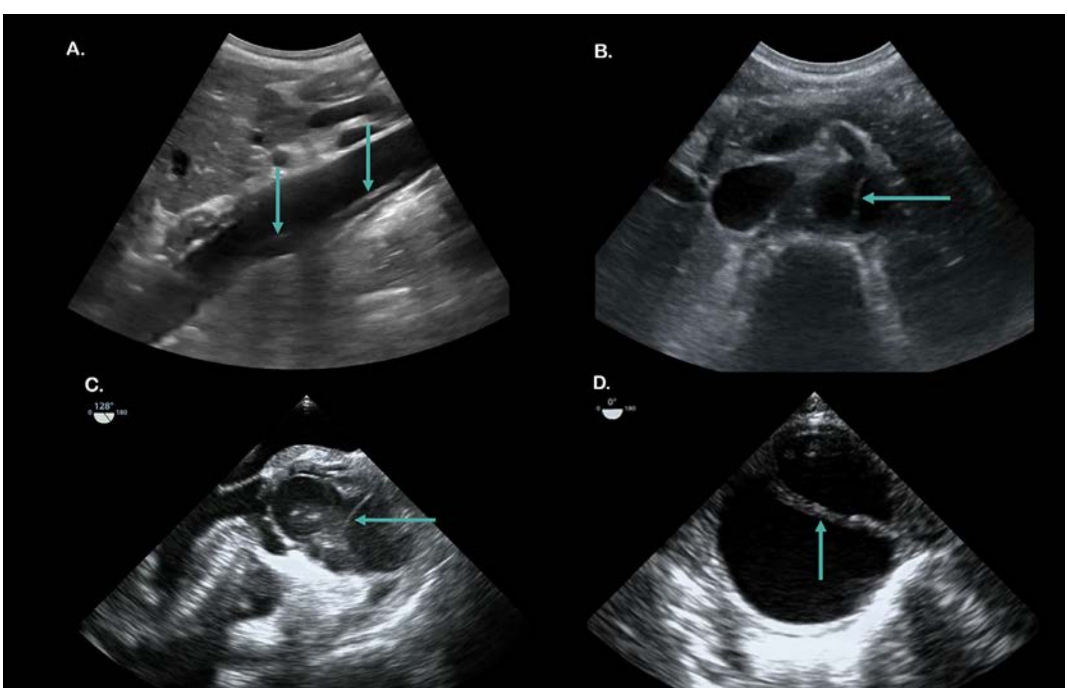

Fig. 6. Aortic dissection. Arrows indicate intimal dissection flap. A. Abdominal aortic dissection longitudinal axis; B. Abdominal aortic dissection short axis. C. Thoracic aortic dissection in transesophageal midesophageal long-axis aorta; D. Thoracic aortic dissection in midesophageal short-axis aorta. *Images courtesy of Stephen Alerhand, MD (A, B) and Adi Osman, MD (C, D).*

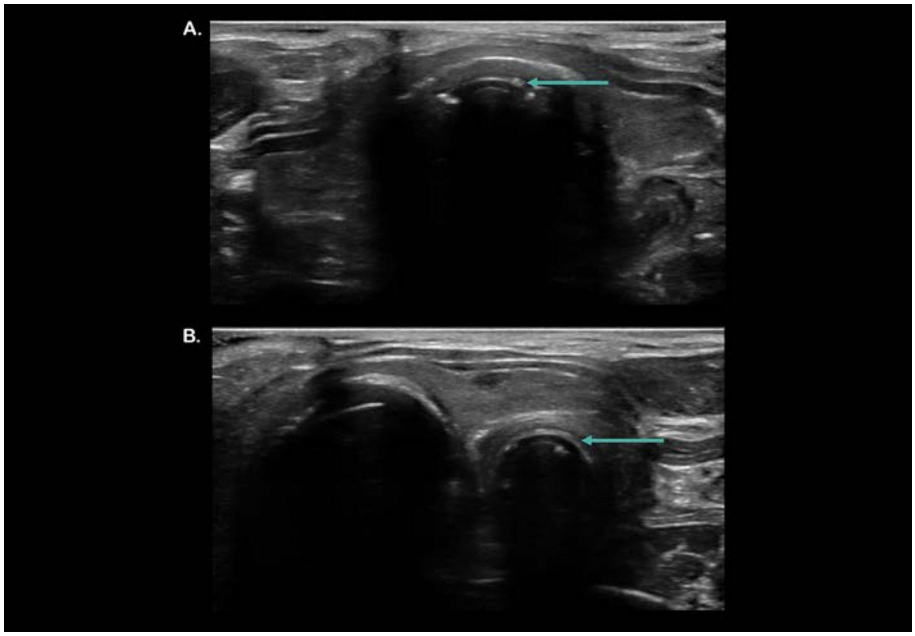

Fig. 7. Endotracheal tube placement. Arrows indicate endotracheal tube. A. Endotracheal tube correctly placed in trachea; B. endotracheal tube incorrectly placed in the esophagus. *Images courtesy of Michael Gottlieb, MD.*

survival. A retrospective study evaluating TEE in 19 patients with cardiac arrest found that all survivors had an open LVOT [155].

2.5. How can interruptions in chest compressions be minimized when using ultrasound in cardiac arrest?

High-quality chest compressions and maximizing chest compression fraction (CCF) are integral in cardiac arrest management, with guidelines recommending that pauses last no longer than 10 s to maintain cerebral and cardiac perfusion [2,3,6,11,14]. There is concern that POCUS in cardiac arrest may lead to prolonged interruptions in compressions, with several retrospective studies finding a 4–8 s increase in the duration of pauses when POCUS was used [90,156,157]. A prospective study evaluating pre-pause imaging, which involved pre-localizing the approximate POCUS window during CPR, found a decrease in CPR pauses with using pre-pause imaging [158]. The sonographic approach may also affect the time to image acquisition and quality. A 2022 multicenter RCT found the parasternal versus subxiphoid approach was associated with shorter time to acquisition (8.8 s, IQR 6.5–13.5 s versus (9.3 s, IQR 6.7–15.0 s) and higher image quality (3.86 vs. 3.54; $p < 0.0001$) [159]. There are several means of minimizing prolonged pauses, demonstrated in Table 2 [16].

2.6. What is the role of transesophageal echocardiography in cardiac arrest?

Transesophageal echocardiography (TEE) has demonstrated promise in cardiac arrest evaluation and management, and 2018 expert guidelines support a limited 3-view protocol for utilizing TEE in managing cardiac arrest [160]. TEE involves placing a transducer directly into

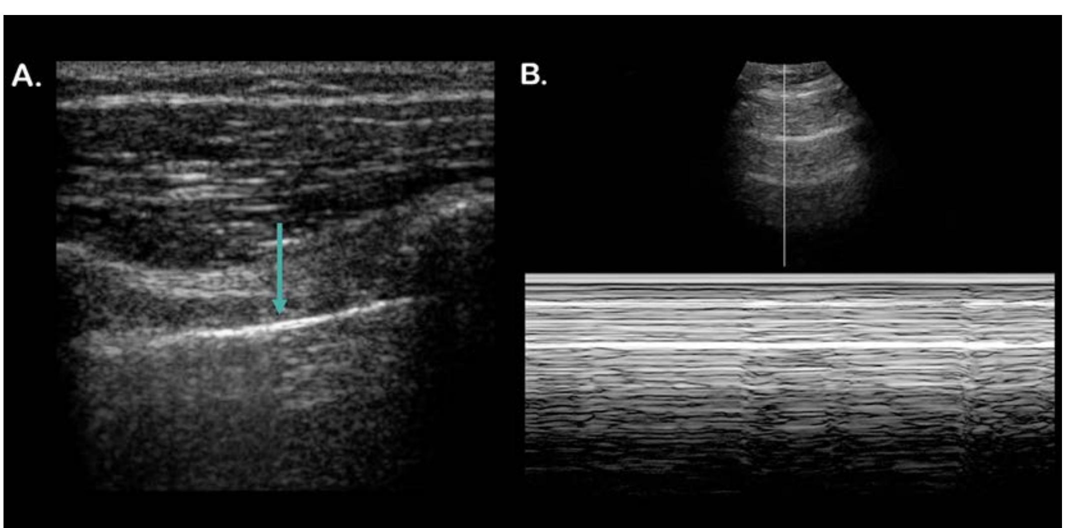

Fig. 8. Pneumothorax. A. Pneumothorax with an arrow indicating the lung point; B. Pneumothorax using M-mode. *Images courtesy of Robert James Adrian, MD (A) and Michael Gottlieb, MD (B).*

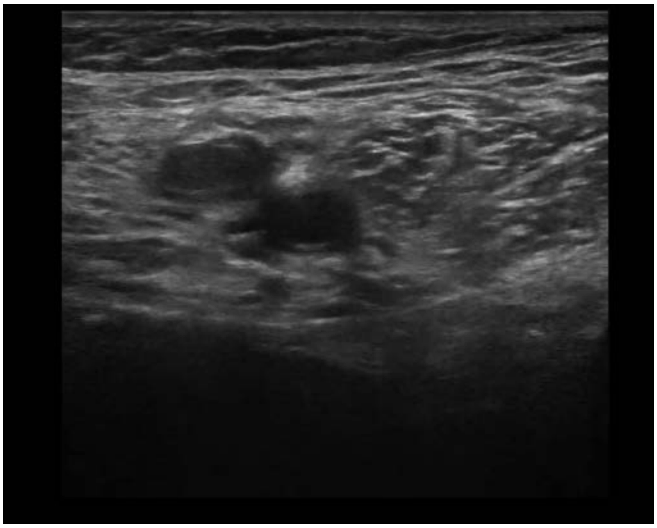

Fig. 9. Deep vein thrombosis in the femoral vein. *Image courtesy of Robert James Adrian, MD.*

the esophagus to visualize the heart, which offers several advantages over standard transthoracic POCUS. Benefits include that placement and obtaining images does not interfere with chest compressions, TEE shortens duration of rhythm checks, and TEE can evaluate the area of maximal compression during CPR and guide repositioning to avoid LVOT compression [160,161]. Additionally, TEE also avoids limitations due to gastric insufflation, lung pathology, or obesity. Ultimately TEE may allow providers to better evaluate for shockable rhythms, organized cardiac activity, left ventricular systolic function, chest compression location and quality, and responses to interventions [16,160,161]. A 2025 study with 811 patients in cardiac arrest found 43 (5.3 %) had occult VF on TEE [70]. Authors found those with occult VF had similar survival rates to those with ECG VF, suggesting a role for POCUS to diagnose and manage VF [70]. A 2021 systematic review found that TEE identified reversible etiologies of cardiac arrest in 41 % of patients [162], and literature suggests that emergency clinicians who are competent in TTE can perform TEE following a structured, short simulation training program [160,163-167].

There are several complications that have been reported with TEE. These can include oral or upper gastrointestinal injuries such dental injuries, jaw subluxation, pharyngeal/esophageal wall injury or perforation, pharyngeal/upper gastrointestinal bleeding, or dysphagia [168-171]. However, in trained personnel, TEE is safe, with a low rate of complications (rate of 0.2 %) [168-171]. Thus, for experienced clinicians, TEE serves as a valuable tool for the evaluation of patients in cardiac arrest.

2.7. What are prognostic applications of ultrasound in cardiac arrest?

The absence of cardiac activity via cardiac POCUS has been evaluated for prognostication in cardiac arrest. A 2017 meta-analysis including nontraumatic and traumatic cardiac arrest patients found that the absence of cardiac activity on POCUS had a negative likelihood ratio of 0.06 (95 % CI 0.01 to 0.39) for predicting ROSC. Spontaneous cardiac activity on POCUS demonstrated 95 % sensitivity (95 % CI 72 % to 99 %) and 80 % specificity (95 % CI 63 % to 91 %) in predicting ROSC [172]. A 2019 meta-analysis evaluated the use of POCUS in patients with atraumatic, nonshockable cardiac arrest and found the sensitivity of cardiac activity for predicting ROSC was 26.1 % (95 % CI 7.8 % to 59.6 %) in asystole compared with 76.7 % (95 % CI 61.3 % to 87.2 %) in PEA [173]. The presence of cardiac activity demonstrated an odds ratio (OR) of 10.30 (95 % CI 5.32 to 19.98) for survival to admission, and an OR of 8.03 (95 % CI 3.01 to 21.39) for survival to discharge. Absence of cardiac activity on POCUS was 92 % sensitive and 60 % specific for failing to achieve ROSC [173]. A 2021 meta-analysis with 8 studies evaluating POCUS for cardiac activity in traumatic cardiac arrest found the specificity was 98 % (95 % CI 13 % to 100 %) for predicting ROSC, and the sensitivity was 91 % (95 % CI 67 % to 98 %) for patients with no cardiac activity who failed to achieve ROSC [174]. The definition of cardiac activity varied among these studies, ranging from reported activity to organized left

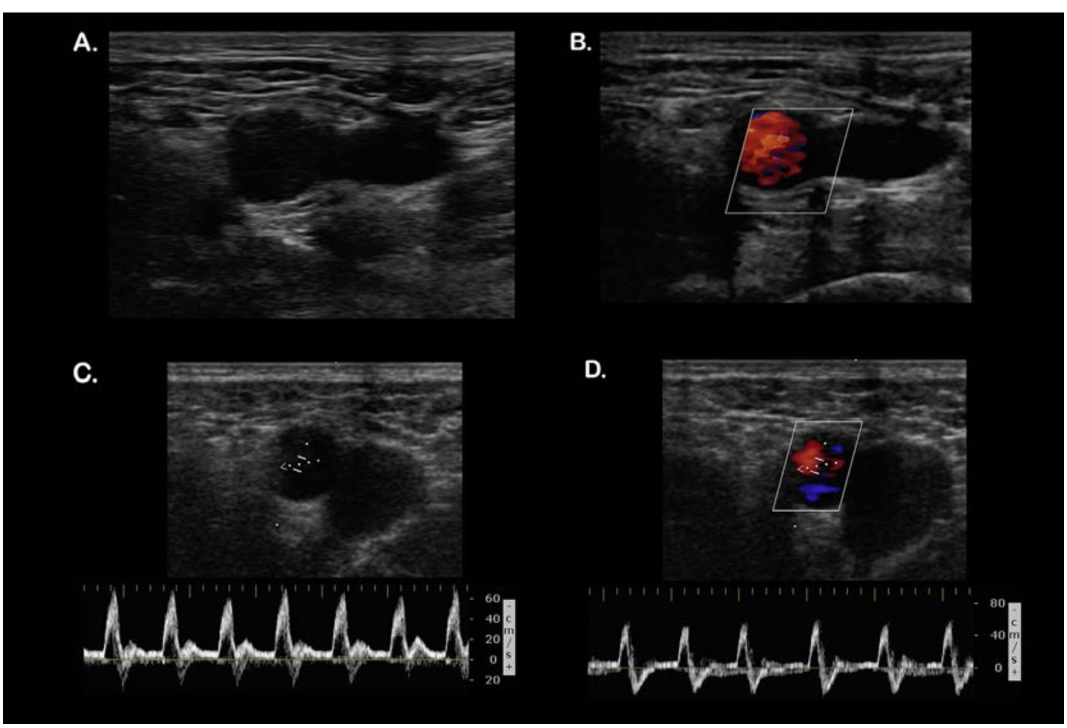

Fig. 10. POCUS pulse and peak systolic velocity of the right femoral artery. A. B-mode; B. Color Doppler; C. Pulsed-wave Doppler; D. Color Doppler, pulsed-wave Doppler. *Images courtesy of Robert James Adrian, MD.*

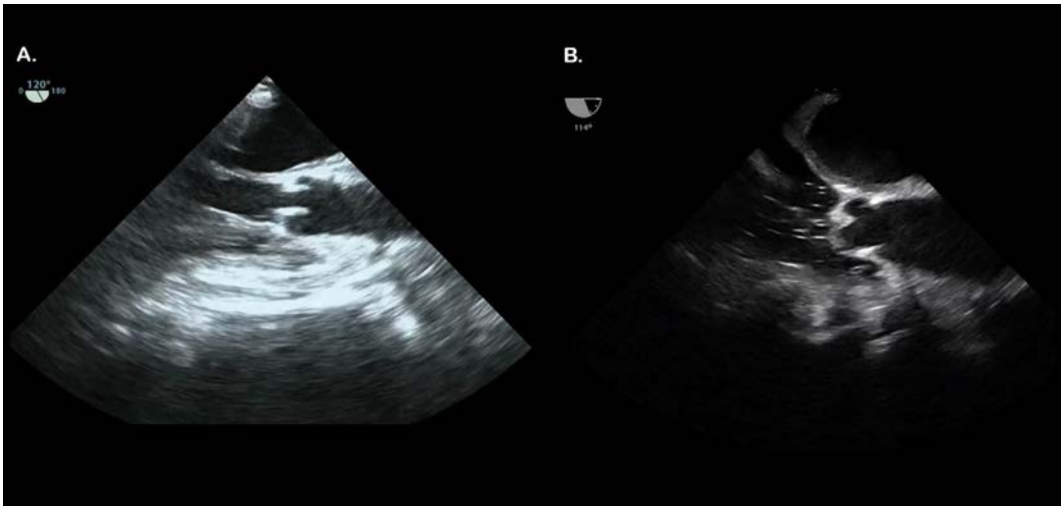

Fig. 11. Cardiac arrest with ongoing compressions using transesophageal echocardiography in midesophageal long-axis. A. Opening of the aortic valve suggesting appropriately positioned chest compressions over the left ventricle versus B. Non-opening of the aortic valve suggesting inappropriately positioned compressions over the left ventricular outflow tract/aorta. *Image courtesy of Stephen Alerhand, MD (A) and Felipe Teran, MD (B).*

ventricular contraction and visible valvular movement. Experts have proposed organized cardiac activity be defined as "movement of the myocardium with change in the size of the ventricular cavity and synchronized movement of the ventricular wall." [175]. While expert sonographers agree on the absence of cardiac activity with moderate-to-high interrater reliability, less experienced sonographers have lower interrater reliability [176,177]. Ultimately, POCUS may be used as an adjunct for prognostication, but it should not be used in isolation. The presence of cardiac activity is associated with improved odds of ROSC and survival to admission and discharge.

3. Conclusions

POCUS has demonstrated significant utility in cardiac arrest with both cardiac and non-cardiac applications. POCUS can be used to evaluate for pericardial effusion and tamponade physiology, right ventricular dilation, occult ventricular fibrillation, and quality and location of chest compressions. Non-cardiac applications include evaluation for free intra-abdominal fluid, aortic pathology, endotracheal tube position, and pneumothorax. Manual palpation for pulses is not accurate, and POCUS may also evaluate for the presence or absence of a pulse more quickly and accurately. TEE has demonstrated promise in cardiac arrest as well. Finally, POCUS may guide prognosis by evaluating for cardiac activity.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajem.2025.09.021.

Table 2
POCUS strategies to minimize chest compression pauses. Adapted with permission from Gottlieb et al. [16].

- The most experienced ultrasonographer should perform the US evaluation.
- The ultrasonographer should not be responsible for team management during the arrest.
- POCUS evaluating for other conditions that may contribute to the cardiac arrest should be completed during compressions, rather than during pauses.
- The POCUS transducer should be placed on the chest to obtain the optimal window before compressions are stopped, preferably using the parasternal long axis approach.
- The ultrasonographer should record a clip during the compression pause, followed by analysis of the clip when compressions have been restarted.
- The chest should be cleaned with a towel following the POCUS.
- A timer should count down from 10 s when compressions are stopped. The POCUS should be performed for no longer than 5 s to ensure compressions are restarted appropriately.

CRediT authorship contribution statement

Brit Long: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Conceptualization. **Robert James Adrian:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Formal analysis, Conceptualization. **Michael Gottlieb:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Formal analysis, Conceptualization.

Declaration of competing interest

None.
No AI program was used in the construction of this manuscript.

Acknowledgements

BL, RJA, and MG conceived the idea for this manuscript and contributed substantially to the writing and editing of the review. This manuscript did not utilize any grants, and it has not been presented in abstract form. This clinical review has not been published, it is not under consideration for publication elsewhere, its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

References

[1] Tsao CW, Aday AW, Almarzooq ZI, et al. American Heart Association Council on epidemiology and prevention statistics committee and stroke statistics subcommittee. Heart disease and stroke statistics-2023 update: a report from the American Heart Association. Circulation. 2023 Feb 21;147(8):e93-621. doi:10.1161/CIR.0000000000001123. Epub 2023 Jan 25. Erratum in: Circulation. 2023 Feb 21;147(8):e622.Virani SS, Alonso A, Aparicio HJ, et al. Heart Disease and Stroke Statistics—2021 Update. Circulation. 2021;143(8):e254–743.
[2] Merchant RM, Topjian AA, Panchal AR, et al. Part 1: executive summary: 2020 American heart association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation. 2020;142:S337.
[3] Panchal AR, Bartos JA, Cabañas JG, et al. Part 3: adult basic and advanced life support: 2020 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation. 2020;142(16 2):S366–468.
[4] Nolan JP, Maconochie I, Soar J, et al. Executive summary 2020 emergency cardiovascular care science with treatment recommendations. Resuscitation. 2020;156:A1–A22.

[5] Monsieurs KG, Nolan JP, Bossaert LL, et al. European resuscitation council guidelines for resuscitation 2015: section 1. Executive Summary Resuscitation. 2015; 95:1–80.
[6] Van Diepen S, Le May MR, Alfaro P, et al. Canadian cardiovascular society/Canadian cardiovascular critical care society/Canadian Association of Interventional Cardiology Clinical Practice Update on optimal post cardiac arrest and refractory cardiac arrest patient care. Can J Cardiol. 2024 Apr;40(4):524–39.
[7] Dreyfuss A, Carlson GK. Defibrillation in the cardiac arrest patient. Emerg Med Clin North Am. 2023 Aug;41(3):529–42.
[8] Mayron R, Gaudio FE, Plummer D, et al. Echocardiography performed by emergency physicians: impact on diagnosis and therapy. Ann Emerg Med. 1988;17 (2):150–4.
[9] Salerno A, Gottlieb M. Point-of-care ultrasound in the emergency department: past, present, and future. Emerg Med Clin North Am. 2024.;42(4) xvii-xxi.
[10] Smalley CM, Simon EL, Muir MR, Fertel BS. A real-world experience: retrospective review of point-of-care ultrasound utilization and quality in community emergency departments. West J Emerg Med. 2023;24(4):685–92.
[11] Long B, Gottlieb M. Emergency medicine updates: cardiopulmonary resuscitation. Am J Emerg Med. 2025 Mar 24;93:86–93.
[12] Long B, Gottlieb M. Emergency medicine updates: cardiac arrest medications. Am J Emerg Med. 2025.
[13] Long B, Gottlieb M. Emergency medicine updates: managing the patient with return of spontaneous circulation. Am J Emerg Med. 2025 Mar 19;93:26–36.
[14] Long B, Gottlieb M. Cardiopulmonary resuscitation: the importance of the basics. Emerg Med Clin North Am. 2023 Aug;41(3):509–28.
[15] Long B, Gottlieb M. Emergency medicine updates: defibrillation strategies in cardiac arrest. Am J Emerg Med [In press].
[16] Gottlieb M, Alerhand S. Managing cardiac arrest using ultrasound. Ann Emerg Med. 2023 May;81(5):532–42.
[17] Gaspari R, Weekes A, Adhikari S, et al. Emergency department point-of-care ultrasound in out-of-hospital and in-ED cardiac arrest. Resuscitation. 2016;109:33–9.
[18] Kleber C, Giesecke MT, Lindner T, et al. Requirement for a structured algorithm in cardiac arrest following major trauma: epidemiology, management errors, and preventability of traumatic deaths in Berlin. Resuscitation. 2014 Mar;85(3): 405–10.
[19] Alerhand S, Adrian RJ, Long B, et al. Pericardial tamponade: a comprehensive emergency medicine and echocardiography review. Am J Emerg Med. 2022;58:159–74.
[20] Alerhand S, Carter JM. What echocardiographic findings suggest a pericardial effusion is causing tamponade? Am J Emerg Med. 2019;37:321–6.
[21] Eke OF, Selame L, Gullikson J, et al. Timing of pericardiocentesis and clinical outcomes: is earlier pericardiocentesis better? Am J Emerg Med. 2022;54:202–7.
[22] Eisenberg MJ, Oken K, Guerrero S, et al. Prognostic value of echocardiography in hospitalized patients with pericardial effusion. Am J Cardiol. 1992;70:934–9.
[23] Tsang TS, Oh JK, Seward JB. Diagnosis and management of cardiac tamponade in the era of echocardiography. Clin Cardiol. 1999;22:446–52.
[24] Saito Y, Donohue A, Attai S, et al. The syndrome of cardiac tamponade with “small” pericardial effusion. Echocardiography. 2008;25:321–7.
[25] Spodick DH. Acute cardiac tamponade. N Engl J Med. 2003;349:684–90.
[26] Armstrong WF, Schilt BF, Helper DJ, et al. Diastolic collapse of the right ventricle with cardiac tamponade: an echocardiographic study. Circulation. 1982;65: 1491–6.
[27] Engel PJ, Hon H, Fowler NO, et al. Echocardiographic study of right ventricular wall motion in cardiac tamponade. Am J Cardiol. 1982;50:1018–21.
[28] Singh S, Wann LS, Schuchard GH, et al. Right ventricular and right atrial collapse in patients with cardiac tamponade—a combined echocardiographic and hemodynamic study. Circulation. 1984;70:966–71.
[29] Singh S, Wann LS, Klopfenstein HS, et al. Usefulness of right ventricular diastolic collapse in diagnosing cardiac tamponade and comparison to pulsus paradoxus. Am J Cardiol. 1986;57:652–6.
[30] Kürkciyan I, Meron G, Sterz F, et al. Pulmonary embolism as a cause of cardiac arrest: presentation and outcome. Arch Intern Med. 2000;160:1529–35.
[31] Alerhand S, Sundaram T, Gottlieb M. What are the echocardiographic findings of acute right ventricular strain that suggest pulmonary embolism? Anaesth Crit Care Pain Med. 2021;40:100852–3.
[32] Kronzon I, Cohen ML, Winer HE. Diastolic atrial compression: a sensitive echocardiographic sign of cardiac tamponade. J Am Coll Cardiol. 1983;2:770–5.
[33] Gillam LD, Guyer DE, Gibson TC, et al. Hydrodynamic compression of the right atrium: a new echocardiographic sign of cardiac tamponade. Circulation. 1983; 68:294–301.
[34] Materazzo C, Piotti P, Meazza R, et al. Respiratory changes in transvalvular flow velocities versus two-dimensional echocardiographic findings in the diagnosis of cardiac tamponade. Ital Heart J. 2003;4:186–92.
[35] Klein AL, Abbara S, Agler DA, et al. American Society of Echocardiography clinical recommendations for multimodality cardiovascular imaging of patients with pericardial disease: endorsed by the Society for Cardiovascular Magnetic Resonance and Society of cardiovascular computed tomography. J Am Soc Echocardiogr. 2013;26(965–1012):e15.
[36] Leeman DE, Levine MJ, Come PC. Doppler echocardiography in cardiac tamponade: exaggerated respiratory variation in transvalvular blood flow velocity integrals. J Am Coll Cardiol. 1988;11:572–8.
[37] Appleton CP, Hatle LK, Popp RL. Cardiac tamponade and pericardial effusion: respiratory variation in transvalvular flow velocities studied by Doppler echocardiography. J Am Coll Cardiol. 1988;11:1020–30.
[38] Adler Y, Charron P, Imazio M, et al. 2015 ESC guidelines for the for the diagnosis and Management of Pericardial Diseases of the European Society of Cardiology (ESC)endorsed by: the European Association for Cardio-Thoracic Surgery (EACTS). Eur Heart J. 2015;36:2921–64.
[39] Hoit BD, Gabel M, Fowler NO. Cardiac tamponade in left ventricular dysfunction. Circulation. 1990;82:1370–6.
[40] Imazio M, De Ferrari GM. Cardiac tamponade: an educational review. Eur Heart J Acute Cardiovasc Care. 2020:102–9. Published online July 6. 2048872620939341.
[41] Gonzalez MS, Basnight MA, Appleton CP. Experimental pericardial effusion: relation of abnormal respiratory variation in mitral flow velocity to hemodynamics and diastolic right heart collapse. J Am Coll Cardiol. 1991;17:239–48.
[42] Mercé J, Sagristà-Sauleda J, Permanyer-Miralda G, et al. Correlation between clinical and Doppler echocardiographic findings in patients with moderate and large pericardial effusion: implications for the diagnosis of cardiac tamponade. Am Heart J. 1999;138(4 Pt 1):759–64.
[43] Bougouin W, Marijon E, Planquette B, et al. On behalf from the sudden death expertise center. Pulmonary embolism related sudden cardiac arrest admitted alive at hospital: management and outcomes. Resuscitation. 2017 Jun;115:135–40.
[44] Hess EP, Campbell RL, White RD. Epidemiology, trends, and outcome of out-of-hospital cardiac arrest of non-cardiac origin. Resuscitation. 2007 Feb;72(2):200–6.
[45] Kuisma M, Alaspää A. Out-of-hospital cardiac arrests of non-cardiac origin. Epidemiology and outcome. Eur Heart J. 1997 Jul;18(7):1122–8.
[46] Javaudin F, Lascarrou JB, Le Bastard Q, et al. Research Group of the French National out-of-Hospital Cardiac Arrest Registry (GR-RéAC). Thrombolysis during resuscitation for out-of-hospital cardiac arrest caused by pulmonary embolism increases 30-day survival: findings from the French National Cardiac Arrest Registry. Chest. 2019 Dec;156(6):1167–75.
[47] Wardi G, Blanchard D, Dittrich T, et al. Right ventricle dysfunction and echocardiographic parameters in the first 24h following resuscitation in the post-cardiac arrest patient: a retrospective cohort study. Resuscitation. 2016;103:71–4.
[48] Aagaard R, Granfeldt A, Bøtker MT, et al. The right ventricle is dilated during resuscitation from cardiac arrest caused by hypovolemia: a porcine ultrasound study. Crit Care Med. 2017;45:e963–70.
[49] Aagaard R, Caap P, Hansson NC, et al. Detection of pulmonary embolism during cardiac arrest-ultrasonographic findings should be interpreted with caution. Crit Care Med. 2017;45:e695–702.
[50] Sørensen AH, Wemmelund KB, Møller-Helgestad OK, et al. Asphyxia causes ultrasonographic D-shaping of the left ventricle–an experimental porcine study. Acta Anaesthesiol Scand. 2016 Feb;60(2):203–12.
[51] Aagaard R, Løfgren B, Caap P, et al. A low end-tidal CO2/arterial CO2 ratio during cardiopulmonary resuscitation suggests pulmonary embolism. Resuscitation. 2018;133:137–40.
[52] Berg RA, Sorrell VL, Kern KB, et al. Magnetic resonance imaging during untreated ventricular fibrillation reveals prompt right ventricular overdistention without left ventricular volume loss. Circulation. 2005;111:1136–40.
[53] Comess KA, DeRook FA, Russell ML, et al. The incidence of pulmonary embolism in unexplained sudden cardiac arrest with pulseless electrical activity. Am J Med. 2000;109:351–6.
[54] Rudski LG, Lai WW, Afilalo J, et al. Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. J Am Soc Echocardiogr. 2010;23:685–713. quiz786–788.
[55] Kostura M, Smalley C, Koyfman A, Long B. Right heart failure: a narrative review for emergency clinicians. Am J Emerg Med. 2022 Aug;58:106–13.
[56] Budhram GR, Mader TJ, Lutfy L, et al. Left ventricular thrombus development during ventricular fibrillation and resolution during resuscitation in a swine model of sudden cardiac arrest. Resuscitation. 2014;85:689–93.
[57] Lau V, Blaszak M, Lam J, et al. Point-of-care resuscitative echocardiography diagnosis of Intracardiac Thrombus during cardiac arrest (PREDICT study): a retrospective, observational cohort study. Resusc Plus. 2022;10:100218–9.
[58] Konstantinides SV, Torbicki A, Agnelli G, et al. ESC guidelines on the diagnosis and management of acute pulmonary embolism. Eur Heart J. 2014;35(43):3033–69. 2014. 3069a-3069k.
[59] Lee JH, Lee SH, Yun SJ. Comparison of 2-point and 3-point-of-care ultrasound techniques for deep vein thrombosis at the emergency department: a meta-analysis. Med (Baltim). 2019;98:e15791.
[60] Pomero F, Dentali F, Borretta V, et al. Accuracy of emergency physician-performed ultrasonography in the diagnosis of deep-vein thrombosis: a systematic review and meta-analysis. Thromb Haemost. 2013;109:137–45.
[61] Rouleau SG, Casey SD, Kabrhel C, Vinson DR, Long B. Management of high-risk pulmonary embolism in the emergency department: a narrative review. Am J Emerg Med. 2024 May;79:1–11.
[62] Berdowski J, Berg RA, Tijssen JGP, Koster RW. Global incidences of out-of-hospital cardiac arrest and survival rates: systematic review of 67 prospective studies. Resuscitation. 2010;81(11):1479–87.
[63] Adabag AS, Luepker RV, Roger VL, Gersh BJ. Sudden cardiac death: epidemiology and risk factors. Nat Rev Cardiol. 2010 Apr;7(4):216–25.
[64] Cournoyer A, Chauny JM, Paquet J, et al. Electrical rhythm degeneration in adults with out-of-hospital cardiac arrest according to the no-flow and bystander low-flow time. Resuscitation. 2021;167:355–61.
[65] Sedgwick ML, Dalziel K, Watson J, et al. The causative rhythm in out-of-hospital cardiac arrests witnessed by the emergency medical services in the heartstart Scotland project. Resuscitation. 1994;27:55–9.
[66] Holmberg M, Holmberg S, Herlitz J. Incidence, duration and survival of ventricular fibrillation in out-of-hospital cardiac arrest patients in Sweden. Resuscitation. 2000;44:7–17.

[67] Gaspari R, Weekes A, Adhikari S, et al. Comparison of outcomes between pulseless electrical activity by electrocardiography and pulseless myocardial activity by echocardiography in out-of-hospital cardiac arrest; secondary analysis from a large, prospective study. Resuscitation. 2021;169:167–72.
[68] Amaya SC, Langsam A. Ultrasound detection of ventricular fibrillation disguised as asystole. Ann Emerg Med. 1999;33:344–6.
[69] Buick JE, Drennan IR, Scales DC, et al. Rescu investigators. improving temporal trends in survival and neurological outcomes after out-of-hospital cardiac arrest. Circ Cardiovasc Qual Outcomes. 2018 Jan;11(1):e003561.
[70] Gaspari R, Lindsay R, She T, et al. Incidence and clinical relevance of echocardiographic visualization of occult ventricular fibrillation: a multicenter prospective study of patients presenting to the emergency department after out-of-hospital cardiac arrest. Ann Emerg Med. 2025 Jun 30.;S0196-0644(25) 00208–2.
[71] Gaspari R, Adhikari S, Gleeson T, et al. Occult ventricular fibrillation visualized by echocardiogram during cardiac arrest: a retrospective observational study from the real-time evaluation and assessment for sonography-outcomes network (REASON). J Am Coll Emerg Physicians Open. 2025 Jan 13;6(1):100028.
[72] Wardi G, Gottlieb M. Visualizing the invisible: the expanding role of echocardiography in cardiac arrest. Ann Emerg Med. 2025 Jun 4.;S0196-0644(25) 00282–3.
[73] Breitkreutz R, Price S, Steiger HV, et al. Emergency ultrasound working Group of the Johann Wolfgang Goethe-University Hospital, Frankfurt am Main. Focused echocardiographic evaluation in life support and peri-resuscitation of emergency patients: a prospective trial. Resuscitation. 2010 Nov;81(11):1527–33.
[74] Kedan I, Ciozda W, Palatinus JA, et al. Prognostic value of point-of-care ultrasound during cardiac arrest: a systematic review. Cardiovasc Ultrasound. 2020 Jan 13;18 (1):1.
[75] Tomruk O, Erdur B, Cetin G, et al. Assessment of cardiac ultrasonography in predicting outcome in adult cardiac arrest. J Int Med Res. 2012;40(2):804–9.
[76] Teran F, Dean AJ, Centeno C, et al. Evaluation of out-of-hospital cardiac arrest using transesophageal echocardiography in the emergency department. Resuscitation. 2019;137:140–7.
[77] Thandar S, Sahu AK, Sinha TP, Bhoi S. Role of initial cardiac activity assessed by point-of-care ultrasonography in predicting cardiac arrest outcomes: a prospective cohort study. Turk J Emerg Med. 2023 Jan 2;23(1):24–9.
[78] Zaki HA, Iftikhar H, Shaban EE, et al. The role of point-of-care ultrasound (POCUS) imaging in clinical outcomes during cardiac arrest: a systematic review. Ultrasound J. 2024 Jan 24;16(1):4.
[79] Rabjohns J, Quan T, Boniface K, Pourmand A. Pseudo-pulseless electrical activity in the emergency department, an evidence based approach. Am J Emerg Med. 2020 Feb;38(2):371–5.
[80] Cheung JC, Yip YY. Pseudo-PEA: an easily overlooked player in cardiac arrest. Resuscitation. 2021 Nov;168:240–1.
[81] Heradstveit BE, Sunde K, Sunde GA, et al. Factors complicating interpretation of capnography during advanced life support in cardiac arrest–a clinical retrospective study in 575 patients. Resuscitation. 2012 Jul;83(7):813–8.
[82] Long B, Koyfman A, Vivirito MA. Capnography in the emergency department: a review of uses, waveforms, and limitations. J Emerg Med. 2017 Dec;53(6):829–42.
[83] Xu J, Li C, Tang H, Tan D, et al. Pulse oximetry waveform: A non-invasive physiological predictor for the return of spontaneous circulation in cardiac arrest patients —— A multicenter, prospective observational study. Resuscitation. 2021 Dec;169: 189–97.
[84] Eberle B, Dick WF, Schneider T, et al. Checking the carotid pulse check: diagnostic accuracy of first responders in patients with and without a pulse. Resuscitation. 1996;33:107–16.
[85] Ochoa FJ, Ramalle-Gómara E, Carpintero JM, et al. Competence of health professionals to check the carotid pulse. Resuscitation. 1998 Jun;37(3):173–5.
[86] Deakin CD, Low JL. Accuracy of the advanced trauma life support guidelines for predicting systolic blood pressure using carotid, femoral, and radial pulses: observational study. BMJ. 2000 Sep 16;321(7262):673–4.
[87] Badra K, Coutin A, Simard R, et al. The POCUS pulse check: a randomized controlled crossover study comparing pulse detection by palpation versus by point-of-care ultrasound. Resuscitation. 2019;139:17–23.
[88] Simard RD, Unger AG, Betz M, et al. The POCUS pulse check: a case series on a novel method for determining the presence of a pulse using point-of-care ultrasound. J Emerg Med. 2019;56:674–9.
[89] Cohen AL, Li T, Becker LB, et al. Northwell health biostatistics unit. Femoral artery Doppler ultrasound is more accurate than manual palpation for pulse detection in cardiac arrest. Resuscitation. 2022 Apr;173:156–65.
[90] Clattenburg EJ, Wroe PC, Gardner K, et al. Implementation of the cardiac arrest sonographic assessment (CASA) protocol for patients with cardiac arrest is associated with shorter CPR pulse checks. Resuscitation. 2018;131:69–73.
[91] Hernandez C, Shuler K, Hannan H, et al. C.A.U.S.E.: cardiac arrest ultra-sound exam —a better approach to managing patients in primary non-arrhythmogenic cardiac arrest. Resuscitation. 2008;76:198–206.
[92] Chu SE, Chang CJ, Chen HA, et al. Core ultrasound in REsuscitation (CURE): a novel protocol for ultrasound-assistant life support via application of both transesophageal and transthoracic ultrasound. Resuscitation. 2022;173:1–3.
[93] Breitkreutz R, Price S, Steiger HV, et al. Focused echocardiographic evaluation in life support and peri-resuscitation of emergency patients: a prospective trial. Resuscitation. 2010;81:1527–33.
[94] Breitkreutz R, Walcher F, Seeger FH. Focused echocardiographic evaluation in resuscitation management: concept of an advanced life support-conformed algorithm. Crit Care Med. 2007;35(suppl):S150–61.
[95] Testa A, Cibinel GA, Portale G, et al. The proposal of an integrated ultrasonographic approach into the ALS algorithm for cardiac arrest: the PEA protocol. Eur Rev Med Pharmacol Sci. 2010;14:77–88.
[96] Ávila-Reyes D, Acevedo-Cardona AO, Gómez-González JF, et al. Point-of- care ultrasound in cardiorespiratory arrest (POCUS-CA): narrative review article. Ultrasound J. 2021;13:46.
[97] Niendorff DF, Rassias AJ, Palac R, et al. Rapid cardiac ultrasound of inpatients suffering PEA arrest performed by nonexpert sonographers. Resuscitation. 2005;67: 81–7.
[98] Seif D, Perera P, Mailhot T, et al. Bedside ultrasound in resuscitation and the rapid ultrasound in shock protocol. Crit Care Res Prac. 2012;2012:503254.
[99] Chua MT, Chan GW, Kuan WS. Reversible causes in cardiovascular collapse at the emergency department using ultrasonography (REVIVE-US). Ann Acad Med Singapore. 2017;46:310–6.
[100] Lichtenstein DA. How can the use of lung ultrasound in cardiac arrest make ultrasound a holistic discipline. The example of the SESAME protocol. Med Ultrason. 2014;16:252–5.
[101] Atkinson P, Bowra J, Milne J, et al. International Federation for Emergency Medicine Consensus Statement: sonography in hypotension and cardiac arrest (SHoC): an international consensus on the use of point of care ultrasound for undifferentiated hypotension and during cardiac arrest. CJEM. 2017;19:459–70.
[102] Lien WC, Liu YP, Chong KM, et al. A novel US-CAB protocol for ultrasonographic evaluation during cardiopulmonary resuscitation. Resuscitation. 2017;115: e1–2.
[103] Kongkatong M, Ottenhoff J, Thom C, Han D. Focused ultrasonography in cardiac arrest. Emerg Med Clin North Am. 2023 Aug;41(3):633–75.
[104] Pearl WS, Todd KH. Ultrasonography for the initial evaluation of blunt abdominal trauma: a review of prospective trials. Ann Emerg Med. 1996 Mar;27(3):353–61.
[105] Ullah N, Bacha R, Manzoor I, et al. Reliability of focused assessment with sonography for trauma in the diagnosis of blunt torso trauma. J Diagn Med Sonogr. 2021;38 (1):60–70.
[106] Moore C, Todd WM, O'Brien E, et al. Free fluid in Morison's pouch on bedside ultrasound predicts need for operative intervention in suspected ectopic pregnancy. Acad Emerg Med. 2007;14:755–8.
[107] Hendrickson RG, Dean AJ, Costantino TG. A novel use of ultrasound in pulseless electrical activity: the diagnosis of an acute abdominal aortic aneurysm rupture. J Emerg Med. 2001;21:141–4.
[108] Netherton S, Milenkovic V, Taylor M, et al. Diagnostic accuracy of eFAST in the trauma patient: a systematic review and meta-analysis. CJEM. 2019;21:727–38.
[109] Harris DG, Garrido D, Oates CP, et al. Repair of ruptured abdominal aortic aneurysm after cardiac arrest. J Vasc Surg. 2016 Nov;64(5):1497–502.
[110] Gouveia E, Melo R, Machado C, Caldeira D, et al. Incidence of acute aortic dissections in patients with out of hospital cardiac arrest: a systematic review and meta-analysis of observational studies. Int J Cardiol Heart Vasc. 2021 Dec 23; 38:100934.
[111] Gottlieb M, Holladay D, Burns KM, et al. Ultrasound for airway management: an evidence-based review for the emergency clinician. Am J Emerg Med. 2020;38: 1007–13.
[112] Gottlieb M, Olszynski P, Atkinson P. Just the facts: point-of-care ultrasound for airway management. CJEM. 2021;23:277–9.
[113] Tanigawa K, Takeda T, Goto E, et al. The efficacy of esophageal detector devices in verifying tracheal tube placement: a randomized cross-over study of out-of-hospital cardiac arrest patients. Anesth Analg. 2001;92:375–8.
[114] Li J. Capnography alone is imperfect for endotracheal tube placement confirmation during emergency intubation. J Emerg Med. 2001;20:223–9.
[115] Takeda T, Tanigawa K, Tanaka H, et al. The assessment of three methods to verify tracheal tube placement in the emergency setting. Resuscitation. 2003;56:153–7.
[116] Zechner PM, Breitkreutz R. Ultrasound instead of capnometry for confirming tracheal tube placement in an emergency? Resuscitation. 2011;82:1259–61.
[117] Ornato JP, Shipley JB, Racht EM, et al. Multicenter study of a portable, hand-size, colorimetric end-tidal carbon dioxide detection device. Ann Emerg Med. 1992; 21:518–23.
[118] Gottlieb M, Holladay D, Peksa GD. Ultrasonography for the confirmation of endotracheal tube intubation: a systematic review and meta-analysis. Ann Emerg Med. 2018;72:627–36.
[119] Gottlieb M, Holladay D, Serici A, et al. Comparison of color flow with standard ultrasound for the detection of endotracheal intubation. Am J Emerg Med. 2018;36: 1166–9.
[120] Gottlieb M, Nakitende D, Sundaram T, et al. Comparison of static versus dynamic ultrasound for the detection of endotracheal intubation. West J Emerg Med. 2018;19:412–6.
[121] Gottlieb M, Holladay D, Burns K, et al. Accuracy of ultrasound for endotracheal intubation between different transducer types. Am J Emerg Med. 2019;37:2182–5.
[122] Gottlieb M, Holladay D, Nakitende D, et al. Variation in the accuracy of ultrasound for the detection of intubation by endotracheal tube size. Am J Emerg Med. 2019; 37:706–9.
[123] Gottlieb M, Burns K, Holladay D, et al. Impact of endotracheal tube twisting on the diagnostic accuracy of ultrasound for intubation confirmation. Am J Emerg Med. 2020;38:1332–4.
[124] Gottlieb M, Patel D, Jung C, et al. Comparison of saline versus air for identifying endotracheal intubation with ultrasound. Am J Emerg Med. 2022;58:131–4.
[125] Gottlieb M, Patel D, Sundaram T. Comparison of endotracheal tube location on ultrasound accuracy, time, and confidence. Am J Emerg Med. 2022;S0735-6757: 00550–2.
[126] Gottlieb M. Point-of care ultrasound in cardiac arrest: a focused review. J Acute Med. 2025 Sep 1;15(3):77–85.
[127] Leigh-Smith S. European Resuscitation Council guidelines for resuscitation–ruling out tension pneumothorax in cardiac arrest. Resuscitation. 2006 Dec;71(3):395. author reply 395-6.

[128] Chan KK, Joo DA, McRae AD, et al. Chest ultrasonography versus supine chest radiography for diagnosis of pneumothorax in trauma patients in the emergency department. Cochrane Database Syst Rev. 2020;7:CD013031–2.
[129] Helland G, Gaspari R, Licciardo S, et al. Comparison of four views to single-view ultrasound protocols to identify clinically significant pneumothorax. Acad Emerg Med. 2016;23:1170–5.
[130] Laan DV, Vu TDN, Thiels CA, et al. Chest wall thickness and decompression failure: a systematic review and meta-analysis comparing anatomic locations in needle thoracostomy. Injury. 2016;47:797–804.
[131] Gottlieb M, Long B. Managing spontaneous pneumothorax. Ann Emerg Med. 2023 May;81(5):568–76.
[132] Lee JH, Lee SH, Yun SJ. Comparison of 2-point and 3-point point-of-care ultrasound techniques for deep vein thrombosis at the emergency department: a meta-analysis. Medicine. 2019;98:e15791.
[133] Burnside PR, Brown MD, Kline JA. Systematic review of emergency physician-performed ultrasonography for lower-extremity deep vein thrombosis. Acad Emerg Med. 2008;15:493–8.
[134] Zaki HA, Albaroudi B, Shaban EE, et al. Deep venous thrombosis (DVT) diagnostics: gleaning insights from point-of-care ultrasound (PoCUS) techniques in emergencies: a systematic review and meta-analysis. Ultrasound J. 2024;16:37.
[135] Hercz D, Mechanic OJ, Varella M, et al. Ultrasound performed by emergency physicians for deep vein thrombosis: a systematic review. West J Emerg Med. 2024;25:282.
[136] Nakagawa Y, Inokuchi S, Morita S, et al. Accuracy of pulse checks in terms of basic life support by lifesavers, as lay persons. Circ J. 2010;74:1895–9.
[137] Dick WF, Eberle B, Wisser G, Schneider T. The carotid pulse check revisited: what if there is no pulse? Crit Care Med. 2000;28:N183.
[138] Tibballs J, Russell P. Reliability of pulse palpation by healthcare personnel to diagnose paediatric cardiac arrest. Resuscitation. 2009;80:61–4.
[139] Bahr J, Klingler H, Panzer W, et al. Skills of lay people in checking the carotid pulse. Resuscitation. 1997;35:23–6.
[140] Lee Y, Shin H, Choi HJ, Kim C. Can pulse check by the photoplethysmography sensor on a smart watch replace carotid artery palpation during cardiopulmonary resuscitation in cardiac arrest patients? A prospective observational diagnostic accuracy study. BMJ Open. 2019:9.
[141] Tibballs J, Weeranatna C. The influence of time on the accuracy of healthcare personnel to diagnose paediatric cardiac arrest by pulse palpation. Resuscitation. 2010;81:671–5.
[142] Kilgannon JH, Kirchhoff M, Pierce L, et al. Association between chest compression rates and clinical outcomes following in-hospital cardiac arrest at an academic tertiary hospital. Resuscitation. 2017;110:154–61.
[143] Zengin S, Yavuz E, Al B, et al. Benefits of cardiac sonography performed by a non-expert sonographer in patients with nontraumatic cardiopulmonary arrest. Resuscitation. 2016;102:105–9.
[144] Sanchez S, Miller M, Asha S. Assessing the validity of two dimensional carotid ultrasound to detect the presence and absence of a pulse. Resuscitation. 2020;157:67–73.
[145] Schwartz BE, Gandhi P, Najafali D, et al. Manual palpation vs. femoral arterial Doppler ultrasound for comparison of pulse check time during cardiopulmonary resuscitation in the emergency department: a pilot study. J Emerg Med. 2021;61:720–30.
[146] Kang SY, Jo IJ, Lee G, et al. Point-of-care ultrasound compression of the carotid artery for pulse determination in cardiopulmonary resuscitation. Resuscitation. 2022;S0300-9572:00590–1.
[147] Adedipe AA, Fly DL, Schwitz SD, et al. Carotid Doppler blood flow measurement during cardiopulmonary resuscitation is feasible: a first in man study. Resuscitation. 2015;96:121–5.
[148] Smith DJ, Simard R, Chenkin J. Checking the pulse in the 21st century: interobserver reliability of carotid pulse detection by point-ofcare ultrasound. Am J Emerg Med. 2021;45:280–3.
[149] Germanoska B, Coady M, Ng S, et al. The reliability of carotid ultrasound in determining the return of pulsatile flow: a pilot study. Ultrasound. 2018;26:118–26.
[150] Humphries AL, White JMB, Guinn RE, Braude DA. Paramedic-performed carotid artery ultrasound heralds return of spontaneous circulation in out-of-hospital cardiac arrest: a case report. Prehosp Emerg Care. 2023;27(1):107–11.
[151] Haddad G, Margius D, Cohen AL, et al. Doppler ultrasound peak systolic velocity versus end tidal carbon dioxide during pulse checks in cardiac arrest. Resuscitation. 2023 Feb;183:109695.
[152] Mueller M, Strassl A, Stelzer PD, et al. Under pressure - association of the arm position and leading circulatory structure behind the pressure point in cardiopulmonary resuscitation patients. Eur J Radiol. 2024 Nov;180:111706.
[153] Teran F, Sands N, Wray T. Abstract 200: left-ventricular outflow compression during cardiopulmonary resuscitation is associated with lower return of spontaneous circulation in out-of-hospital cardiac arrest. Circulation. 2022.;146(Suppl_1).
[154] Hwang SO, Zhao PG, Choi HJ, et al. Compression of the left ventricular outflow tract during cardiopulmonary resuscitation. Acad Emerg Med. 2009 Oct;16(10):928–33.
[155] Catena E, Ottolina D, Fossali T, et al. Association between left ventricular outflow tract opening and successful resuscitation after cardiac arrest. Resuscitation. 2019;138:8–14.
[156] Clattenburg EJ, Wroe P, Brown S, et al. Point-of-care ultrasound use in patients with cardiac arrest is associated prolonged cardiopulmonary resuscitation pauses: a prospective cohort study. Resuscitation. 2018;122:65–8.
[157] Huis In't Veld MA, Allison MG, Bostick DS, et al. Ultrasound use during cardiopulmonary resuscitation is associated with delays in chest compressions. Resuscitation. 2017 Oct;119:95–8.
[158] Gaspari R, Harvey J, DiCroce C, et al. Echocardiographic pre-pause imaging and identifying the acoustic window during CPR reduces CPR pause time during ACLS - a prospective cohort study. Resusc Plus. 2021 Mar 6;6:100094.
[159] Gaspari RJ, Gleeson T, Alerhand S, et al. A multicenter, prospective study comparing subxiphoid and parasternal views during brief echocardiography: effect on image quality, acquisition time, and visualized anatomy. J Emerg Med. 2022 May;62(5):648–56.
[160] Fair J, Mallin M, Mallemat H, et al. Transesophageal echocardiography: guidelines for point-of-care applications in cardiac arrest resuscitation. Ann Emerg Med. 2018 Feb;71(2):201–7.
[161] Parker BK, Salerno A, Euerle BD. The use of transesophageal echocardiography during cardiac arrest resuscitation: a literature review. J Ultrasound Med. 2019 May;38(5):1141–51.
[162] Hussein L, Rehman MA, Jelic T, et al. Transoesophageal echocardiography in cardiac arrest: a systematic review. Resuscitation. 2021;168:167–75.
[163] Fair J, Tonna J, Ockerse P, et al. Emergency physician-performed transesophageal echocardiography for extracorporeal life support vascular cannula placement. Am J Emerg Med. 2016;34:1637–9.
[164] Arntfield R, Pace J, McLeod S, et al. Focused transesophageal echocardiography for emergency physicians-description and results from simulation training of a structured four-view examination. Crit Ultrasound J. 2015;7:27–8.
[165] Byars DV, Tozer J, Joyce JM, et al. Emergency physician-performed transesophageal echocardiography in simulated cardiac arrest. West J Emerg Med. 2017;18:830–4.
[166] Nazerian P, De Stefano G, Albano G, et al. Transesophageal echocardiography (TEE) in cardiac arrest: results of a hands-on training for a simplified TEE protocol. Ultrasound J. 2020;12:41–2.
[167] Reardon RF, Chinn E, Plummer D, et al. Feasibility, utility, and safety of fully incorporating transesophageal echocardiography into emergency medicine practice. Acad Emerg Med. 2022;29:334–43.
[168] Daniel WG, Erbel R, Kasper W, et al. Safety of transesophageal echocardiography. A multicenter survey of 10,419 examinations. Circulation. 1991;83:817–21.
[169] Kallmeyer IJ, Collard CD, Fox JA, et al. The safety of intraoperative transesophageal echocardiography: a case series of 7200 cardiac surgical patients. Anesth Analg. 2001;92:1126–30.
[170] Mathur SK, Singh P. Transoesophageal echocardiography related complications. Indian J Anaesth. 2009 Oct;53(5):567–74.
[171] Patel KM, Desai RG, Trivedi K, et al. Complications of transesophageal echocardiography: a review of injuries, risk factors, and management. J Cardiothorac Vasc Anesth. 2022 Aug;36(8 Pt B):3292–302.
[172] Tsou PY, Kurbedin J, Chen YS, et al. Accuracy of point-of-care focused echocardiography in predicting outcome of resuscitation in cardiac arrest patients: a systematic review and meta-analysis. Resuscitation. 2017 May;114:92–9.
[173] Lalande E, Burwash-Brennan T, Burns K, et al. SHoC investigators. Is point-of-care ultrasound a reliable predictor of outcome during atraumatic, non-shockable cardiac arrest? A systematic review and meta-analysis from the SHoC investigators. Resuscitation. 2019 Jun;139:159–66.
[174] Lalande E, Burwash-Brennan T, Burns K, et al. Is point-of-care ultrasound a reliable predictor of outcome during traumatic cardiac arrest? A systematic review and meta-analysis from the SHoC investigators. Resuscitation. 2021;167:128–36.
[175] Gaspari R, Weekes A, Adhikari S, et al. A retrospective study of pulseless electrical activity, bedside ultrasound identifies interventions during resuscitation associated with improved survival to hospital admission. A REASON Study Resuscitation. 2017 Nov;120:103–7.
[176] Gaspari R, Teran F, Kamilaris A, et al. Development and validation of a novel image quality rating scale for echocardiography during cardiac arrest. Resusc Plus. 2021;6:100097–8.
[177] Hu K, Gupta N, Teran F, et al. Variability in interpretation of cardiac standstill among physician sonographers. Ann Emerg Med. 2018;71:193–8.