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REVIEW

POCUS series: ultrasound during cardiopulmonary resuscitation

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Abstract
This article is part of the point-of-care ultrasound (POCUS) series. During cardiopulmonary resuscitation, bedside ultrasound has important clinical value for confirming a diagnosis, establishing a prognosis and in therapeutic decision-making. In this article we provide a practical review on how to implement and apply POCUS during cardiopulmonary resuscitation and discuss its merits and pitfalls.

Introduction
Point-of-care ultrasound (POCUS) has shown promise in a variety of clinical scenarios. In most emergency wards and intensive care departments, ultrasound devices are standard equipment and ultrasound skills are becoming more commonplace. An increasing amount of evidence has been acquired from large clinical studies indicating the added diagnostic and prognostic value of dedicated ultrasound application during cardiac arrest.[1] During advanced cardiac life support (ACLS) in a patient in cardiac arrest, the establishment of a diagnosis and the early start of specific therapies can improve outcome.

The traditional approach for the identification of treatable causes during a cardiac arrest can nowadays be bolstered by the implementation of ultrasound. The merits of POCUS during ACLS are threefold. Firstly, the use of POCUS improves standard ACLS, by confirming the return of spontaneous circulation (ROSC), based on the presence of cardiac motion and carotid flow. Secondly, POCUS has proven to be a reliable tool for providing an 'on the spot' diagnosis for common causes of cardiac arrest and to shorten time to treatment.[1-3] And lastly, POCUS may be used during ACLS for prognostication of survival. Several clinical algorithms have been developed for the use of POCUS during cardiac arrest. In this article, we provide a practical review on the use of POCUS in ACLS, with our main focus on the subxiphoid view (*figure 1*).[2,3]

Protocols and training
Many POCUS protocols have been developed, each with their own acronym, set of diagnostic algorithms, and required training (examples in *table 1*).[4-6] What they all have in common is the focus on the cardiac view from the subxiphoid window. Any other cardiac window can be chosen in ACLS protocols, provided interference with thoracic compressions is avoided.[4-6] The differences in these protocols are mainly found in whether they include pulmonary, abdominal and vascular examinations. Also the order of sequence in which these organ systems are evaluated differs. Applying such a protocol provides a standard of care for quality and training purposes and most of these protocols are being evaluated in studies on clinical outcome.

Regardless of the protocol chosen, team training is essential to appropriately integrate POCUS into the workflow of ACLS. Delays in the rhythm check can easily be caused, but should be avoided at all costs. The operator should therefore be skilled enough to make and save the required images during the rhythm checks, with timeframes of no more than 10 sec. Next, the operator must systematically review the results with the team members during the next CPR cycle. Given the demands these requirements take on the person performing the POCUS examination (*figure 2*), delegating the task of team leader to another ACLS member should be considered early, because maintaining an adequate level of situational awareness may not be possible during sonography. A therapeutic strategy can be chosen from team-based decision-making and this may improve the effectiveness of ACLS.[4-6]

Bringing POCUS to this performance level in cardiopulmonary resuscitation requires practice during advanced life support training. This improves time efficiency and the overall performance of the team (*figure 3*).[6] Specific criteria for an adequate performance level could not be found in the literature.

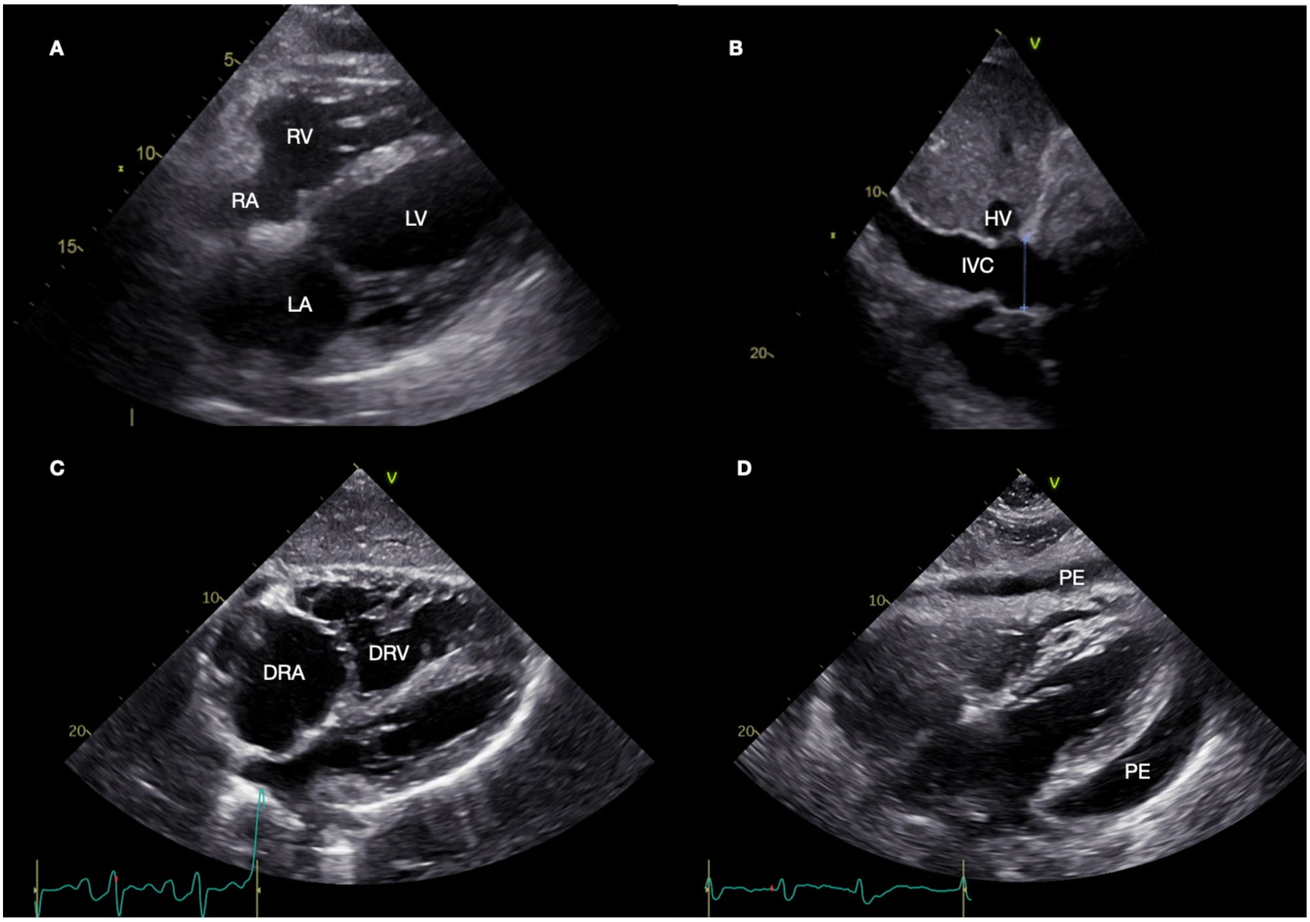

Figure 1. A) Frozen image of the subxiphoid view from a patient without cardiac pathology. B) Subxiphoid view (rotation of probe from position A), inflow from the vena cava into the right atrium. C) Pathology: Dilated right atrium and right ventricle, with shift from interatrial septum and interventricular septum to the left. D) Pathology: Pericardial fluid resulting in cardiac tamponade
RA = right atrium; RV = right ventricle; LA = left atrium; LV = left ventricle; IVC = inferior vena cava; HV = hepatic vein; DRA = dilated right atrium; DRV = dilated right ventricle; PE = pericardial effusion

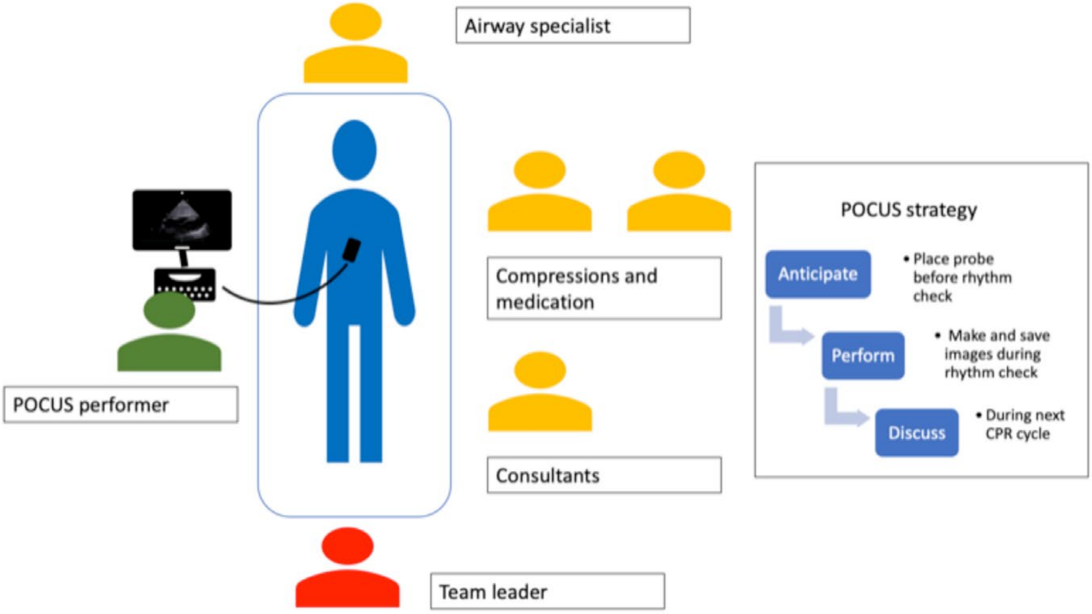

Figure 2. The main recommendation is to separate the role of team leader (red) and the person performing the POCUS (green). During CPR, the probe should be placed in the correct position for the required view. Images can then be made during the rhythm check and the results discussed in the next cycle.

Table 1. POCUS protocols for CPR ultrasound

	COACHRED	FEEL	CASA	POCUS	PEA	CAUSE	SESAME
Cardiac	1	1	1	1	2	1	4
Subxiphoid view	✓	✓	✓	✓	✓	✓	✓
Inclusion other views	✓	✓	✓	✓	—	✓	✓
Tamponade	✓	✓	✓	✓	✓	✓	✓
Right ventricular strain	✓	✓	✓	✓	—	✓	✓
Cardiac wall motion	✓	✓	✓	✓	✓	✓	✓
Hypovolaemia	✓	✓	✓	✓	✓	✓	✓
Regional wall abnormality	✓	✓	✓	✓	—	✓	✓
Pulmonary	—	—	2	4	1	2	1
Pneumothorax	—	—	✓	✓	✓	✓	✓
Consolidation	—	—	—	—	—	—	✓
Pleural effusion	—	—	—	—	—	—	✓
Abdominal	—	—	3	2	3	—	3
Aortic rupture	—	—	✓	✓	✓	—	✓
Peritoneal fluid	—	—	✓	✓	✓	—	✓
Vascular	—	—	—	3	4	—	2
Carotid flow	—	—	—	—	—	—	—
Distal venous thrombosis	—	—	—	✓	✓	—	✓

COACHRED: Continue compressions, Oxygen away, All others away, Charging, Hands off, Evaluate rhythm and Defibrillate or Disarm charge
FEEL: Focused Echocardiographic Evaluation in Life support
CASA: Cardiac Arrest Sonographic Assessment
POCUS: Point Of Care UltraSound
PEA: Pulmonary; Epigastric; Abdominal scans
CAUSE: Cardiac Arrest Ultrasound Exam
SESAME: (originally SESAMOOSIC) Sequential Emergency Scanning Assessing Mechanism Or Origin of Shock of Indistinct Cause
The numbers in the table indicate the order of acquisition of views, pathology or organ system. ✓ : included in exam. — : not included in exam

In general, being certified for an already existing ultrasound protocol, having received a period of supervision or reviews from peers and maintaining the obtained skills with a minimum amount of images per unit of time should suffice. Incorporating ultrasound in regular ACLS training should condition the team for the presence of POCUS during a real event.

As previous studies have pointed out, adhering to and practising established ultrasound protocols is necessary to benefit from POCUS, without interfering with the standards of care of ACLS.[6]

Technique

As mentioned in the previous section, the only moment for acquiring images is during the rhythm check. Usage of this limited timeframe should be optimised by placing the phased array probe (cardiac probe) in the subxiphoidal space in anticipation of the rhythm check.[4,6] Other cardiac views, such as the apical, parasternal short-axis and long-axis views are usually less appropriate and inaccessible since these views generally require more time to acquire and interfere with the resuscitation procedure.[7] Views directed at excluding tension pneumothorax or at signs of pulmonary embolism (e.g. venous duplex exam of popliteal and femoral veins) can be incorporated as a next step, as is done in the SESAME protocol of Lichtenstein.[2]

Quality of CPR, presence of cardiac activity and confirmation of ROSC

Recently, two studies were performed that compared ultrasound detection of flow through the carotid artery with manual carotid pulse palpation.[8,9] Badra et al. found that ultrasound pulse confirmation was more successful than manual palpation

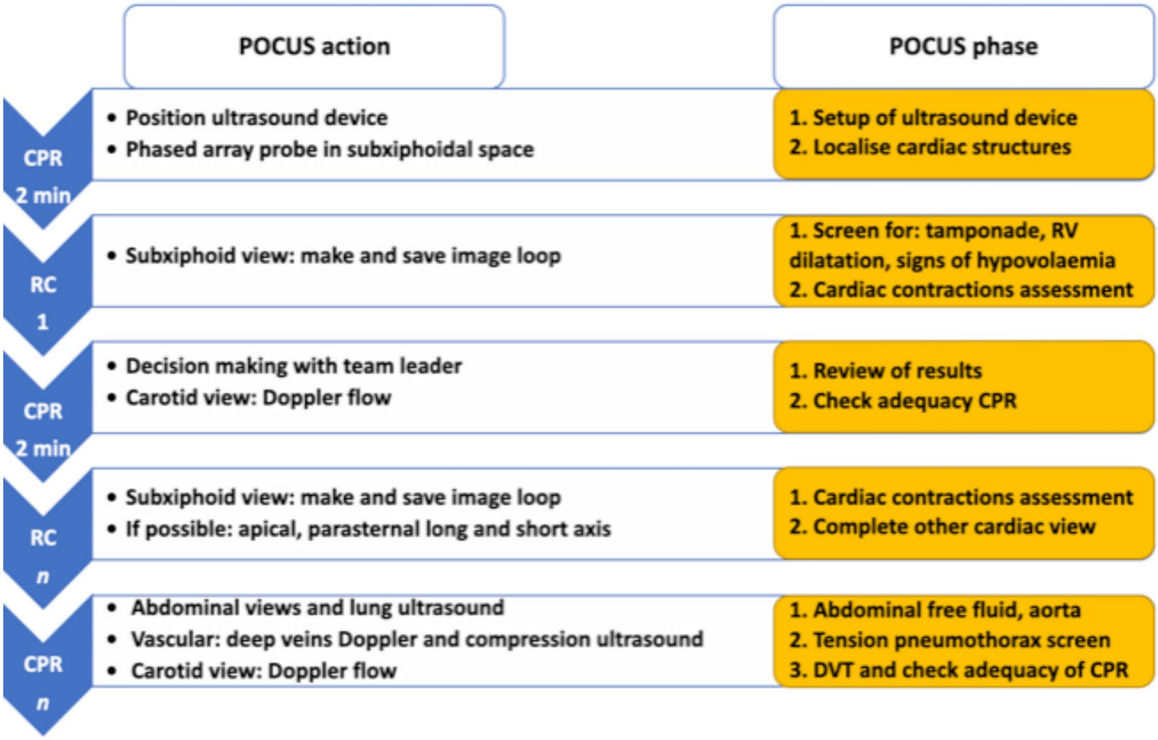

Figure 3. Flowchart showing the deployment phases of POCUS during ongoing ACLS. Every specific action of POCUS connects to a diagnostic ultrasound phase. These actions and phases should be assigned to either the rhythm check (RC) or thoracic compression blocks (CPR). In this way POCUS can follow the ACLS workflow and reach completion in a limited number of blocks. This proposed flowchart is based on the concept that a dedicated POCUS ACLS member can obtain a complete evaluation and that priority is given to the subxiphoid view.

in healthy volunteers, with ultrasound being correct in 99.1% of cases, whereas manual palpation was correct in only 85.6% ($p<0.0001$).[9] An observer confirmed the pulse detection whilst simultaneously palpating the radial pulse. Independent reviewers measured the time to successful pulse detection from audio recordings. In this study, ultrasound had no negative effects on the duration of the pulse check. Mastering ultrasound pulse confirmation required little training and improved post-training confidence in pulse detection as compared with traditional manual confirmation alone. Whether manual carotid pulse finding during ACLS can be replaced by ultrasound techniques needs to be evaluated in further studies. The mode (standard 2D grey-scale, Doppler, M-mode) which is most accurate for confirming a carotid flow that provides an adequate cerebral flow has not been validated either.

To investigate the influence of POCUS on patient management, Breitkreutz et al. performed a prospective study of 230 cardiac arrest patients without a palpable pulse, of which 51 were diagnosed with pulseless electrical activity and 37 had asystole.[10] In the group with pulseless electrical activity, 38 patients had viable cardiac activity on ultrasound. These patients had a better prognosis than those who did not. In the asystole group, based on pulse palpation, 13 patients had detectable wall motion on ultrasound. This deviation can possibly be explained by a misinterpretation of the ECG. Whether these study patients had, in hindsight, reversible fine ventricular fibrillation, was not known.

Diagnosing specific causes and guidance of treatment

The findings obtained during POCUS-guided ACLS may lead to accelerated decision-making and faster application of life-saving therapies. For diagnosing pulmonary embolism, cardiac tamponade, hypovolaemia and pneumothorax, POCUS assisted diagnosis has been shown to improve outcome.[11,12] Integration of POCUS into the existing ACLS approach increases the diagnostic and therapeutic abilities of the CPR team.

Pulmonary embolism

Ultrasonographic signs indicative of pulmonary embolism are right ventricular dilation, interventricular septal displacement to the left side or both; thrombus in transit and/or finding non-compressible popliteal or femoral veins. POCUS can expedite the confirmation of this diagnosis, with reduction of the time to administering thrombolysis, catheter thrombectomy, surgery or even the start of extracorporeal life resuscitation.[13] This acceleration in decision-making can be lifesaving, as demonstrated in a case report by Piggot et al.[13] Accurately confirming or rejecting the diagnosis of pulmonary embolism based on ultrasound is challenging. Due to the asymmetric geometry of the right ventricle, correctly assessing its dimensions in a short time frame can be difficult. Another key point to keep in mind is the differential diagnosis of right ventricular dilatation, such as increased intrathoracic pressure (dynamic hyperinflation, tension pneumothorax), pulmonary hypertension, ischaemic cardiomyopathy and arrhythmogenic right ventricular cardiomyopathy.

Cardiac tamponade

Cardiac tamponade can be easily diagnosed by POCUS. Pericardial effusions can be visualised as an increased space (usually >10 mm) separating the two pericardial layers. The earliest signs of tamponade are a widened inferior vena cava and atrial late systolic collapse. Later in the process, early diastolic right ventricular collapse may be observed.[11] POCUS examination for the clinical question of cardiac tamponade has excellent diagnostic accuracy with a sensitivity of 96% and a specificity of 98%.[11] Amongst the common pitfalls is mistaking epicardial fat for pericardial effusion or intrapericardial thrombus. During the assessment, one should keep in mind that pericardial fat is usually hyperechoic as compared with pericardial effusions and does not cause compression of the atria and ventricles. Pericardial collections consisting of pus, fibrin-rich material or haematoma will usually have a more inhomogeneous appearance with varying echogenicity. These can be regionally localised and are therefore more easy to miss on a single subxiphoid view. When pericardial fluid is found to be the cause of cardiac arrest, immediate needle pericardiocentesis should be performed.[11,14] Circulation can be immediately restored in a significant proportion of cases.[8]

Hypovolaemia

Ultrasound can be used to diagnose hypovolaemia, indicating the need for aggressive fluid resuscitation. However, the collapsability of the inferior vena cava (IVC) is unreliable as a parameter for fluid responsiveness. Many factors, including chest compressions and positive pressure ventilation, can alter the diagnostic accuracy of IVC diameter and collapsability Therefore, relying on ultrasound alone to determine hypovolaemia as the cause for cardiac arrest is likely to be inaccurate. However, collapsing hyperdynamic atria and/or ventricles can be seen in extreme cases. ROSC can be achieved when adequate preload is restored.[11]

Tension pneumothorax

Tension pneumothorax can be reliably diagnosed in patients with spontaneous circulation, without mechanical ventilation. Absence of ultrasound 'lung sliding' between the visceral and parietal pleura has a sensitivity of over 92% and specificity of 99% for pneumothorax. The visualisation of a 'lung point' carries a specificity for pneumothorax close to 100%.[11] It is likely that these percentages can still be approximated in intubated patients during CPR, as long as the tube has been placed at the correct depth such that both lungs are equally ventilated by either a bag-mask-valve apparatus or mechanical ventilator. Abdominal ultrasound is usually not part of POCUS during cardiopulmonary resuscitation, but significant free fluid can be reliably excluded and signs for a ruptured aortic aneurysm can be found.[9] The ultrasound sensitivity and specificity of experienced sonographers for diagnosing abdominal aortic aneurysms can reach 99% and 98%, respectively.[15] The Focussed Assessment with Sonography in Trauma (FAST) protocol can be followed to screen for intrapericardial and intraperitoneal free fluid. The FAST exam consists of a subxiphoid, left flank, right flank view and pelvic view.[15]

Prognostication

Life support assisted by POCUS can also be used for predicting the prognosis of resuscitation efforts. In a non-randomised prospective study of 223 patients, those with absent cardiac activity on ultrasound were less likely to have a return of spontaneous circulation (ROSC) than those with activity: 19.5% ROSC (95% CI 13-25%) vs 76% ROSC (95% CI 57-94%).[16] Beckett et al. performed a study in cardiac arrest patients presenting to the emergency ward. When asystole was seen on ultrasound, survival to discharge was only 0.8%.[17] In a systematic review of 1486 patients, visible cardiac activity on ultrasound was associated with an odds ratio for survival to hospital discharge of 8.03 (95% CI 3.01-21.39) compared with absence of cardiac activity.[18] The ACLS teams in the included studies were not blinded, making the review vulnerable to bias. A second systematic review, however, found similar results.[19] Based on the trend in these studies, it may be argued that presence of cardiac activity on POCUS warrants continuation of resuscitation.[20,21]

Integrating POCUS into resuscitation care may therefore lead to more patients achieving ROSC and prevent premature cessation of resuscitation efforts, by continuing CPR in those with cardiac contractions on ultrasound, irrespective of the tracings on the ECG. The presumed rationale behind it is that POCUS distinguishes those patients with unrecoverable cardiac standstill from those that still have recoverable heart function (e.g. pseudo-pulseless electrical activity, low grade ventricular fibrillation, and incorrect diagnosis of asystole).

Limitations

One of the important points to consider is that up to this point in time, randomised trials have not been performed to definitely prove that POCUS improves outcome. Yet, in individual cases performing POCUS can be decisive in finding a treatable cause of cardiac arrest. In this regard, a crucial limitation of POCUS assisted ACLS is that POCUS may prolong the rhythm check. This potentially reduces the effectiveness of the cardiopulmonary resuscitation and thereby an immediate reduction in cerebral blood flow.[22]

One study found a medium increase of 6 sec in the duration of the pulse check pause by applying ultrasound.[23] Two factors were identified to influence the increase. The first factor was the level of ultrasound skill and the second was related to the POCUS provider being the resuscitation leader at the same time. In another study of 23 patients, an increase in mean pulse check duration of 8.4 sec was found.[24] The prerequisites of the POCUS provider are therefore an adequate training level and delegating the team leadership task.

Resuscitation efforts can be unnecessarily obstructed if too much emphasis is placed on taking better images. Placing the probe in advance during ongoing CPR may prevent this from happening.

Other modalities for obtaining a diagnosis should be sought if acquiring adequate images is simply not possible. At all times, priority should be given to recommencing high-quality chest compressions after completing the rhythm check. Preventing delays in administering defibrillation during ventricular fibrillation equally applies.

The time for producing adequate images is therefore highly limited. Saving images provides the opportunity to analyse these during the next cycle of compressions.[25] Taken together, POCUS may only be of use during ACLS if it is performed swiftly by experienced sonographers and only minimally increases down time during ACLS compressions.

Future directions

Transoesophageal echocardiography (TEE) has the potential to overcome the limitations mentioned in the previous section. For a detail explanation of POCUS-TEE, see our recent POCUS-article about this topic.[26] This technique allows cardiac images to be taken without disrupting the CPR cycles. One retrospective study of 139 pulse checks by Fair et al. showed that TEE had a shorter mean compression pause of 9 sec (95% CI 5-12 sec) as compared with TTE: 19 sec (95% CI 16-22 sec).[27] Measuring colour Doppler flow from transoesophageal images allows for continuous monitoring of the adequacy of thoracic compression. Furthermore, TEE can be used to detect left ventricular outflow tract obstruction caused by malpositioned thoracic compressions.[28] These and other studies conducted on the application of TEE during CPR have shown promising results.[29,30]

Conclusion

The application of POCUS has opened up new vistas for improving ACLS, by aiding in establishing a diagnosis, implementing specific treatments and prognostication. The subxiphoidal view can be quickly obtained at the bedside, with modest ultrasound skills. Obtaining other cardiac views can be included as long as the cycles of thoracic compressions are not interrupted. A holistic diagnostic approach, in which pulmonary and abdominal pathology are sought after, as well as deep vein thrombosis, only adds to the value that ultrasound skills have to offer. POCUS should therefore be an integral part of the practice of ACLS.

Disclosures

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