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Review Article

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Ultrasound in Cardiopulmonary Arrest: State of Art

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ABSTRACT

Sudden cardiac arrest (SCA) accounts for about half of all cardiovascular deaths and is one of the leading causes of death in adults. The treatment of cardiac arrest consists of prompt high-quality cardiopulmonary resuscitation, early defibrillation of shockable rhythms, identification and treatment of reversible causes, and post-arrest care. Despite constant updates and wide dissemination of cardiopulmonary resuscitation guidelines, immediate post-SCA survival ranges from 20-50% and 0,5-12% after hospital discharge or within 30 days. In general, non-shockable rhythms are more challenging in identifying the initial cause. In this context, the ultrasound handled by the provider and used as an extension of the physical examination is associated with faster and more specific diagnoses and assertive treatment. In the last decade, many scientific publications have supported the use of the ultrasound in cardiopulmonary resuscitation maneuvers, with a better prognosis in some subgroups. Ultrasound can also be used to diagnose cardiac arrest, monitor compressions quality, guide procedures, and infer prognosis. Currently, ultrasound is incorporated in emergency centers of excellence as a fundamental resource. The purpose of this review is to provide the state-of-the-art use of the ultrasound in SCA.

Keywords: Ultrasound, Cardiac Arrest, Emergency Room, Diagnosis, Prognosis

Introduction

Ultrasound (US) use in the emergency department is one of the most versatile, cost-effective, free of side effects and highly accurate imaging methods. The application of US in various situations is supported by high-level scientific evidence.[1] The devices have become portable maintaining quality and allowing evaluation in the pre-hospital environment, emergency room, operating room, intensive care units, and outpatient clinics.[2] In the last two decades, there was a progressive incorporation of US handled by the patient's attending physician, as an extension of the physical examination.[3] This strategy is universally known as "point-of-care ultrasound" (POCUS).[4] Robust scientific evidence shows that the POCUS positive and negative likelihood ratio is better than most bedside diagnostic strategies, especially in life-threatening situations such as acute dyspnea and shock.[5,6] US also has better accuracy than the clinical impression for predicting volume responsiveness and as a hydration guide, reducing the chance of hypovolemia or congestion due to ineffective treatment.[7] In addition, US-guided emergency procedures, such as thoracentesis and central venous catheterization, are associated with greater success and fewer complications than those performed exclusively by physical examination.[8,9] Initially the US was helpful in peri-cardiac arrest situations and later was extended to cardiopulmonary resuscitation (CPR).[10]

Sudden cardiac arrest (SCA) accounts for

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about half of all cardiovascular deaths and is one of the leading causes of death in adults.[11,12] SCA effective treatment consists of prompt and high-quality CPR, early defibrillation of shockable rhythms, identification and treatment of reversible causes, and attention to post-arrest care.[13] Despite constant updates and wide dissemination of cardiopulmonary resuscitation guidelines and training, immediate post-SCA survival ranges from 20-50% and 0,5-12% after hospital discharge or within 30 days.[14] In the last decade, many scientific publications have supported the use of US in CPR maneuvers, with a better prognosis in some subgroups.[15] Especially in non-shockable SCA, the US handled by the provider and used as an extension of the physical examination during CPR is associated with faster and more specific diagnoses and assertive treatment.[16,17]

Therefore the US is a strategy associated with a better prognosis in SCA, in all its phases: critical situation before cardiac arrest, diagnosis of collapse, identification of the cause, treatment support for reversible causes, quality assurance of CPR and intensive care after the return of spontaneous circulation (ROSC).[18,19] This article compiles current evidence of the US in SCA with the aim of helping professionals to improve the quality of care.

Primary evidence: diagnosis of "pseudo" pulseless electrical activity

The current international guideline for SCA recommends the use of US on suspicion of a reversible mechanical cause, such as cardiac tamponade, pneumothorax, pulmonary thromboembolism (PTE), systolic ventricular dysfunction, and hypovolemia.[20] Despite the ample evidence of US benefit in emergencies in individuals with spontaneous circulation and the possible improvement in prognosis when the cause of SCA is identified, there is limited data demonstrating US as a tool for better outcomes.[21,22] The main limitations of studies in this context are: heterogeneity of the causes of SCA; inclusion of hospitalized patients with prior diseases of poor prognosis; heterogeneity between sites in the quality of CPR and post-ROSC care; failure to measure the effectiveness of US-guided interventions and methodological inadequacy of the studies.

The SCA causes can be summarized as the "5T and 5H": hypovolemia, hypoxia, hydrogen ion (acidosis), hypo/hyperkalemia, hypothermia, toxins (ie, drug use), cardiac tamponade, tension pneumothorax, coronary thrombosis (acute coronary syndrome), and pulmonary thromboembolism. SCA is classified by the American Heart Association as: ventricular fibrillation, ventricular tachycardia, pulseless electrical activity (PEA) and asystole.

Ventricular fibrillation and ventricular tachycardia are mainly caused by acute coronary syndrome and structural heart disease, especially in patients with left ventricular dysfunction.[23] PEA has two main causes: 1) the true PEA or electromechanical dissociation, mostly manifested with low heart rate and wide QRS secondary to a blockage in the transmission of the electrical impulse to the muscle and consequently no mechanical activity, usually is related to a toxic-metabolic disorder, and 2) pseudo-PEA, mainly manifested with a tachycardic rhythm and a narrow QRS. There is ventricular contraction, but an overlying mechanical issue leads to minimal cardiac output. (Figure 1).[24]

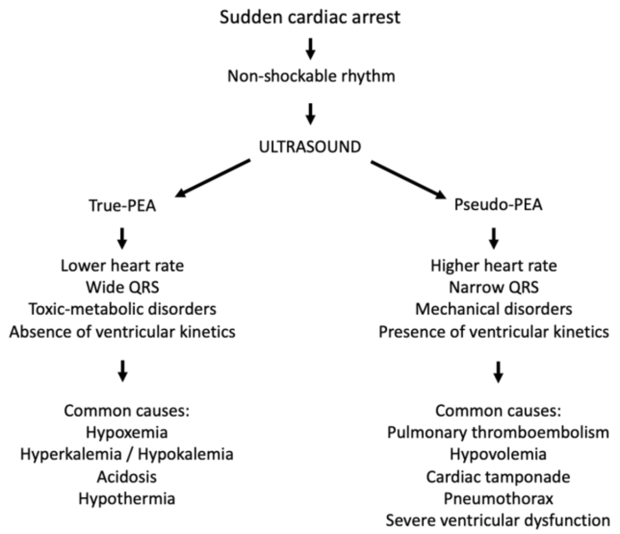

Figure 1. Pulseless electrical activity (PEA) causes

The main application of the US in SCA is in pseudo-PEA and asystole. Some studies investigated the impact of this strategy on the diagnosis of this first condition. Salen et al., in a prospective evaluation of 70 patients with SCA, demonstrated that the simple visualization of left ventricular kinetics in transthoracic cardiac US evaluation quickly identified 15.7% of patients with pseudo-PEA.[25] Teran et al. performed a prospective observational study with transesophageal echocardiography in 33 patients with out-of-hospital SCA. The investigators assessed 100% of the eligible patients with a mean of 12±8.16 minutes between arrival and examination, 64% during CPR and 36% post-ROSC. There were changes in the management of CPR in 97% of the cases based on echocardiographic findings, such as the reclassification of the rhythm of 4 patients (12%)

initially diagnosed with asystole to fine ventricular fibrillation, which were promptly submitted to defibrillation. Among the cases classified as pseudo-PEA, one patient had an intracardiac thrombus and underwent fibrinolysis, and two patients had signs of PTE.[26] Another study by Zengin et al. found that transthoracic US in 99 patients with out-of-hospital SCA had about 4 times greater accuracy for ventricular kinetics compared to clinical evaluation in identifying pseudo-PEA.[27] Breitkreuz et al. reclassified 46% of SCA based in US findings.[28] Thus, the US is fundamental for diagnosis of pseudo-PEA, and should be the employed for PEA, especially when the SCA etiology is not obvious and when a mechanical cause is suspected. (Figure 1) The systematization of the US assessment will be discussed below.

Diagnosis of the mechanical cause of pseudo-PEA

There are several possibilities for systematizing the US evaluation in unstable patients. The RUSH (rapid ultrasound in shock) protocol was the pioneer and has been validated by several studies, with a high positive likelihood ratio (19.9) and a low negative likelihood ratio (0.23) for the etiological diagnosis of undifferentiated shock at the emergency department.29 This protocol recommends evaluation of the "pump", "pipes" and "tank". The evaluation of the "pump" is performed searching for low cardiac output by echocardiographic evaluation with a clockwise approach, starting with the parasternal long axis (PLAX) view, then the parasternal short axis (PSAX) view, the apical four-chamber (A4-C) view, and the subcostal (or subxiphoid) view. Secondly, the "pipes" integrity is checked by arterial and venous vessels examination from head to toe, looking for signs of aortopathy and deep vein thrombosis. Finally, the "tank" evaluation of extravasation or collections is assessed by pursuing for pneumothorax and free fluid in the abdomen, similar to FAST (north, south, east and west analysis, which involves subcostal/epigastrium, pelvis, upper and lower left and right quadrants).[6] The RUSH protocol was validated exclusively in spontaneously circulating patients, and should be performed in the instability phase (pre-SCA) or post-ROSC care, when the etiology of the collapse has not yet been identified. Some of its steps can be performed during SCA and are consistent with focused cardiac ultrasound (FOCUS) recommendations.[30]

Six US protocols were proposed to identify the cause of SCA in non-shockable rhythms: CASA, CAUSE, FEEL, FEER, PEA, and SESAME (table 1).[28,31-35]

PEA and pseudo-PEA initial approach

As the initial step, we recommend the investigation of pseudo-PEA, assessing whether there is ventricular kinetics through the subcostal view. This method allows visualization of the heart 80% of the time during CPR, with a diagnostic rate about twice as high as the others. (Figure 2)

In case of a limited view, we suggest the A4-C, then PSAX views, and PLAX view in a counterclockwise approach. (Figure 3, 4, and 5).[36]

Variations of this approach are possible, depending on the provider's expertise. There is no evidence of better prognosis regarding the number or sequence of the echocardiographic views.37 The absence of ventricular contraction confirms true PEA, and toxic-metabolic disorders should be considered.

The diagnosis of pseudo-PEA implies looking for the four potentially reversible SCA causes: cardiac tamponade, PTE, hypovolemia, and tension pneumothorax.

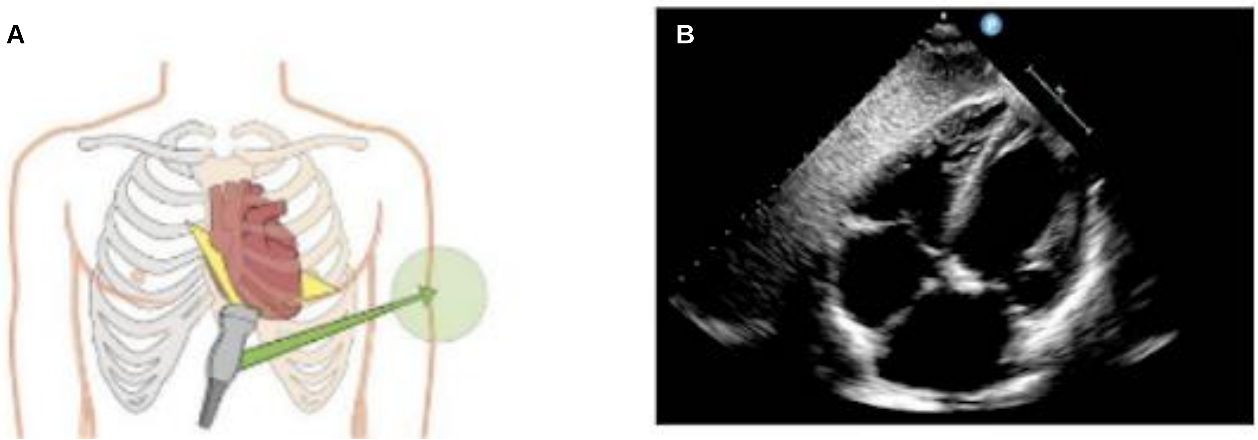

Figure 2. Subcostal view - initial position for US evaluation in SCA: A) transducer position; B) echocardiographic image

Table 1. US protocols used in SCA in non-shockable rhythms

Protocol	Patient particularities	Transducer	Methodology
CASA (Cardiac Arrest Sonographic Assessment)	None	Phased array	Subcostal view as first option. Evaluations should last less than 10 seconds during CPR pause check for pulse, images should be recorded for review. This is a three step evaluation: 1- cardiac tamponade, 2- pulmonary thromboembolism (dilated right ventricle and comparatively small left ventricle), 3- cardiac activity assessment for global cardiac activity or fibrillation. Ancillary steps: tension pneumothorax and FAST.
CAUSE (Cardiac-arrest ultrasound exam)	Intubated	2.5-5 MHz Phased array	Four-chamber subcostal view and then apical if necessary. If normal, next step: anteromedial view of lung and pleura in the second intercostal space in the midclavicular line bilaterally. The main objective is to search for: 1- pericardial effusion associated to right ventricular collapse indicating tamponade; 2- collapsed right and left ventricles suggesting hypovolemia; 3- enlarged right atrium and right ventricle with collapsed left ventricle corresponding to massive pulmonary thromboembolism; 4- if heart and pericardium are normal, lung ultrasound performed in the second intercostal space in the midclavicular line bilaterally can reveal absence of pleural slip (lung sliding) and B lines indicating pneumothorax. Normal A4-C and lung US evaluation should alert to metabolic causes and post massive infarction cardiogenic shock.

(contd.)

Protocol	Patient particularities	Transducer	Methodology
FEER (Focused Echocardiographic Evaluation in Resuscitation)	After at least 5 cycles or 2 minutes of CPR	Not mentioned	Four-chamber subcostal, long axis; if fail, repeat or change for PLAX or PSAX; at last, A4-C view. Evaluation should be completed within 5 secs during CPR pauses. The authors propose a 8-hour course for non-experts to quickly recognize echocardiographic findings in 5 seconds, minimizing time to perform the exam and to improve success rate to achieve subcostal four-chamber view.
PEA (Pulmonary-Epigastric-Abdomen)	SCA and/or peri-arrest conditions	Convex and phased array	1- Pulmonary scans: performed by a convex transducer longitudinal in the second or third intercostal space adjacent to sternum. 2- Epigastric and other scans: heart view in subcostal long axis or A4-C as an alternative view by a phased array transducer and inferior vena cava filling. 3-Abdominal and other scans: left parasternal scan on the third or fourth intercostal space (thoracic aorta evaluation) followed by upper lateral abdominal and pelvis, epigastrium and mesogastrium – probe select according to patients' particularities.
SESAME (Sequential Echographic Scanning Assessing MEchanism or origin of severe shock of indistinct cause)	None	Microconvex probe which covers a 0.6−17 cm area. Avoid changing probes to avoid loss of time.	Rule-out: 1- Pneumothorax: 5 seconds per lung; 2- Deep vein thrombosis: detection at the V-point, 5 seconds per side (during CPR); 3- Hypovolemia: fluid collections in the abdomen: 10−12 seconds (during CPR); 4- Pericardium tamponade: less than 8−10 seconds; 5- Cardiac causes: less than 40 seconds, if no window is seen after 12 seconds, resume the cardiac compressions, and try again later.

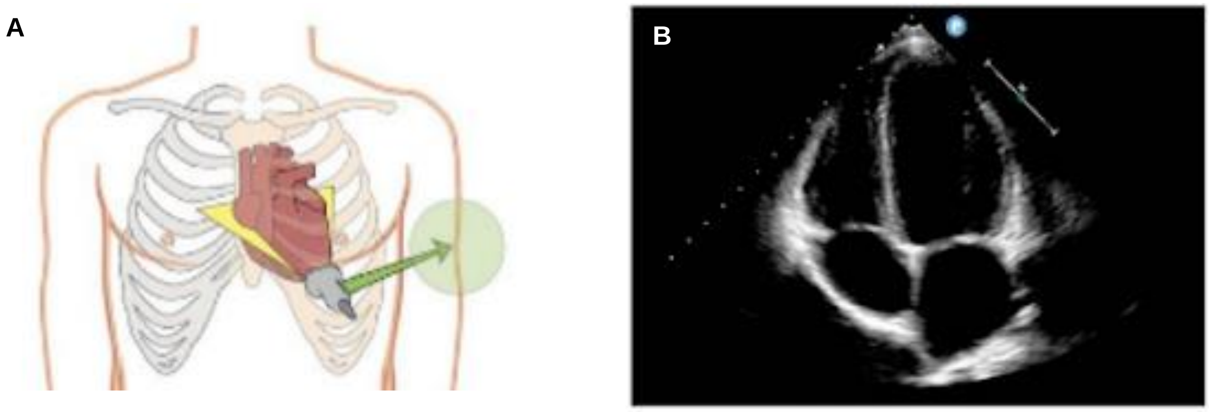

Figure 3. Apical four-chamber view: A) transducer position; B) echocardiographic image

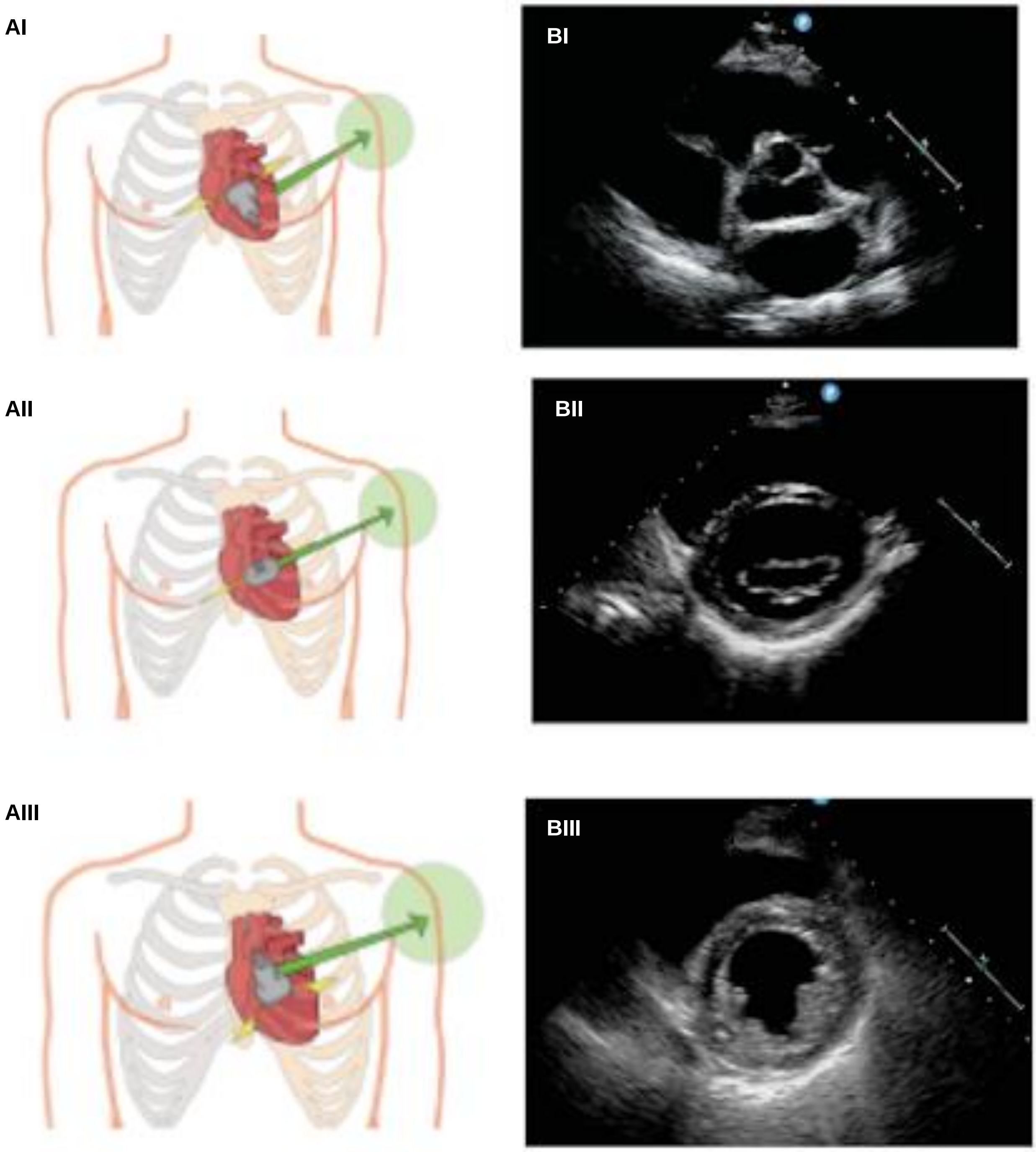

Figure 4. Parasternal short axis view: AI-III) transducer position; BI-III) echocardiographic image

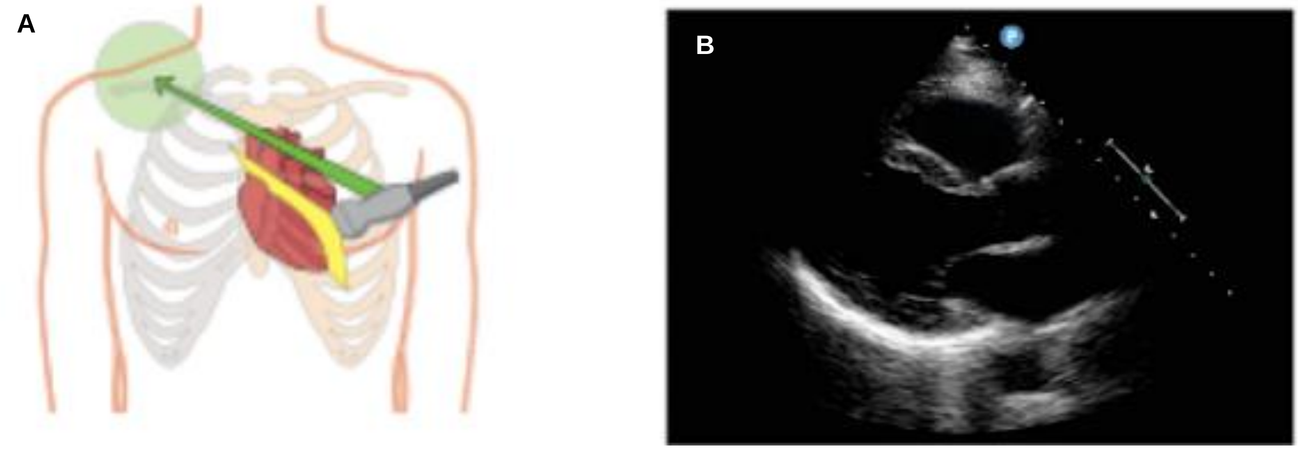

Figure 5. Parasternal long axis view: A) transducer position; B) echocardiographic image

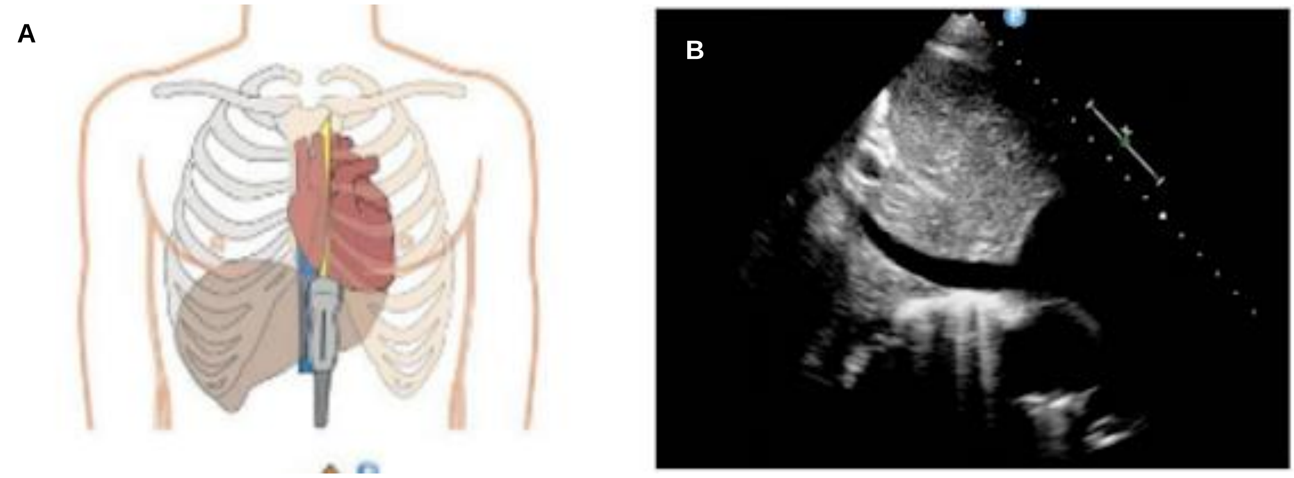

Figure 7. Perpendicular subcostal view - cardiac tamponade: dilated inferior vena cava: A) transducer position; B) echocardiographic image

The "4F approach" (fluid, form, function, filling, respectively: volume assessment, ventricular form, ventricular function, and ventricular filling) encompass most critical data.[38] In intubated patients, transesophageal US is possible, as it is associated with few side effects, and less interruptions and interferences in CPR.[39] Although feasible, this strategy makes it difficult to assess other structures, such as lungs, abdomen, and lower limb veins, and there is no current evidence of cost-effectiveness.[40]

We suggest the pulmonary assessment as the second step. There is greater evidence for echocardiographic data than for the lung and inferior vena cava during SCA. More important than following a specific protocol is the rationale for applying the US to diagnose potentially reversible causes, detailed below.

Cardiac tamponade

The diagnosis is made in the presence of a pericardial effusion with compressive effect in the cardiac chambers. During SCA, pericardial effusion associated with right atrium collapse (earliest sign), right ventricle collapse (highly specific), and plethoric inferior vena cava can be considered a diagnostic criterion of cardiac tamponade.(Figure 6, 7 and 8). In the presence of a pulse, it is also possible to identify right chamber collapse during systole and, in 25% of the cases, left atrial collapse. Left ventricular collapse is a sign of regional tamponade.[41,42]

Figure 6. Cardiac tamponade: pericardial effusion with hemodynamic repercussions in the right chambers. Subcostal view.

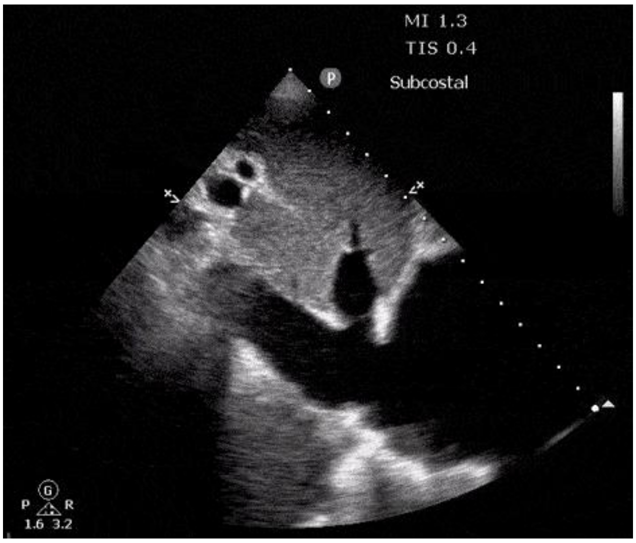

Figure 8. Perpendicular subcostal view - cardiac tamponade: dilated inferior vena cava.

The best US-guided intervention in SCA is to guide pericardiocentesis. The puncture of the pericardial space is performed with a needle inserted in the subcostal region beside the transducer (Figure 9). The US reduces complications compared to the blind technique.[28]

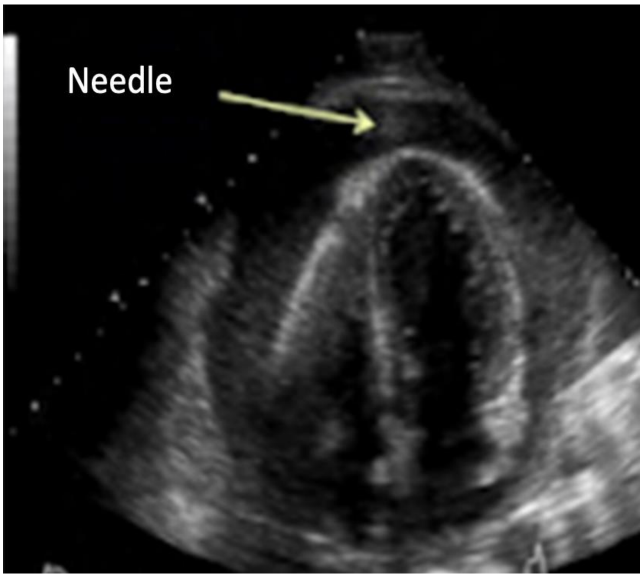

Figure 9. Pericardiocentesis: US-guided puncture of the pericardial space. Apical four chamber view.

Pulmonary thromboembolism

PTE manifests with a diameter of the right ventricle greater than or equal to the left ventricle, with a positive likelihood ratio of 90, a negative likelihood ratio of 0, sensitivity of 100%, and specificity of 99% (Figures 10 and 11).[42]

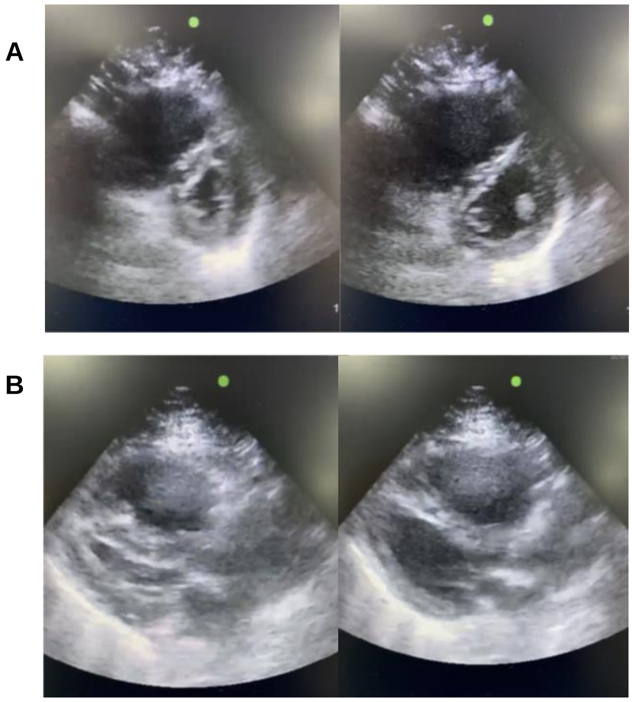

Figure 10. Pulmonary thromboembolism with acute right ventricular dysfunction: right ventricular diameter greater than the left ventricular diameter. A) Parasternal short-axis view-pulmonary thromboembolism, B) Parasternal long axis view

Tension pneumothorax

The pulmonary analysis must be performed in at least four quadrants in each hemithorax (upper and lower hemiaxillary, upper and lower hemiclavicular). Assessing sliding lung in ongoing CPR is difficult, especially for less experienced providers, due to restricted examination time and chest hypoexpansion.

The absence of pleural slip (lung sliding) and B lines has a positive likelihood ratio of 50 and a negative likelihood ratio of 0.09, with 90% sensitivity and 98% specificity for pneumothorax diagnosis (Figure 11 and 12).[43] The presence of a transition between lung sliding and absent sliding - the lung point, is pathognomonic of pneumothorax. A lateral lung point usually represents a large pneumothorax, whereas an anterior position commonly is related to a small one (figure 12).[44]

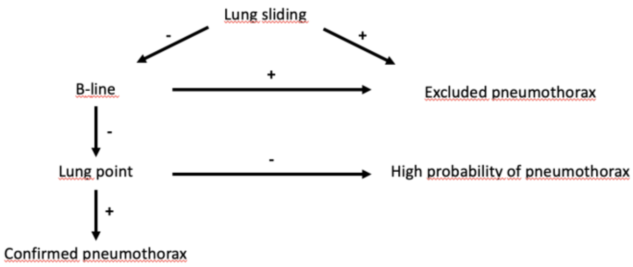

Figure 11. Pneumothorax diagnosis flowchart. The presence of lung sliding at all points rules out

pneumothorax. The absence of lung sliding associated with the presence of B lines also rules-out pneumothorax. The junction of normal lung and absence of lung sliding and B lines (lung point) confirms the diagnosis of pneumothorax.

A

B

C

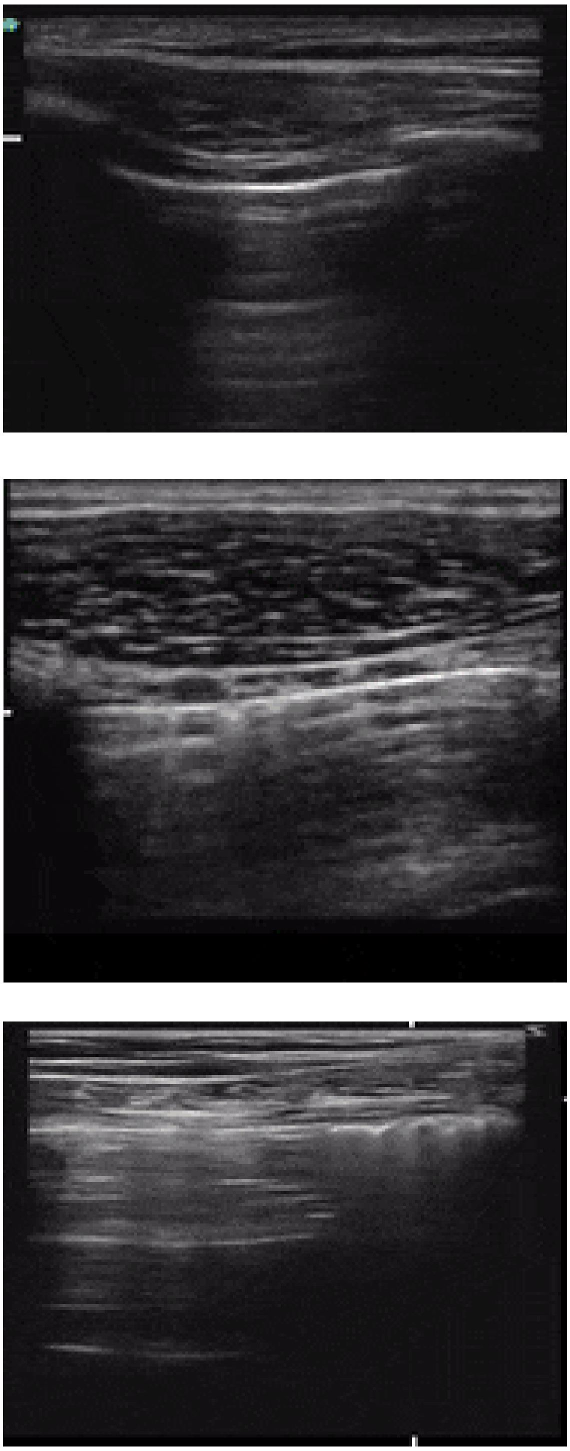

Figure 12. Lung ultrasound. A) normal lung: bat sign (dynamic analysis of pleural lung sliding); B) absence of lung sliding (dynamic image) with present B lines implying the presence of air between the pleura; C) lung point: absent lung sliding and B lines on the left while maintaining lung sliding and B lines on the right.

Hypovolemia

The signs of hypovolemia in SCA are collapsed right and left ventricles. In spontaneous circulation other features can be found: small hyperdynamic left ventricle (end-diastolic volume less than 10cm2 in the PLAX image), small hyperdynamic right ventricle, vena cava diameter less than 10 mm and dynamic left ventricular outflow tract obstruction (Figure 13).[7]

Figure 13. Hypovolemia: left and right ventricular small diameter - “kissing walls”. Parasternal long-axis view

Other causes of pseudo-PEA

In addition to these four potentially reversible causes of pseudo-PEA, other conditions can be diagnosed, such as: severe left ventricular dysfunction, severe valve disease, ventricular septal defect, and cardiac rupture. Despite the diagnosis, the prognosis of these situations is limited. Nevertheless, there is no evidence to interruption CPR efforts based only on this information.[45] Figure 14 summarizes the approach to the patient with pseudo-PEA.

Asystole – initial approach

The US is a useful tool to differentiate true asystole from fine ventricular fibrillation.[46] A straight line on the monitor without ventricular kinetics confirms the diagnosis of asystole, while the presence of kinetics acknowledges ventricular fibrillation. In the

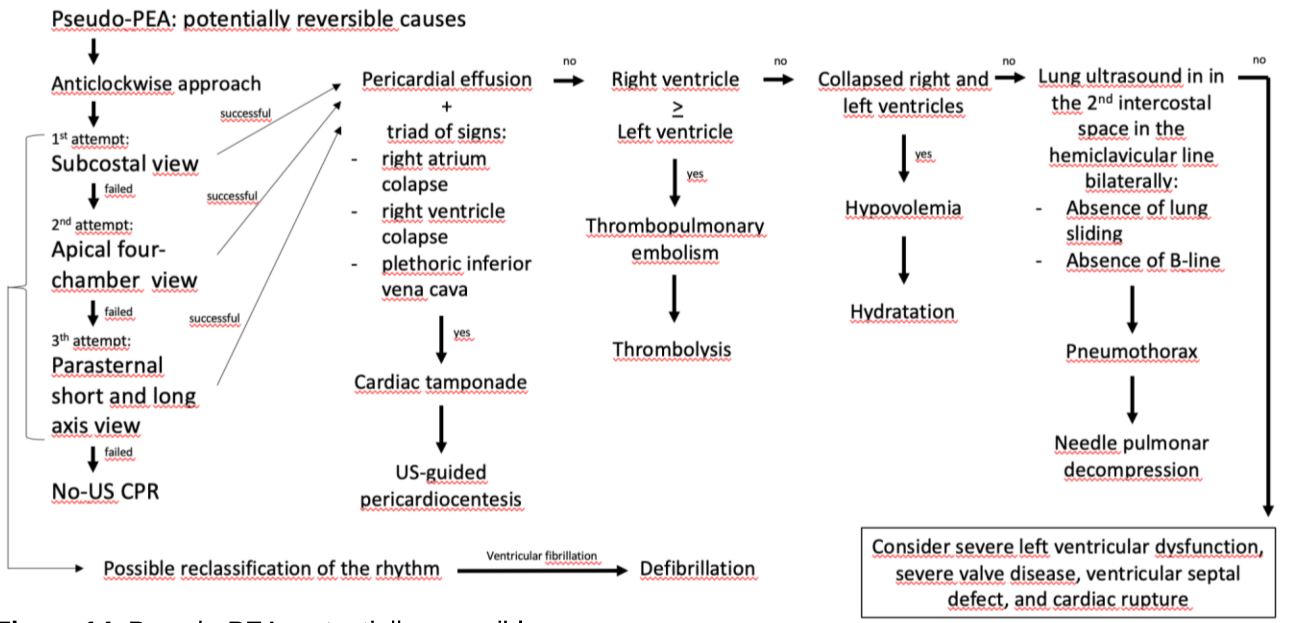

Figure 14. Pseudo-PEA: potentially reversible causes

second case, immediate defibrillation is indicated, with potential improvement in the prognosis. About 10 to 35% of asystoles can be reclassified with the US.[47] Although there is no current recommendation for this strategy, the US should be considered in straight-line SCA.

Prognostication

US can support sustained CPR efforts on specific diagnoses. The rate of ROSC was greater than 50% if a cardiac activity was detected versus 14.1% if none was documented. Ventricular kinetics is also associated with a greater survival after hospitalization (OR 3.6; 2.2-5.9), and chance of hospital discharge (OR 5.7; 1.5-21.9).48,49,50 A meta-analysis concluded that in patients with a low pretest probability of ROSC, absence of cardiac activity and reversible causes on echocardiography could predict a low probability of survival.[51] The prognosis of these patients was reserved regardless US findings and until now, US information is not enough to warrant the termination of resuscitation efforts.

Monitoring the quality of CPR

Unfortunately, ineffective CPR is common. Good quality chest compressions are critical to improve chances of ROSC. Several effective strategies are recommended to monitor quality of chest compressions: leader call-out, capnography, blood pressure curve, and real time feedback adhesive pads.[13,20] Although US evaluation of cardiac chambers in ongoing CPR is possible, the flow assessment is complex, and transducer movement difficulties interpretation.[52] These limitations, associated with the ease and superiority of other monitoring means, make the US not practical for this purpose. On the other hand, transesophageal echocardiography is promising in this scenario, however no standard method has been determined so far.[53,54]

Conclusion

Portable US is increasingly available and should be used during CPR. Several studies showed that the US can be quickly applied, does not impair CPR maneuvers, and impacts arrest and post-ROSC care when properly used.[55,56] The use of US in unstable patients, during cardiac arrest and after ROSC should be encouraged.[57,58]

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Abbreviations: AESP, asystole or pulseless electrical activity; CPA, cardiopulmonary arrest; POCUS, point-of-care ultrasound; CPR, cardiopulmonary resuscitation; PTE, pulmonary thromboembolism; US, ultrasound.