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Review

Usefulness of emergency ultrasound in nontraumatic cardiac arrest

Giovanni Volpicelli MD*

Department of Emergency Medicine, San Luigi Gonzaga Hospital, Orbassano (Torino), Italy

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Abstract Treatment of nontraumatic cardiac arrest in the hospital setting depends on the recognition of heart rhythm and differential diagnosis of the underlying condition while maintaining a constant oxygenated blood flow by ventilation and chest compression. Diagnostic process relies only on patient's history, physical findings, and active electrocardiography. Ultrasound is not currently scheduled in the resuscitation guidelines. Nevertheless, the use of real-time ultrasonography during resuscitation has the potential to improve diagnostic accuracy and allows the physician a greater confidence in deciding aggressive life-saving therapeutic procedures. This article reviews the current opinions and literature about the use of emergency ultrasound during resuscitation of nontraumatic cardiac arrest. Cardiac and lung ultrasound have a great potential in identifying the reversible mechanical causes of pulseless electrical activity or asystole. Brief examination of the heart can even detect a real cardiac standstill regardless of electrical activity displayed on the monitor, which is a crucial prognostic indicator. Moreover, ultrasound can be useful to verify and monitor the tracheal tube placement. Limitation to the use of ultrasound is the need to minimize the no-flow intervals during mechanical cardiopulmonary resuscitation. However, real-time ultrasound can be successfully applied during brief pausing of chest compression and first pulse-check. Finally, lung sonographic examination targeted to the detection of signs of pulmonary congestion has the potential to allow hemodynamic noninvasive monitoring before and after mechanical cardiopulmonary maneuvers.

1. Introduction

The American and European resuscitation guidelines provide algorithms for managing cardiac arrest whose main objectives are to ensure a constant blood flow to the brain while identifying the causes of the condition, and treating them, if possible [1-3]. The ability to succeed in resolving cardiac arrest is strictly time-dependent. The critical points to be pursued to improve prognosis are the early initiation of resuscitation maneuvers, the quick identification and treatment of underlying causes, and also the reduction of the duration of no-flow intervals. For these reasons, the only diagnostic technology recommended by the Advanced Cardiac Life Support (ACLS) protocols during resuscitation is active electrocardiography. Except for the evaluation of cardiac rhythm, all the other diagnostic procedures are based only on physical examination and patient's history. The need for quick initiation of resuscitation and strict limitation of pauses during chest compression prevents the use of sophisticated diagnostic devices.

* S.C.D.O. Medicina d'Urgenza, Ospedale San Luigi Gonzaga, Torino, Italy. Tel.: +39 011 9026603 (9026827); fax: +39 011 545001.
E-mail address: gio.volpicelli@tin.it.

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In recent years, emergency ultrasound has gained broader acceptance as a clinical tool for the clinician, and this has led to several new applications. Point-of-care focused ultrasound results in a narrower differential diagnosis and improved outcome in adult patients with undifferentiated hypotension [4]. Clinician's ability to assess bedside cardiac function by gross visual sonographic estimates is adequately accurate [5-8]. Moreover, sonographic evaluation of lung diseases has been proved to be extremely useful and accurate in the emergency settings [9-11]. Finally, newly developed, highly portable ultrasound devices have sufficient quality and resolution to assess cardiac status and performance: thus, they may deeply affect bedside diagnostic procedures. For these reasons, many recent studies and case reports have examined the application of emergency ultrasound to different scenarios of cardiac arrest [12-20]. Particularly, the ability of clinicians to rapidly obtain adequate images of the heart using subxiphoid approach in the cardiac arrest setting has been widely tested [12,13,15,17]. The general purpose of these studies is to find a compromise between the need to limit the pauses during chest compression coupled with the need for an increased diagnostic clarity.

This article reviews and discusses current knowledge on the diagnostic application of emergency ultrasound during cardiac arrest. We have identified some issues that have been mostly discussed in literature.

2. Diagnostic usefulness of sonography during pulseless electrical activity

Cardiac arrest can occur with 3 different rhythms: shockable rhythms, asystole, or pulseless electrical activity (PEA). The ACLS guidelines provide 3 different algorithms for the resuscitative procedures in cardiac arrest, depending on the rhythm that is recorded during the event. In recent years, major efforts have been made to show the usefulness of emergency ultrasound during PEA [12,13,16]. There are at least 2 main reasons explaining the interest of researchers on this application: the possibility of a more accurate and prompt differential diagnosis of the underlying potentially reversible condition and the opportunity to perform ultrasound during time intervals of chest compression.

2.1. Differential diagnosis of PEA

Pulseless electrical activity may result from a list of conditions that are potentially reversible. The importance of accurate and timely diagnosis of a reversible underlying cause is highly stressed in the ACLS algorithm of PEA, whereas in ventricular fibrillation the shock is the mainstay of treatment. Among the causes of PEA, some are easily recognizable by emergency ultrasound [4,8,16,21,22]. All of

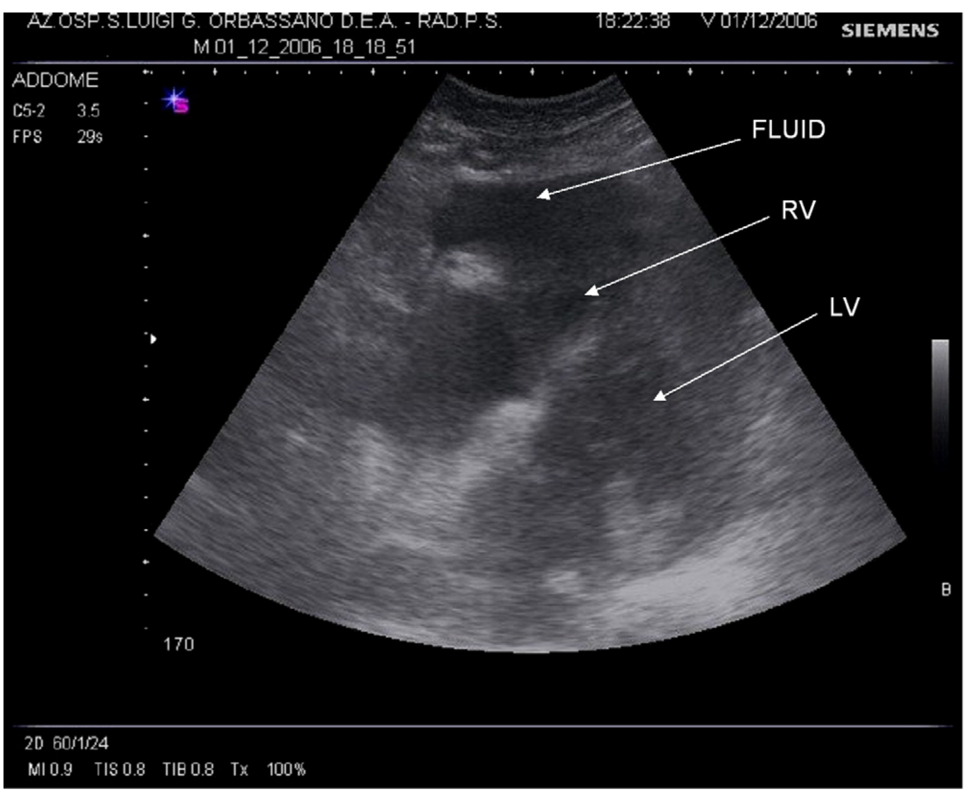


Fig. 1 Sonographic image of the heart of a patient with tamponade as a cause of cardiac arrest. This subxiphoid view, performed during pausing of chest compression and checking carotid pulse, shows some pericardial effusion (upper white arrow). In real time, the mechanical collapse of the right ventricle was clearly visible. RV indicates right ventricle; LV, left ventricle.

these are mechanical reversible conditions including severe hypovolemia, cardiac tamponade, pulmonary embolism, and tension pneumothorax. Diagnosis can be made by sonographic examination of the heart and lungs. Sonography can be performed with convex, microconvex, or cardiac probe, and the first organ to be examined is the heart. The usual window is subxiphoid, but parasternal and apical views can also be used depending on patient's constitution and presence of bandages, wounds, or others. The aim is to obtain a glimpse of the ventricles, possibly gaining a complete 4-chamber cardiac view. Once the heart is visualized and severe hypovolemia, cardiac tamponade, or pulmonary massive embolism are excluded, the same probe can be moved to obtain a parasternal anterior view of the lungs to rule out pneumothorax. Even a negative ultrasound examination is useful because it eliminates many conditions from the differential.

2.1.1. Severe hypovolemia

Reduction of intravascular volume is well detected by measuring sonographic left ventricular end-diastolic area [23]. In the most severe cases that may lead to cardiac arrest, the sonographic pattern of underfilled right ventricle in the presence of a small dynamic left ventricle is easy to detect [15,20]. In this case, the resuscitation maneuvers should be directed toward prompt fluid replacement while continuing chest compression. A valuable adjunct to cardiac imaging could be venous assessment. Sonography of the inferior vena cava by subxiphoid transverse scan represents fluid status [24]. Visualization of collapsed venous walls should confirm hypovolemia and the need for aggressive fluid resuscitation [25]. A common cause of PEA due to hypovolemia is the rupture of an abdominal aortic aneurysm. In case of a cardiac and venous sonographic pattern suggestive of hypovolemia, the probe should be slightly moved downward from the subxiphoid approach to evaluate the diameter of the abdominal aorta [20]. A dilated aorta up to 30 mm makes vascular rupture a likely cause of PEA. In this case, blood loss can be confirmed by a sonographic quick search of effusion in the pleural and peritoneal spaces [20].

2.1.2. Cardiac tamponade

Pericardial effusion causing cardiac tamponade is commonly encountered in cardiac arrest with PEA. Potentially, it is readily reversible if treated invasively with immediate pericardiocentesis. Diagnostic certainty by emergency cardiac ultrasound is crucial to guide the resuscitation team toward the rescue drainage [16]. Only effusion in the pericardial sac coupled with right chamber collapse demonstrates real cardiac tamponade, irrespective of the thickness of the fluid layer (Fig. 1). Emergency cardiac ultrasound by any thoracic window is highly accurate in detecting this association, even if performed by emergency physicians [26].

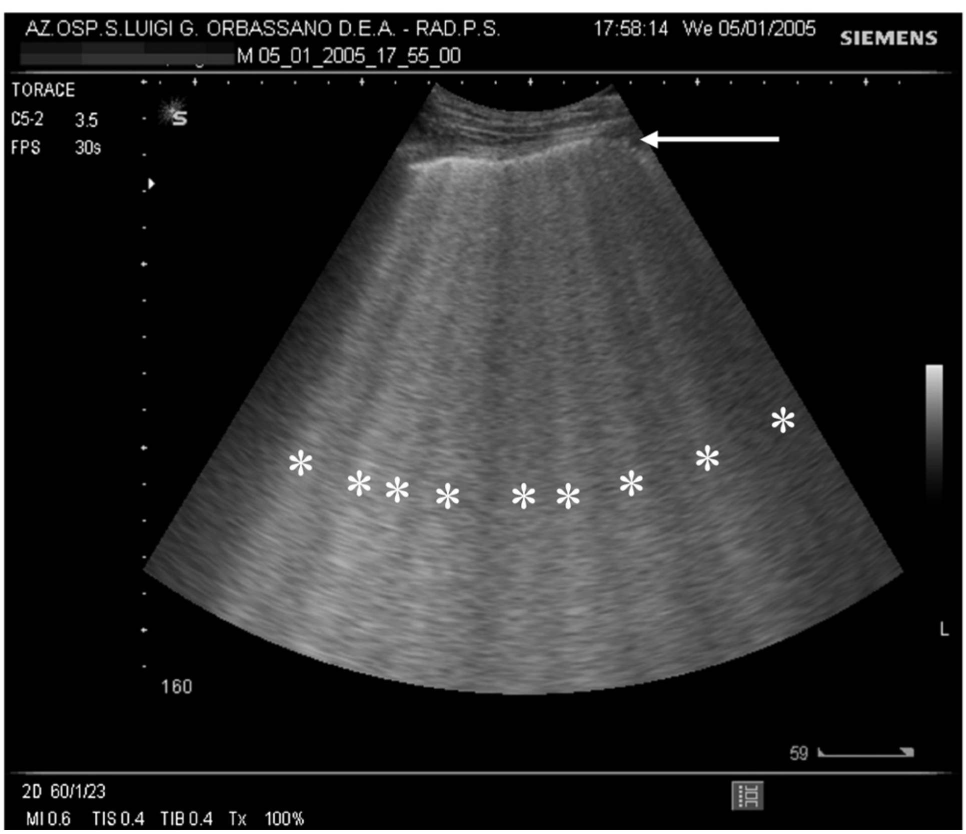


Fig. 2 This anterior oblique lung scan shows multiple vertical echogenic artefacts, named *B lines* (asterisks). They are a sign of properly aerated lung (thus, ruling out pneumothorax) and can be a sign of pulmonary congestion. White arrow indicates pleural line.

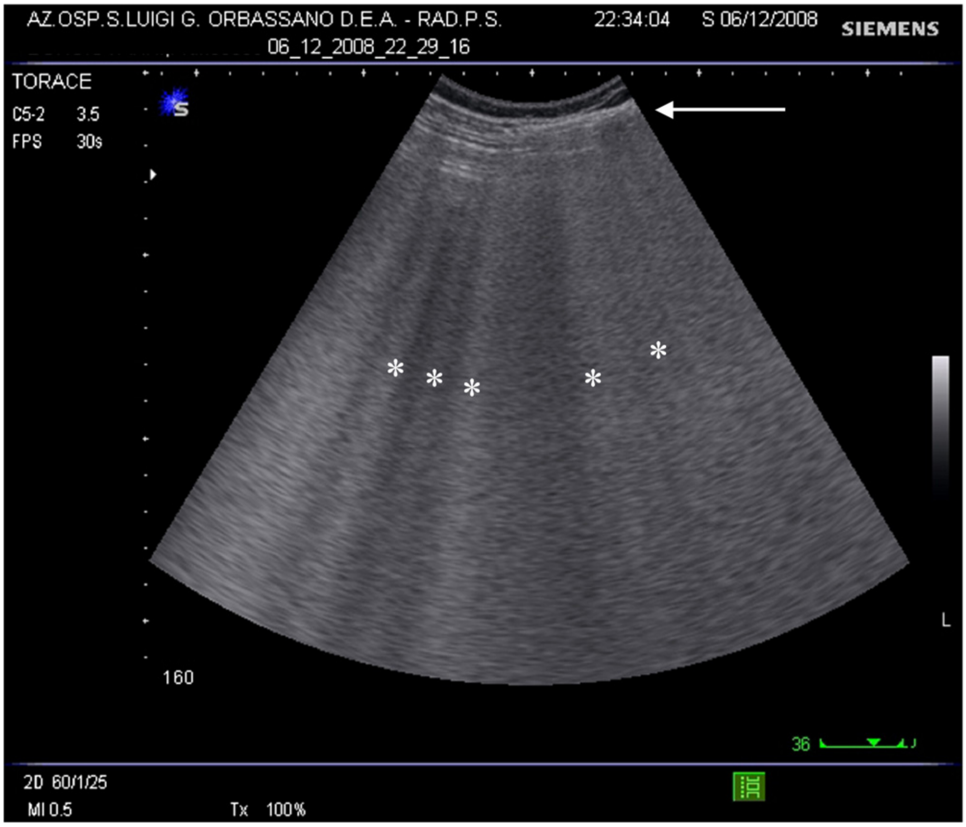


Fig. 3 Anterior oblique lung scan recorded during cardiac arrest due to tension pneumothorax with parietal subcutaneous emphysema. The scan is similar to that of Fig. 2. Notice some vertical echogenic artefacts (asterisks) that can mislead the sonographer because they may be confused with B lines. In this case, the echogenic horizontal line (white arrow) is not the pleural line but the muscular layer of the chest wall.

2.1.3. Massive pulmonary embolus

Another highly prevalent mechanic cause of PEA arrest is pulmonary embolus. Prompt administration of thrombolytic agents can be rapidly effective, and it is recommended in the ACLS guidelines because it has the potential of greatly impact outcomes [19]. The ability to immediately diagnose acute pulmonary embolus can be dramatically increased by the use of emergency echocardiography [19,21,22,27]. The finding of an engorged and dilated right ventricle with flattened left chambers is the sonographic pattern identifying acute obstruction of the pulmonary arterial bed as the cause of cardiac arrest [12,19].

2.1.4. Tension pneumothorax

In recent years, lung sonography has gained increasing diagnostic potential in detecting signs of pneumothorax [28]. The ability of sonography in allowing a prompt diagnosis of tension pneumothorax relies on 2 signs: the absence of lung sliding and B lines when the lung is visualized anteromedially along the mid-clavicular line [9,28,29]. The lung sliding is a slight to-and-fro movement of the echogenic pleural line during active or passive respiration [28]. The B lines are vertical echogenic rays that arise from the plural line, reach the lower edge of the screen without fading, and move synchronous with respiratory movements (Fig. 2) [29]. The sonographic lung pattern of absence of lung sliding and B lines is accurate in detecting pneumothorax, but some possible pitfalls should be remembered [30]. The presence of parietal emphysema may prevent the diagnosis of pneumothorax as it may lead into a false view of pleural motion and vertical artefacts very similar to B lines (Fig. 3). In this circumstance, safe detection of the pleural line by searching for the “bat sign” (Fig. 4) and bilateral comparison of lung scans are essential steps (Fig. 5A and B). Despite this limitation, emergency lung ultrasound is often critical to guide the physician toward the diagnosis and consequent prompt drainage of pneumothorax during PEA. Sonographic intercostal scans of both lungs can be performed in a few seconds by the same probe used for cardiac evaluation, just moving it from the subxiphoid to the anterior chest wall.

2.2. Pulse-check pausing

The other reason why researchers are testing the diagnostic application of sonography in PEA arrest is the possibility to perform it during pulse-check pausing of chest compression. The need to limit the no-flow intervals during resuscitation frustrates the use of emergency

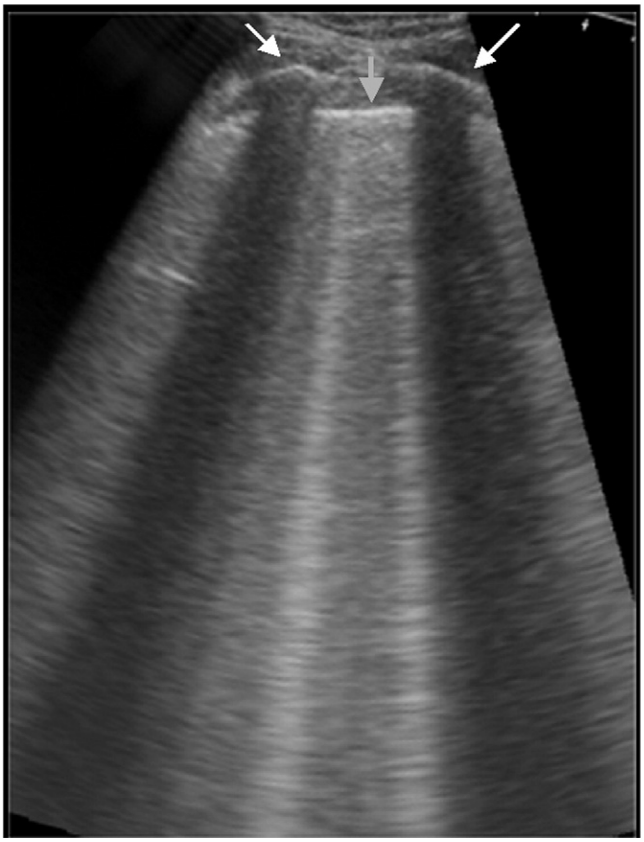


Fig. 4 This longitudinal lung scan shows the "bat sign": 2 adjacent ribs (white arrows) and the echogenic pleural line between and below them (gray arrow). Visualization of this sign is fundamental for the safe detection of the pleural line.

ultrasound in other conditions of cardiac arrest (asystole and shockable rhythm), where chest compressions are not allowed to be interrupted. On the contrary, the algorithm of PEA provides repeated pauses, up to 10 seconds each, during the resuscitative effort. Pauses during chest compression, while PEA persists, are essential to palpate a possible carotid pulse in presence of a cardiac rhythm potentially compatible with a spontaneous circulation [1-3]. These brief interruptions can be used to repeatedly perform real-time cardiac, vascular, and lung ultrasound targeted to the search of the above-mentioned sonographic signs. On discontinuation of chest compression, the probe must be positioned as fast as possible to gain a complete 4-chamber view of the heart and then moved to the lungs to check for pleural sliding and B lines. These targets can be achieved using even more than a pause for pulse-check during the cyclic algorithm of resuscitation [12,13].

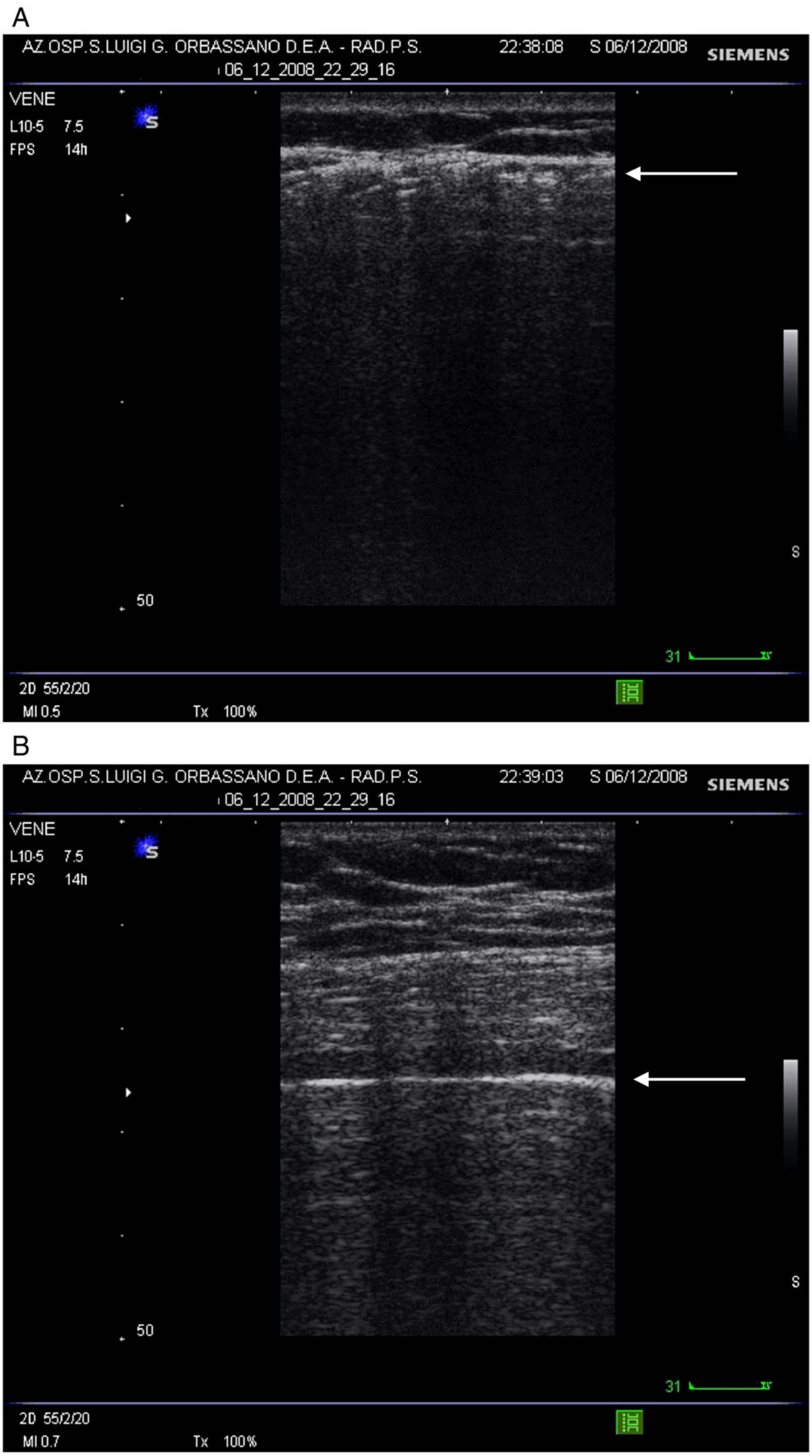
3. Diagnosis of cardiac standstill

Protocols for treating patients in cardiac arrest provide hints for cessation of resuscitative efforts. Time limit is commonly used to cease maneuvers, when the patient does not appear to be responding to treatment. Despite these indications, stopping resuscitation procedures is problematic, especially when electrical activity is still noted on a cardiac monitor [31]. Early abortion of resuscitative efforts can have catastrophic consequences, but also perpetuation on a patient who has already died has deleterious effects because a great deal of time and ED resources are wasted [14]. Current guidelines do not provide any accurate method for predicting certain death and real cardiac electromechanical dissociation. Sonography has the potential of providing information about the real contractility of the heart in pulseless patients, regardless of the rhythm displayed in the monitor. The sonographic pattern of cardiac standstill and complete absence of any motion indicate a poor outcome despite resuscitation [14]. Some authors noted that 100% of patients presenting with cardiac standstill detected by ultrasound did not survive the arrest despite resuscitative efforts [14-16,32]. Most of the patients of these studies presented with cardiac electrical activity, either PEA or ventricular fibrillation. These observations may help in the future in the implementation of existing guidelines with sonographic evaluation of real cardiac kinetic activity, which may be added to the criteria used to limit resuscitation efforts for cardiac arrest patients.

4. Application of sonography during continuous chest compression

Studies about the usefulness of emergency echocardiography performed during chest compression in cardiac arrest are not numerous. The reason is obvious, because accuracy of emergency ultrasound is likely to be too low when the hands of the rescuer push hardly on the thorax and hinder the search for an optimal acoustic window. Moreover, because of external compression, the real cardiac motion can be misdiagnosed. For these reasons, most of the trials on the use of sonography during cardiac arrest have been performed during pulse-check pausing of PEA algorithm or first pulse-check at presentation in the ED [12-14,32]. Nevertheless, some authors published their experience of sonography approach during continuous chest compression [18]. This approach is desirable, but the detection of most of the above-

Fig. 5 Bilateral anterior lung scans of a patient with cardiac arrest: the presence of echogenic horizontal lines at different heights allows diagnosis of right-sided parietal emphysema. In the right side, the echogenic horizontal line is the sonographic representation of the muscular layer of the chest wall (A, white arrow) and should not be confounded with the pleural line. Subcutaneous emphysema hides the pleural line, making detection of sonographic signs of pneumothorax impossible. The left lung shows a deeper echogenic horizontal line, that is the regular pleural imaging (B, white arrow).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mentioned sonographic signs presents a number of potential pitfalls [24].

When regular and effective chest compression is being performed at the usual rate of 100 min^{-1}, distinguishing between spontaneous or induced cardiac motion may be challenging. Moreover, assessment of severe impairment of intravascular volume is difficult even if the sonographic evaluation of the inferior vena cava is added to cardiac imaging. External compression could cause a confounding collapse of the venous walls and even flattened right and left ventricles, leading to a possible misdiagnosis. Finally, during compressions, thoracic acoustic windows are reduced and only the subxiphoid approach can be used. Even if preferable most of the time, this window does not always allow sufficient visualization of the heart chambers, and sometimes parasternal or apical sonographic approaches should be attempted. Further studies are needed to evaluate the exact accuracy of sonography during chest compression.

5. Hemodynamic evaluation by lung ultrasound

In recent years, the usefulness of lung ultrasound in the assessment of pulmonary congestion and extravascular lung water has been shown [33,34]. The sonographic method relies on detection of some vertical artefatcts named *B lines*, which are constant in cardiogenic pulmonary edema (Fig. 2) [35]. The number and diffusion of these artefacts correlate with extravascular lung water assessed by invasive determinations [34]. Implication is the possible use of real-time lung ultrasound in the monitoring of the hemodynamic state before and after a mechanical cardiopulmonary resuscitation. Moreover, pulmonary congestion could be monitored during fluid replacement in hypovolemic patients. The appearance of pulmonary B lines during volume resuscitation warns the clinician that a patient was becoming volume overloaded before he became dyspneic. Moreover, the absence of B lines could suggest euvolemia or hypovolemia more appropriately than physical findings. Lung ultrasound monitoring is a relatively simple and cost-saving diagnostic skill compared to echocardiography that is relatively complex and expensive.

6. Verification of tracheal intubation

Tracheal tube insertion is one of the major elements of resuscitation. A failed intubation can have catastrophic consequences in the management of patients with cardiac arrest. After insertion of the tube, the ACLS guidelines suggest a confirmatory procedure to exclude esophageal or endobronchial intubation. Moreover, once the tube has been inserted correctly and verified, position should be continuously monitored to avoid lung atelectasis due to accidental endobronchial displacement. The routine methods for confirmation of endotracheal tube are auscultation and end-tidal carbon dioxide detection, but the accuracy of both is limited [36,37]. Emergency ultrasound of the lung can be useful to verify and monitor tube position and can be proposed as a real-time method to be performed immediately after tube placement during cardiac arrest [38]. Lung ultrasound provides an indirect indicator of lung expansion by visualization of the pleural motion. This method is easy to perform during the resuscitation procedures and requires a few seconds. The probe should be positioned at the same anterior chest areas where the emergency physicians usually perform auscultation after tube placement, corresponding to the 2° to 3° intercostal spaces along the midclavicular line. Endotracheal position of the tube gives bilateral equal motion of the pleural line synchronized with ventilation (lung sliding). A regular lung sliding visualized on the left lung or on both sides is a sign of correct positioning of the tube and regular bilateral ventilation. During assisted ventilation, main bronchus position of the tube is suggested by absence of lung sliding of the left lung while the right pleural line is regularly moving. This sign indicates the need to move the tube backward. The bilateral absence of lung sliding is a sign of esophageal position of the tube and should urge the physician to perform a new attempt [28,39].

7. Conclusion

Cardiac arrest scenarios are often sudden chaotic, and physicians who attempt resuscitation need prompt diagnostic certainties. Sonographic evaluation can be applied during resuscitative maneuvers: it provides physicians with some novel items to take proper decisions. Procedural limitations are due to the need of continuous chest compressions necessary to generate blood flow during cardiac arrest. Nevertheless, trained personnel can apply sonography during the brief interruptions of chest compression provided by the ACLS guidelines. On the other hand, application of emergency ultrasound during chest compression deserves further careful evaluation by specifically designed clinical trials. Echocardiography and lung ultrasound can be used to clarify the cause of cardiac arrest. Moreover, the diagnosis of cardiac standstill can be confirmed by sonography with high accuracy. Real-time lung ultrasound can be useful to assess pulmonary congestion before and after cardiac arrest, having the potential to drive resuscitative fluid replacement. Finally, the role of lung ultrasound in verification of correct tracheal tube position may lead to its routine use during resuscitation. These and other items about the appropriateness of diagnostic emergency ultrasound during cardiac arrest deserve further studies. Particularly, the proper timing of sonographic evaluation during the resuscitative effort of cardiac arrest should be further examined.

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