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Application of ultrasound diagnostics in cardiopulmonary resiscitation

Примена ултразвучне дијагностике у кардиопулмоналној реанимацији

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SUMMARY

As bedside ultrasound is increasingly available and incorporated into emergency medicine. Focused echocardiographic evaluation in resuscitation (FEER) is a training program available to emergency doctors in order to ensure adequate application of echocardiography in the cardiac arrest (CA) setting. The FEER protocol provides an algorithm, whereby a "quick view" can be provided in 10 seconds during minimal interruptions in chest compressions. Performing ultrasound in the CA setting is challenging for emergency doctors. The International Liaison Committee on Resuscitation recommend the 'quick look' echocardiography view can be obtained during the 10-s pulse check, minimizing the disruption to cardiopulmonary resuscitation.

Keywords: cardiopulmonary resuscitation; critical care; advanced cardiac life support; ultrasound;

САЖЕТАК

Ултразвук се све више користи у ургентној медицини. Фокусирана ехокардиографска процена у реанимацији (ФЕЕР) је програм обуке намењен лекарима хитне помоћи који желе да се оспособе за примену ехокардиографије на локацији срчаног застоја. ФЕЕР протокол садржи алгоритам, у коме се "брзи поглед" може обезбедити у року од 10 секунди, током минималних прекида у грудним компресијама. Примена ултразвука у срчаном застоју представља велики изазов за лекаре хитне медицинске помоћи. Међународни комитет за реанимацију препоручује ехокардиографију по принципу "брзог погледа" који се може урадити током 10-секундне провере пулса уз минимално ометање кардиопулмоналне реанимације.

Кључне речи: кардиопулмонална реанимација; интензивна нега; ултразвук;

INTRODUCTION

Over the last decades a rapidly growing trend of the application of ultrasonography (USG) at the out-of-hospital level has become evident [1]. Along with the technological development, ultrasound (US) apparatuses has been improved while the trend of minimization leads to the creation of small, manually transportable equipments of good resolution and accessible prices [2]. Simple to manipulate, it finds application at the various location of the cardiac arrest – CA (at the patient's house/apartment, at out-door/working place) as well as in the ambulance vehicle under different conditions of external circumstances (light, temperature).

USG utilization in emergency medicine (EM) is presented through the Focused Cardiac Ultrasound ("FoCUS") where the EM physician who is not an imaging specialist, but has undergone a corresponding education within the field of echocardiography (echo), performs a focused USG examination. The advantage of prehospital application of a portable US apparatus is in its non-invasive method, it can be done in a short time beside the patient's bed and also it's possibility of multiple repetitions, while sensitivity in the detection of free liquid is as equal as by CT examination [3]. Insufficiencies are that US finding depends on the physician's education; specific injuries can not be identified, the visualization of retroperitoneal injuries is low, and also obesity and subcutaneous emphysema can substantially interfere examination. Although attempting for EM physicians, the US apparatus has their own limitation such as technical possibilities of the very apparatus (small monitor, lower resolution), length of examination duration, patient's condition and the possibility of positioning the patient into a certain position.

After adequate anamnesis/heteroanamnesis and a complete physical examination USG represents the unavoidable differential-diagnostic method in the early detection of emergency conditions at the prehospital level [4]. A detailed description of US findings is not expected from the EM physician, but only a statement whether a certain clinical pathology is present or not.

US DURING CARDIOPULMONARY REANIMATION (CPR)

Novelty within the field of US diagnostics during the application of the Advanced Life Support (ALS) [5] is that an educated EMS physician can use portable (handheld) devices with transthoracic echocardiogram. According to the current guidelines by the American Heart Association (AHA) and European Resuscitation Council (ERC), and on the basis of consensus International Liaison Committee on Resuscitation (ILCOR) [6-8], it is recognized the possible role of USG during CPR (Figure 1).

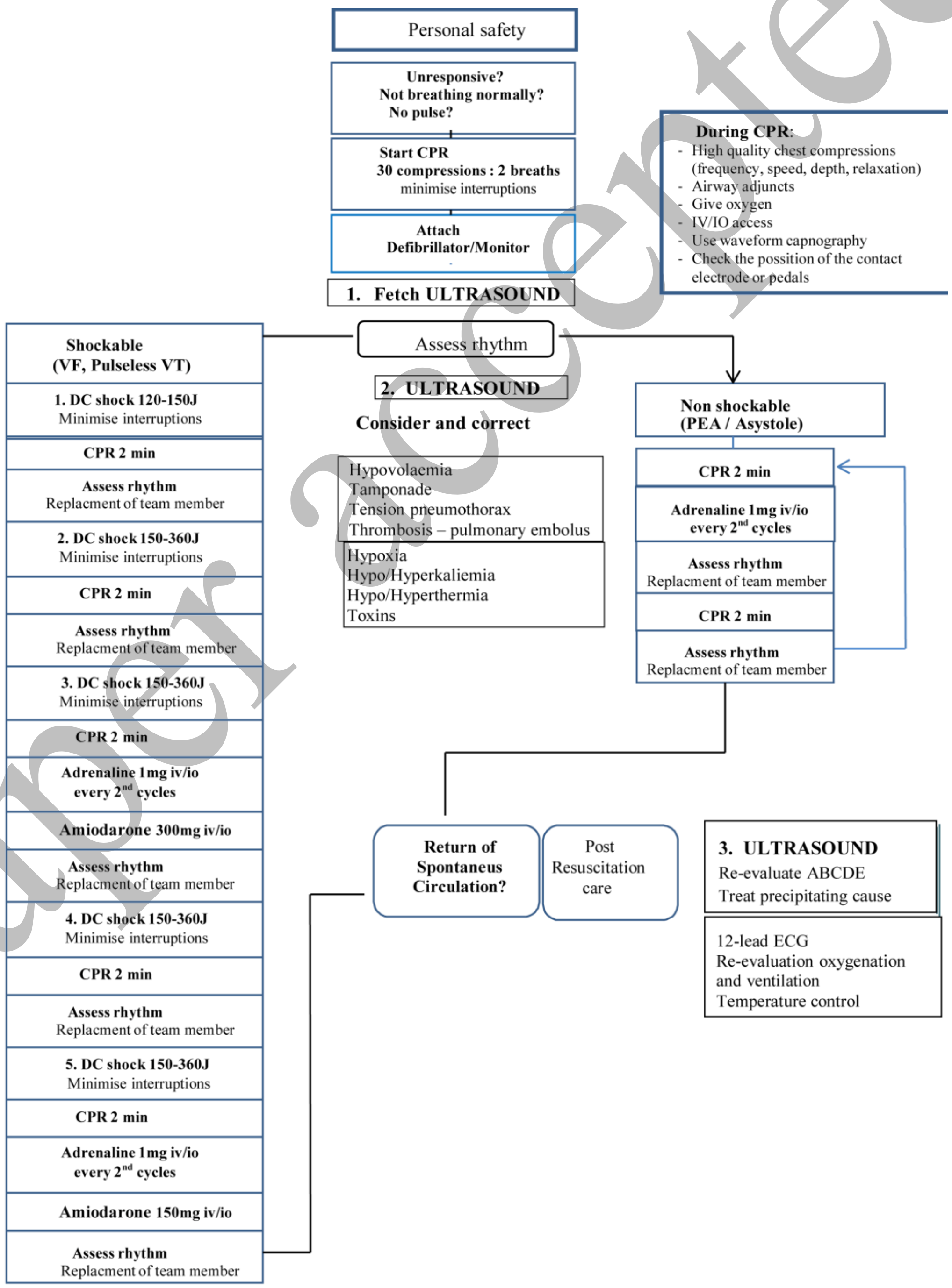

Figure 1. Ultrasonography during Advanced Life Support.

Ultrasound assessment is addressed above to identify and treat reversible (hypovolemia, cardiac tamponade, tension pneumothorax, pulmonary thromboembolism, aortic dissection, ischemia-region wall motion abnormality) causes of cardiac arrest, and identify low cardiac output states ('pseudo-PEA'). Several studies have investigated the application of USG during CPR [9,10] with the aim of detection of reversible causes (DRC).

Focused Echo Evaluation in Resuscitation (FEER) [11] involves application of emergency procedures in ten steps with CPR measures applied at the same time (Table 1). It is recommended to perform USG examination during the pause in chest compressions of about 10 seconds planned for carotid pulse check-up. Indications for immediate echosonography are presented on table 2.

Table 1. Focused Echo Evaluation in Resuscitation [11].

PHASES	STEPS
High quality CPR, preparation and information of prehospital team members	1. Begining CPR (5 circles 30 chest compression: 2 artificial ventilations. 2. Inform other team members: "Preparing echo". 3. Preparing and testing US apparatus. 4. Adapt to the situation (take the best position in relation to the patient and other team members).
Application of US	5. Inform team members that US examination will be performed no longer than in 10 sec in the period of minimal interruptions of chest compression planned that another team member make the check-up of the carotid pulse. 6. Give command: "Stop with compressions". 7. Place US sonde above the patient's subxiphoid region during the last (30^{th}) chest compression. 8. As soon as possible perform US examination of the subcoastal region. If echogram is not done after 3 sec attempt US examination of the parasternal zone during the next 5 sec.
Continue CPR	9. After 9 sec give command:"Continue with CPR".
Interpretation of findings and planned emergency interventions	10. Communication with team members (inform about US findings) and application of emergency therapeutic intervention (pericardiocentesis, thoracocentesis, thrombolytic drugs, etc.).

Table 2.Indication for immediate echosonography [11].

Before reanimation	Unconscious person Acute myocardial infarction Atypical chest pain: suspected aortic dissection, suspected aneurysm Penetrating trauma, blunt trauma Hypotension, shock of unknown cause Acute severe dyspnea Sincope of young person Venous thrombosis of thoracic or abdominal aorta Iatrogenic complications
During CPR	PEA Suspected cardiac tamponade Early detection of ROSC Bradycardia-asystole, pacemaker-ECG Performance CPR Efficient chest compression
Post-resuscitation care	Hypotension, adaptation to vasopressors

Echo-Guided Life Support (EGLS) algorithm contains "Airway–Breathing-Circulation" sequence of 5 questions [12]: 1) Is it a pneumothorax? 2) Is there a presence of cardiac tamponade? 3) Is the patient hypovolemic? 4) If poor function of the left ventricle is noted, is that the main cause of shock? 5) Are there a signs of right ventricle failure?

USG as a diagnostic method can also answer the following questions: Is the tracheal tube correctly positioned? Are there signs of return of spontaneous circulation (ROSC)? Is there a presence of cardiac rhythmic motion in pulseless electrical activity (PEA)?

TENSION PNEUMOTHORAX (TP)

Dramatic clinical condition can be exclusively caused by mistake during the mechanical ventilation enabling the breach of the fresh air into the pleural space. Thoracic needle decompression is lifesaving in TP. In the TP diagnostics USG was used for the first time in 1987 in a study by Wernecke et al. [13]. Since that time a great number of investigations have proved a high sensitivity and specificity of USG in the diagnostics of TP, which have overcome the classical radiography of the thorax and are close in sensibility and specificity to multidetector computed tomography (MDCT) [14]. Owing to the technological progress US diagnostics has gained its position in the TP diagnostics in emergent conditions when making diagnosis is of vital significance. Therefore FAST (Focused Assessment with Sonography in Trauma) protocol has been supplemented with a chest examination (lungs), so that now E-FAST (Extended-FAST) protocol is used which also contains standardized lung examination [15].

On examination the patient lies on the back, while the physician is mostly positioned on his/hers right side. Initially, the insertion site of the catheter is located in the 2nd intercostal space on the mid clavicular line in the sagittal plane (with positioning indicator situated via cranium) [16, 17]. At the beginning of examination anatomic structures should be identified so that two ribs and the belonging intercostal space are within the visual field. The ribs can be visualized as glowing hyperechogenic reflective areas with posterior acoustic shadow, while in the intercostal area a hyperechogenic line can be seen that corresponds to the pleural leaves ("the bat sign").

By the normal US finding the most significant sign is sliding of the visceral toward the parietal pleura („pleural sliding", „lung sliding sign") [18] during respiratory movements. The M-mode cursor is positioned over the hyperechogenic pleural line, while two different pictures appear on the screen. Immobile parts of the chest wall above the pleural line form a picture of horizontal lines („waves") ,while pleural leaves create a granular form („send") below the pleural line that gives a characteristic „seashore sign" [18].

During the examination in B-mode,in a normal finding we can notice B-lines or „comet-tail artifacts (sign)" [19], which is the consequence of reverberation artifacts that present as vertical hyperechogenic lines extending from the pleural line to the pleural parenchyma.

US signs of pneumothorax [20]: Absence of the „lung sliding sign" in TP is the consequence of air presence among the leaves of the parietal and visceral pleura. The air separates pleural leaves thus enabling the visceralization of the visceral pleura and leads to the absence of pleural sliding in B-mode. By using M-mode the absence of pleural sliding is presented as a uniform picture of horizontal lines above and below the pleural line („barcode sign"' or „stratosphere sign"). The existence of this phenomenon presents the picture of TP in this space. The absence of B-lines („comet-tail sign") in TP is the result of air accumulation in the pleural space, which disturbs the propagation of ultrasound waves and eliminates the gradients of acoustic impedance. The negative predictive value of B-lines is high, 98-100%, so that the visualization of only one B-line excludes TP diagnosis.

A-lines are present in patients with TP, while due to the absence of B-lines they are clearly seen. „Lung-point sign" represents TP border that develops on the periphery and defines the real size of TP. In this sign, in M-mode the „seashore sign"' and the „stratosphere sign" are exchanged during time. This sign has the sensitivity 79% and specificity100%.

CARDIAC TAMPONADE

Clinical syndrome is life-threatening condition caused by the increased pericardial pressure developed due to the accumulation of the fluid into the pericardial space [21]. With each cardiac contraction this condition deteriorates resulting in PEA. US heart examination is the diagnostic method of the first choice in the diagnostics of TS that should be done without postponement. The most frequent finding is the feature of pericardial discharge, i.e. the separation of pericardial leaves during the entire cycle [21]. There are several echo signs of TP danger, so that accordingly 2D-mod can register by presentation the increase of RV in the expirium and collapse of the right prechamber in inspirium (Figure 2). RPS collapse in systole in the duration longer than 1/3 of systole duration of over 1/3, paradoxical movements of the interventricular septum and RV collapse in diastole. FAST examination includes the subxiphoid window and/or parasternal "long axis" approach [23]. In penetration wounds US beside a bed has 100% of sensitivity and 97% of specificity in detecting pericardial effusion and the need for emergent pericardiocentesis [22]. The level of suspected TS must be increased on the "present until proven differently" when the injury is in the rectangular (so-called cardiac box) that form the horizontal lines along the clavicle over the nipples to the ribs edges and the lower horizontal line that joins the vertical lines at the site of connection with ribs edge. Echocardiographically, separation of epicardial layers around the heart can be discovered when the quantity of fluid around the heart is over 15-35 ml. The speed of fluid accumulation defines the clinical course. Therapeutic care assumes emergent pericardiocentesis which is done under US check-up at the site where "the deepest pocket" of fluid is perceived. Resuscitation with needle pericardiocentesis can be of help in carefully selected patients.

Figure 2. Cardiac tamponade.

PULMONARY THROMBOEMBOLISM (PE)

It is one of the frequent immediate causes of CA in prehospital conditions [24, 25]. Therefore, it seems the logical and appealing test for many patients with acute chest pain and/or heavy breathing where PE is one of potential disorders. US examination in patients with suspected PE offers numerous data on the morphology and function of RV, right cardiac pre-chamber (RPC), PA visualization and indirect assessment of pulmonary hypertension. Also, we may exclude with certainty other chemodynamicaly unstable diseases which can imitate PE, such as extensive myocardial infarction, cardiac tamponade or aortic dissection. Echocardiographically, signs of acute overload of RV by pressure (dilatation and hypokinesis of RV, tricuspid regurgitation, increased systolic pressure in RV<60mmHg, dilated non-collapsible right hollow vein - RHV) that indirectly indicate PE (Figure 3).

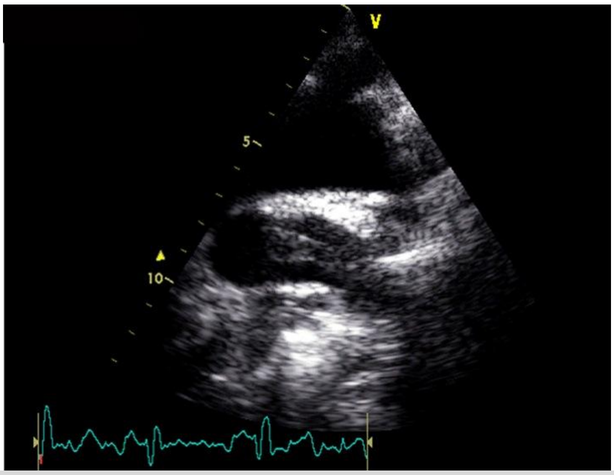

Figure 3. Thrombus in the pulmonary artery right branch – suprasternal cross-section.

The most direct sign of PE is a direct visualization of thrombosis in the PA. In PE it has sensitivity of 80% and specificity of 97%, and it is increased with RV dysfunction. Ribeiro et al. concluded that RV dysfunction confirms the diagnosis of PE and that it is associated with mortality [26].

Echo signs of PE are:

RV dilatation – Due to pulmonary hypertension caused by PE, increased pressure in the right heart and increased relative separation of RV that is normally about 2/3 cross-section of LV. These changes are best detected in the apical projection of four cavities [27, 28]. RV dilatation in the apical projection is considered the increased relation of RV end-dyastolic dimension in comparison with LV larger than1. In the assessment of RV dilatation the long parasternal axis is also of great use in which the infundibular portion can be best visualized. According to different authors, RC dilatation is considered the end-dyastolic dimension of RV larger than 27, i.e. 30 mm. If RV is not evidently larger than LV PE can be excluded with a high probability as the cause of CA.

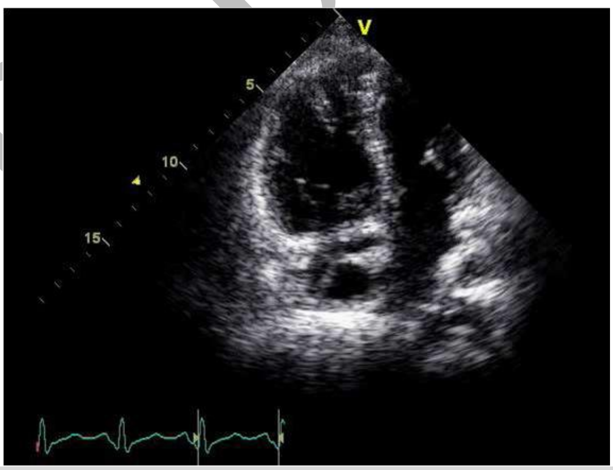

Figure 4. Right ventricule dilatation and right ventricle hypokinesis – McConnell's sign.

Right ventricular hypokinesis – McConnell's sign (Figure 4): RV dilatation with decreased size of LV (relationship RV/LV >0.7). Besides, the association between hypokinesis of RV free wall and preserved top contractility (McConnell sign). Specificity of this sign in the diagnostics of PE is about 94% while the sensitivity is about 20% [29].

Flattening of interventricular septum [30] – Remodeling of RV due to overburden by pressure during PE; echocardiographically it is viewed by its dilatation, regional disorder of free wall kinetics as well as by the pathological mobility of interventricular septum. Having in mind that the compensatory mechanism of dilatation is limited, acute pressure increase in RV can additionally result in the interventricular septal shift from the right toward the left that can be seen during systole and diastole. By flattening of the interventricular septum LV acquires the letter D shape. Such change is best perceived in the short parasternal projection, but can be also visualized in M-mode in the long parasternal projection or double dimensionally in the above mentioned short parasternal and apical projection of four cardiac chambers. The interventricular septum shift, particularly if it occurs during diastole, can compromise LV diastolic filling and cause the patient's additional hemodynamic deterioration. Therefore, US detection of interventricular septal shift is of high importance in the decision to administer fluid therapy with the aim to prevent additional LV dilatation and obstruction of inflow into the right heart.

Tricuspid regurgitation – Maximal speed of tricuspid regurgitation (TR) is the most useful method for the stratification of patients according to the level of systolic pressure in the RV, i.e. pulmonary artery. In support of PE speaks the speed of TR outflow that is between 2.8-3.8, as well as the pressure gradient which is not over 60 mmHg. The speed above those quoted, indicate at primary PE or hypertension of some other etiology.

Sign "60/60"– Dicrotic notch in the profile of RV (AcT) outflow tract. It represents the acceleration time in the RV outflow tract < 60 ms in the presence of systolic gradient TR < 60 mmHg gradient [30].

Other indirect morphological characteristic of RV burdened by pressure include: Dilated (>20mm) hollow lower vein (HLV) that does not collapse during inhalation; Dilated right pre-chamber (RPC) - dilated HLV with collapse index below 40% is a significant sign of increased pressure in RPC; Dicrotic notch in the profile of RV (AcT) outflow tract

HYPOVOLEMIA

Inadequate volume of the circulating blood is the most frequent cause of PEA of cardiac arrest form [6]. A hypovolemic patient has insufficient filling (<1 cm) or dynamic lower hollow vein (LHV). In the patient with spontaneous breathing the size of LHV is increased with each inspirium, while in patients with CA ocurs the opposite if applying artificial ventilation. In patients on mechanical ventilation the increase of LHV size > 18% is in harmony with preload dependence. Each change in size is the indication for a rapid application of fluid during CPR. Echo finding [10] (Table 3, Figure 5).

Table 3. Echocardiographic signs of hypovolemia [10].

Parameter	Static / dynamic	Finding suggestive of hypovolemia	Pitfalls
LV cavity size and function	Dynamic	Small, hypercinetic with end-systolic cavity obliteration	Inotropic support, severe valvular regurgitation, left ventricular hypertrophy
LV end-diastolic area	Static	$5.5 cm^2/m^2$ BSA	As above
IVC size and inspiratory collapse	Dynamic	> 10 mm collapse on inspiration	Spontaneously breathing patients in sinus rhythm only
IVC size and expiratory airway collapse	Dynamic	Variable	Intubated and mechanically ventilated. Sinus rhythm only

BSA – body surface area; IVC – inferior vena cava.

Figure 5. Echocardiographic signs of hypovolemia.

includes a significantly reduced end-diastolic chamber size and "kissing" ventricular walls during systole. If hypovolemia is indicated possible causes should be searched using US abdominal examination by application of FAST protocol and aortal check-up (aneurysm or rupture of abdominal aorta). Echo finding can confirm the presence of internal bleeding.

POSITION OF ENDOTRACHEAL TUBUS

If the endotracheal tube is in its correct position by US examination [31] only one air filled structure is visible on the neck; in esophageal intubation the characteristic US finding of a duck is the characteristic. US in CA can be a diagnostic method, prognostic method (ROSC/non-ROSC) and ethical method (making decision on emergency transport or interruption of CPR on field). However the decision on the interruption of resuscitation effort can not be passed just based on the US finding.

If the patient is in VF or pulseless VT ultrasound finding is of limited value. In the patient in pulseless electrical activity (PEA) or asystole US has a significantly higher diagnostic significance. According to the new CPR algorithms (2015) [32], if the initial rhythm of cardiac arrest PEA, the application of portable US can enable differentiation between the true PEA from a pseudo-PEA. Beside the above quoted, US finding can indicate at the reduced LV ejection fraction, the finding of free fluid in the peritoneal cavity, the size of abdominal aortic aneurysm, the presence of deep vein thrombosis, etc.

In an interesting letter to the editor published in the Resuscitation [33] authors have presented the analysis to evaluate the possibility to check the efficacy of heart compressions using ultrasoundand to guide changes of hands position in order to improve cardiac contractility. Preliminary observations indicate that changes of hands position guided by USG could improve the quality of chest compressions and important hospital information could be obtained without stopping CPR.

CONCLUSION

Ultrasound during CPR should be performed during the rhythm check, preferably the first rhythm check and each subsequent check, which is recommended to be no longer than 10 seconds, to prevent a fall in coronary perfusion pressure. It is therefore advisable to get the ultrasound machine to the patient's bedside as early as possible. The time required to position the machine, turn it on, to ensure that the correct probe is attached, in position, and screen settings are optimized, can be significant. Hence, the second action in the ECLS algorithm: Attach Defibrillator/Monitor should be replaced with Attach Defibrillator/Monitor and fetch ultrasound. A priority during CPR is to minimize interruptions in CPR, which is associated with a drop in coronary blood flow and outcome, 'Plan before interrupt compressions'. This would include planning to perform ultrasound during the pulse check, i.e. positioning the probe on the patient and readying the ultrasound machine.

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