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REVIEW ARTICLE / ПРЕГЛЕД ЛИТЕРАТУРЕ

Application of ultrasound diagnostics in cardiopulmonary resuscitation

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SUMMARY
Ultrasound is becoming 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 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 cardiac arrest setting is challenging for emergency doctors. The International Liaison Committee on Resuscitation recommend the 'quick look' echocardiography view can be obtained during the 10-second pulse check, minimizing the disruption to cardiopulmonary resuscitation.
Keywords: cardiopulmonary resuscitation; critical care; advanced cardiac life support; ultrasound

INTRODUCTION

Over the last several decades, a rapidly growing trend of the application of ultrasonography (USG) in out-of-hospital settings has become evident [1]. Along with the technological development, ultrasound (US) apparatuses have been improved, while the trend of minimization leads to the creation of small, manually transportable equipment of good resolution and accessible prices [2]. Easy to employ, it finds application at various locations where cardiac arrest (CA) might occur (in patients' homes, outside, at working places, etc.) 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 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 advantages of prehospital application of a portable US apparatus are in its non-invasive method, in the fact that it can be done in a short amount of time beside the patient's bed, and in the possibility of multiple repetitions, while sensitivity in the detection of free liquid is equal to the computed tomography examination [3]. Insufficiencies are that US findings depend on the physician's education; specific injuries cannot be identified, the visualization of retroperitoneal injuries is low, and obesity and subcutaneous emphysema can substantially interfere with the examination. Although tempting for EM physicians, the US apparatus has its limitations, such as technical possibilities (small monitor, lower resolution), length of the examination, and the 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 RESUSCITATION

A novelty within the field of US diagnostics during the application of the Advanced Life Support is that an educated EMS physician can use portable (handheld) devices with transthoracic echocardiogram [5]. According to the current guidelines by the American Heart Association and the European Resuscitation Council, and on the basis of the consensus of the International Liaison Committee on Resuscitation (ILCOR), a possible role of USG during CPR is recognized (Figure 1) [6, 7, 8].

Ultrasound assessment is addressed above to identify and treat reversible (hypovolemia,

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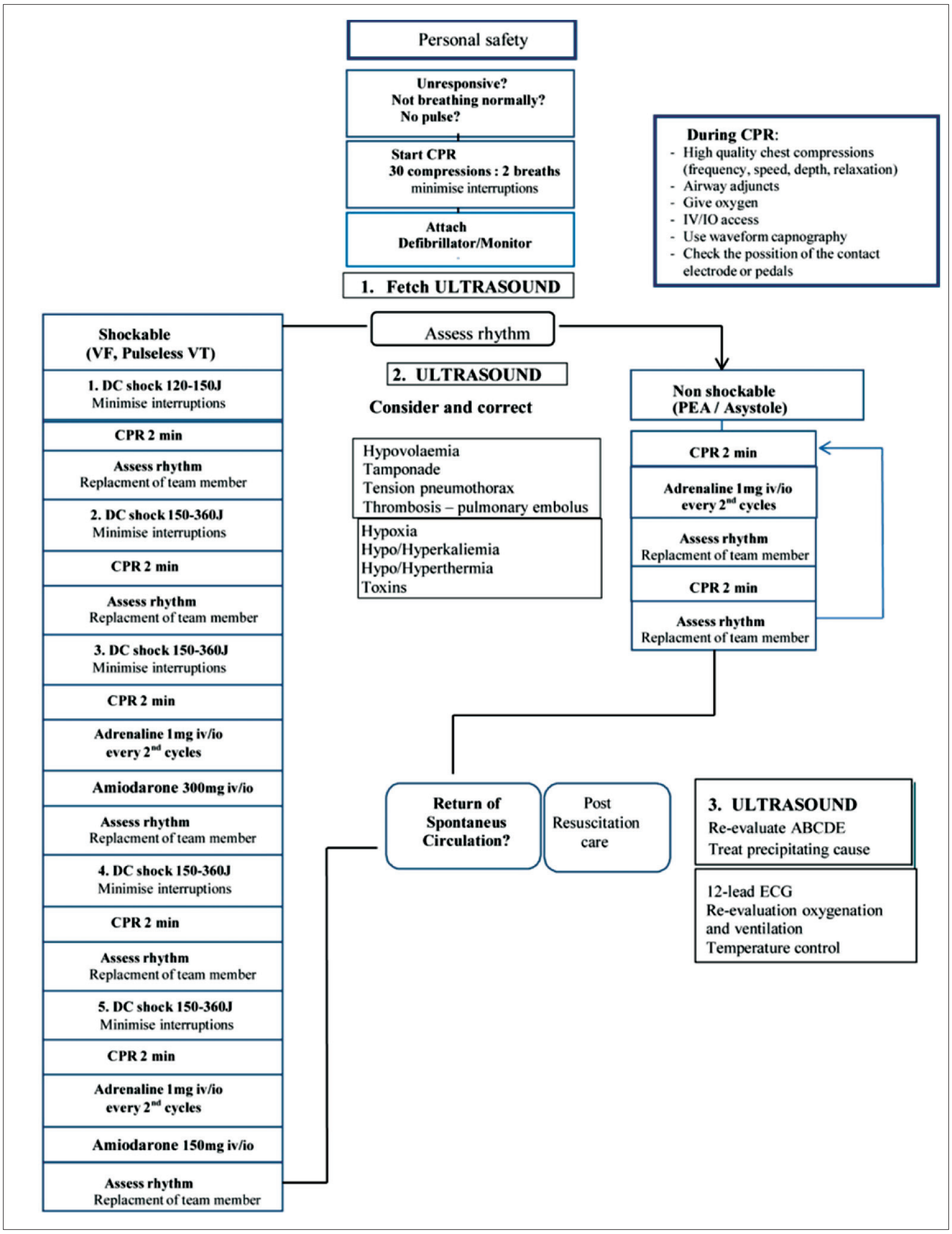

Figure 1. Ultrasonography during Advanced Life Support

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

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

The Echo-Guided Life Support algorithm contains the "Airway–Breathing–Circulation" sequence of five questions [12]: 1) Is it a pneumothorax? 2) Is there cardiac tamponade? 3) Is the patient hypovolemic? 4) If poor function of the left ventricle is noted, is this the main cause of shock? 5) Are there 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 cardiac rhythmic motion in pulseless electrical activity (PEA)?

Table 1. Focused Echo Evaluation in Resuscitation [11]

Phases	Steps
High quality CPR, preparation and information of prehospital team members	1. Begin CPR (5 sets of 30 chest compressions: 2 artificial ventilations) 2. Inform other team members: "Preparing the echo" 3. Prepare and test the US apparatus 4. Adapt to the situation (assume 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 10 seconds in the periods of minimal interruptions of chest compressions planned so that another team member can check the carotid pulse 6. Give the command: "Stop the compressions" 7. Place the US probe above the patient's subxiphoid region during the last (30th) chest compression 8. Perform US examination of the subcoastal region as soon as possible; if the echogram is not done after 3 seconds, attempt US examination of the parasternal zone during the next 5 seconds
Continue CPR	9. After 9 seconds give the command: "Continue with CPR"
Interpretation of findings and planned emergency interventions	10. Communicate with team members (inform them about US findings) and apply appropriate emergency therapeutic intervention (pericardiocentesis, thoracocentesis, thrombolytic drugs, etc.)

CPR – cardiopulmonary resuscitation; US – ultrasound

Table 2. Indications 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 Syncope in a 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 Performing CPR Efficient chest compression
Post-resuscitation care	Hypotension, adaptation to vasopressors

PEA – pulseless electrical activity; ROSC – return of spontaneous circulation CPR – cardiopulmonary resuscitation

TENSION PNEUMOTHORAX

Dramatic clinical condition can be exclusively caused by a mistake during the mechanical ventilation enabling the breach of the fresh air into the pleural space. Thoracic needle decompression is lifesaving in tension pneumothorax (TP). In the TP diagnostics, USG was used for the first time in 1987 in a study by Wernecke et al. [13]. Since then, 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 [14]. Owing to the technological progress, US diagnostics has gained its position in the TP diagnostics in emergent conditions when reaching diagnosis is of vital significance. Therefore, Focused Assessment with Sonography in Trauma (FAST) protocol has been supplemented with a chest examination (lungs), so that now E-FAST (Extended-FAST) protocol is used, which also contains a standardized lung examination [15].

On examination, the patient lies on the back, while the physician is mostly positioned on his/her right side. Initially, the insertion site of the catheter is located in the second intercostal space on the mid-clavicular line in the sagittal plane (with positioning indicator situated via cranium) [16, 17]. At the beginning of the 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 the sliding of the visceral towards the parietal pleura ("pleural sliding," "lung sliding sign") during respiratory movements [18]. 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 ("sand") 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.

The US signs of pneumothorax are described by Zhang et al. [20]**:** the 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 and amounts to 98–100%, so that the visualization of only one B-line excludes the 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 the TP border, which 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 over time. This sign has a sensitivity of 79% and a specificity of 100%.

CARDIAC TAMPONADE

Clinical syndrome is a 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 choice in the diagnostics of cardiac tamponade, which should be done without delay. 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 the 2D mode can accordingly register the increase of the right ventricle (RV) in expirium and collapse of the right atrium (RA) in inspirium (Figure 2), RA collapse in systole in the duration longer than 1/3 of the 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 [22]. In penetration wounds, bedside US has 100% sensitivity and 97% specificity in detecting pericardial effusion and the need for emergent pericardiocentesis [23]. The level of suspected cardiac tamponade must be increased to "present until proven differently" when the injury is rectangular (so-called cardiac box), so that it forms horizontal lines along the clavicle over the nipples to the rib edges, and a lower horizontal line that joins the vertical lines at the site of connection with rib edges. 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 performed under US guidance at the site where "the deepest pocket" of fluid is perceived. Resuscitation with needle pericardiocentesis can be of help in carefully selected patients.

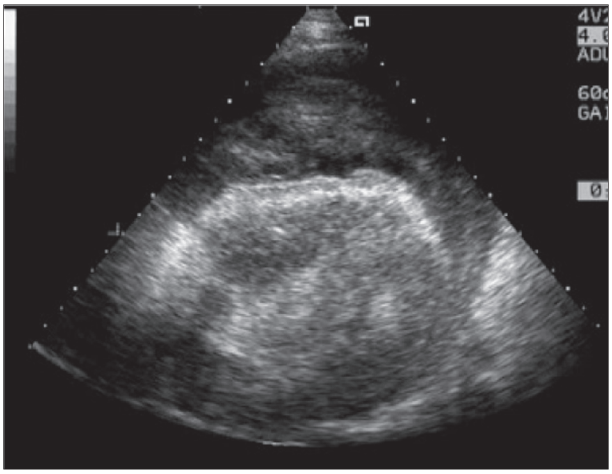

Figure 2. Cardiac tamponade by Dr. Ivan Stanković, Zemun Clinical Hospital Centre, Department of Internal Medicine, Belgrade, Serbia

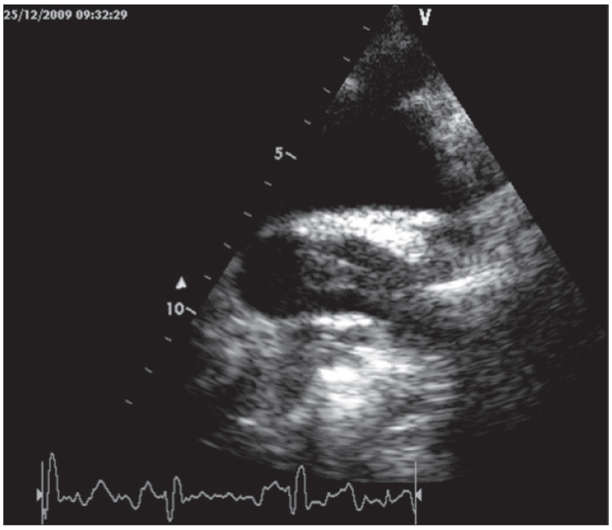

Figure 3. Thrombus in the pulmonary artery right branch – suprasternal cross-section (source: Putniković B. Echocardiography in pulmonary thromboembolism; Medical Days of Sokobanja 2013, Sokobanja, Serbia, October 4–6, 2013)

PULMONARY THROMBOEMBOLISM

Pulmonary thromboembolism (PE) is one of frequent immediate causes of CA in prehospital conditions [24, 25]. Therefore, it seems a 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, RA, pulmonary artery visualization, and indirect assessment of pulmonary hypertension. In addition, we may exclude with certainty other hemodynamically unstable diseases that 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 < 60 mmHg, dilated non-collapsible right hollow vein) that indirectly indicate PE (Figure 3).

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

There are several echo signs of PE.

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 the cross-section of the LV (left ventricle). 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 the RV end-diastolic dimension in comparison with LV larger than 1 mm. 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-diastolic dimension of the RV larger than 27, i.e. 30 mm. If the RV is not evidently larger than the LV, PE can be excluded as the cause of CA with high probability.

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

Flattening of interventricular septum [30] – remodeling of the 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 the interventricular septum. Having in mind that the compensatory mechanism of dilatation is limited, acute pressure increase in the 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 abovementioned short parasternal and apical projection of four cardiac chambers. The interventricular septum shift, particularly if it occurs during diastole, can compromise the 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 (TR) – maximal speed of 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 cm/s, as well as the pressure gradient which is not over 60 mmHg. The speeds above the stated ones indicate primary PE or hypertension of some other etiology.

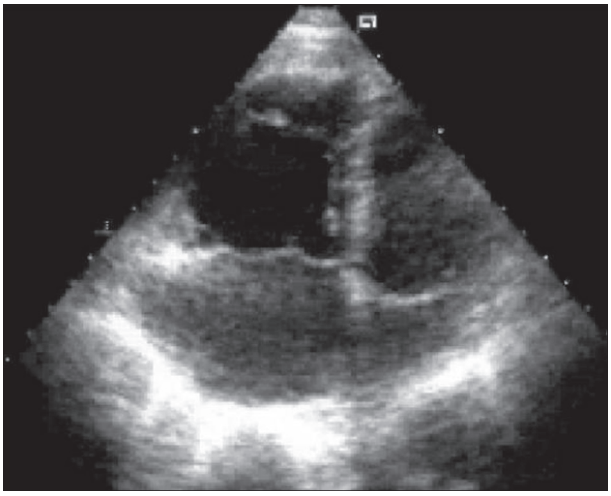

Figure 4. Right ventricle dilatation and hypokinesis – McConnell's sign, by Dr. Ivan Stanković, Zemun Clinical Hospital Centre, Department of Internal Medicine, Belgrade, Serbia

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

Other indirect morphological characteristic of the RV burdened by pressure include the following: dilated (> 20 mm) inferior vena cava (IVC), non-collapsible in inspirium and dilated RA (IVC ≥ 2 cm and IVC collapse < 40% is a significant sign of elevated RA pressure).

HYPOVOLEMIA

Inadequate volume of the circulating blood is the most frequent cause of PEA form of CA [6]. A hypovolemic patient has insufficient filling (<1 cm) or dynamic IVC. In patients with spontaneous breathing, the size of IVC is increased with each inspirium, while in patients with CA, the opposite occurs if applying artificial ventilation. In patients on mechanical ventilation, the increase of IVC size > 18% is in harmony with preload dependence. Each change in size is an indication for a rapid application of fluid during CPR. Echo finding (Table 3, Figure 5) includes a significantly reduced end-diastolic chamber size and "kissing" ventricular walls during systole [10]. If hypovo-

Table 3. Echocardiographic signs of hypovolemia [10]

Parameter	Static/dynamic	Finding suggestive of hypovolemia	Pitfalls
LV cavity size and function	Dynamic	Small, hyperkinetic with end-systolic cavity obliteration	Inotropic support, severe valvular regurgitation, left ventricular hypertrophy
LV end-diastolic area	Static	5.5 cm^2/m^2 of 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, in sinus rhythm only

BSA – body surface area; IVC – inferior vena cava; LV – left ventricle

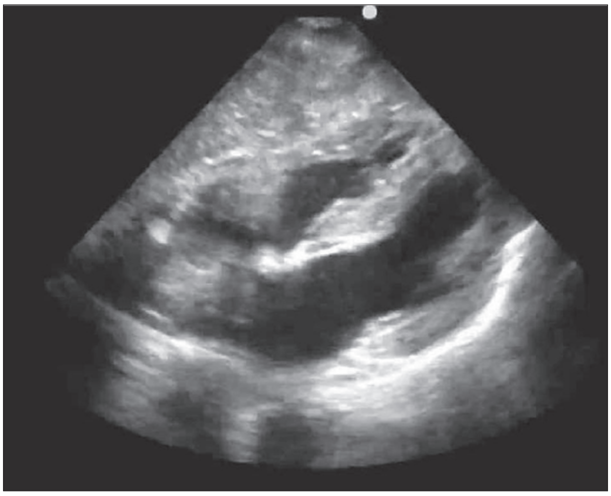

Figure 5. Echocardiographic signs of hypovolemia, by Dr. Ivan Stanković, Zemun Clinical Hospital Centre, Department of Internal Medicine, Belgrade, Serbia

lemia is indicated, possible causes should be searched for using abdominal US examination by implementing the FAST protocol and aortal check-up (aneurysm or rupture of abdominal aorta). Echo finding can confirm the presence of internal bleeding.

POSITION OF THE ENDOTRACHEAL TUBUS

If the endotracheal tube is in its correct position during US examination, only one air-filled structure is visible on the neck [31]. The "double tract" sign indicates esophageal intubation. US in CA can be a diagnostic method, a prognostic method (ROSC/non-ROSC), and an ethical method (making decision on emergency transport or cessation of CPR in the field). However, the decision on the cessation of resuscitation efforts cannot be passed on US findings alone.

If the patient is in ventricular fibrillation or pulseless ventricular tachycardia, US finding is of limited value. In patients in PEA or asystole, US has significantly higher diagnostic significance. According to the new CPR algorithms (2015), if the initial rhythm of CA is PEA, the application of portable US can enable the differentiation between true PEA from pseudo-PEA [32]. In addition to the aforementioned, US findings can indicate reduced LV ejection fraction, 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, its authors have presented the analysis to evaluate the possibility of checking the efficacy of heart compressions using US and of guiding the hands' position in order to improve cardiac contractility. Preliminary observations indicate that changing the position of hands guided by USG could improve the quality of chest compressions and important hospital information could be obtained without stopping CPR [33].

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, to turn it on, to ensure that the correct probe is attached and in position, and that screen settings are optimized, can be significant. Hence, the second action in the Extracorporeal Life Support 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 USG during the pulse check, i.e. positioning the probe on the patient and readying the US machine.

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Примена ултразвучне дијагностике у кардиопулмоналној реанимацији

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САЖЕТАК

Ултразвук се све више користи у ургентној медицини. Фокусирана ехокардиографска процена у реанимацији (ФЕПР) програм је обуке намењен лекарима хитне помоћи који желе да се оспособе за примену ехокардиографије на локацији срчаног застоја. ФЕПР протокол садржи алгоритам у којем 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 десетосекундне провере пулса уз минимално ометање кардиопулмоналне реанимације.

Кључне речи: кардиопулмонална реанимација; интензивна нега; ФЕПР протокол; ултразвук