APPLICATION OF INTERVENTIONAL ULTRASOUND IN EMERGENCY MEDICINE CONDITIONS

Maciej Dudek[1], Lukasz Szarpak[1], Kurt Ruetzler[2]

[1] Lazarski University, Warsaw, Poland
[2] Departments of Outcomes Research and General Anesthesiology, Anesthesiology Institute, Cleveland Clinic, Cleveland, Ohio, United States of America

ABSTRACT

ULTRASONOGRAPHY is a modern diagnostic tool both in intensive care and emergency medicine. Small, portable and simple ultrasound devices have been introduced due to technological advances. The image quality, size, and weight of portable ultrasound devices are improving. Prehospital point-of-care ultrasonography may have an impact on the decision making in prioritizing initial treatment. First aid at the scene of the accident and transporting the patient to the hospital is a key element, which in the case of appropriate diagnostics allows you to fight life-threatening injuries. The intention of using ultrasound protocols is to shorten and simplify the ultrasound examination allowing to eliminate or find complications of an injury as soon as possible. The protocols used include elements of ultrasonography and echocardiography of the lung tissue, abdominal cavity, pelvis, large vessels or the eyeball. The intention of the authors of the article was to present to the reader the basic ultrasound protocols applicable to patients in emergency situations.

KEY WORDS: point-of-care ultrasonography, emergency medicine, ultrasonography, diagnostic imaging, review

Disaster Emerg Med J 2018; 3(4): 137–147

INTRODUCTION

Ultrasonography gives us the opportunity to examine the patient without prior preparation and without any implications of ultrasound [1–3]. It is the fastest and one of the most accurate diagnostic methods. Such examination can be carried out anywhere: street, ambulance, victim's house or the emergency department.

Point of Care (POC) ultrasound is a fairly young field of ultrasound, but the usefulness of protocols and research in this area is invaluable. In particular, when we are dealing with an unconscious patient and gathering an interview is impossible. Interventional ultrasound and Emergency Ultrasonography is not only for diagnostic purposes.It also allows you to monitor the condition of the victim by performing tests such as checking the optic nerve, giving us information on intracranial pressure [4, 5].

The assumption of POC ultrasound is to perform tests by medical personnel in order to assess the current state of the patient and, based on the result of this examination, undertake medical activities. We must distinguish these procedures from ordinary ultrasound examinations. In these studies, we do not assess the condition of organs, we only check the absence or presence of pathology that affects the functioning of the body. We have to treat the ultrasound like a "Stethoscope" — the first contact diagnostic tool. And as you know, the stethoscope serves all medical staff.

ADDRESS FOR CORRESPONDENCE:
Maciej Dudek, Lazarski University, 43 Swieradowska Str., 02–662 Warsaw, Poland; e-mail: silenthealthcare@gmail.com

FOCUSED ASSESSMENT WITH SONOGRAPHY FOR TRAUMA PROTOCOL (FAST)

The purpose of the procedure is to detect free fluid (blood) in the peritoneal cavity and pericardium. When the patient is showing hemodynamic instability with signs of anemization, we can assume that internal hemorrhage has occurred [6]. The fastest way to confirm this diagnosis is to perform the FAST procedure, i.e., Focused Assessment with Sonography for Trauma. Thanks to this examination, the patient can be quickly diagnosed and transported directly from the ambulance or ED to the operating theater, where they will be immediately operated, without unnecessary waste of time, which is critical for the patient's health and life. Examination FAST (extended) is an extended examination of the chest area and is intended to check if there is fluid (blood) or pneumothorax in the chest [7, 8].

Detection of free fluid in the abdominal cavity in patients after injuries using ultrasound is about 75% (up to 95%). The specificity of the method is estimated at 98%. While a physical examination is only 50–60% sensitive.

In the course of the study, it should be remembered that the ultrasound examination in a patient after an injury is not used to assess the extent of organ trauma. The information from the test is binary 0 — no liquid/air or 1 — liquid/air.

When performing the test, we usually use a Convex type head, i.e., a curved head in Poland commonly referred to as the abdominal head. In a situation where we do not have such a transducer, we can use a Phased Array type head, which is a head defined in the sector or cardiology sector in Poland (Fig. 1).

Projections in the FAST study

The whole procedure consists of 4 positions and 5 head applications within the abdominal cavity, chest, and pelvis (Fig. 2). To perform the test, we can use a Convex head or Phased Array head, i.e. a cardiac head with setting for abdominal applications [9]. There are also devices that have dedicated settings for POC procedures. The patient lies supine on a flat surface so that the fluid (blood) flows gravitationally into the open spaces.

The procedure begins with a sub-bridge projection in which we assess the heart and the pericardium. We start from this position because if we do not observe the movement of the heart muscle, it does not make sense to continue the procedure.

Subcostal projection

The position of the head and the space under examination: under the alveolar process in the transverse plane with the head marker pointing to the right (right side of the patient). The head is at a large angle and is directed to the left side of the chest (Fig. 3). We increase the depth of penetration of the device so that the image shows the whole heart and part of the liver, diaphragm, and lungs. When this projection is obtained, we must use adequate force for pressure to get a picture of the heart from under the surface of the ribs. In the absence of the desired image, we perform delicate fan-shaped movements, and left-right movements [10]. The obtained image should show the heart, part of the liver, and lungs. During image analysis, we direct our attention to the way the heart works, its regularity of work, and the quality of the ventricles and atrial contraction. We do not try to assess heart rate under

FIGURE 1. Differend ultrasononogrphy probes: (A) CONVEX probe; (B) Phassed Array probe
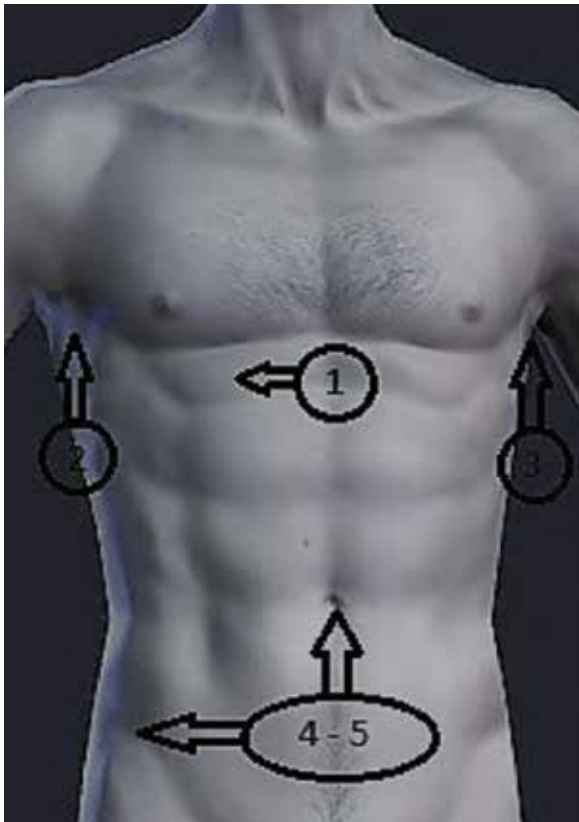
FIGURE 2. Ultrasound projections during FAST protocol

FIGURE 3. Ultrasound subcostal projection

FIGURE 4. Ultrasound right upper quadrant projection

the account of flow speed or quality of valve work. However, irregular or non-synchronized heart work can be an indicator of the appearance of the pericardial sac. Blood in the ultrasound image is presented in black, just like any liquid.

If you cannot get the heart image from the post-bridge position because of the patient's obesity or extensive trauma, we move the head to the chest and place it in the left parasternal longitudinal position. In this position, we keep the heads in a position perpendicular to the surface of the skin with a mark pointing in the cephalic direction.

Right Upper Quadrant projection (RUQ)

The position of the head and the area under study: periosteal area and hepatorenal space (Morison's pouch). We try to show the whole kidney, part of the diaphragm and the right lobe of the liver [11]. We arrange the head in the right axillary line of the anterior or medial plane in the sagittal and sagittal plane of the intercostal space from 7 to 9. Head marker must be directed in the cephalothorax. This part of the procedure is imperative because by correctly orienting the head we can precisely determine the position of free fluid (Fig. 4).

The intercostal spaces are not the same in different people, so often the image is significantly obscured by the acoustic shadow of the ribs. To by-pass this problem, we must arrange the head along them. The ultrasound beam is very narrow because it is about 1.5 mm, so imaging through the intercostal spaces should be a solution to this problem.

2.4. Left Upper Quadrant projection (LUQ)

The position of the head and the space under investigation: the peri-implant space (spleen-renal cantilever). In this projection, we try to present the entire left kidney, spleen, and part of the diaphragm [12]. We arrange the head in the left posterior axillary or axillary line in intercostal spaces from about ribs 5 to 7 in the sagittal or oblique plane with the head marker directed in the cephalothorax. We are proceeding here quite analogously to the RUQ
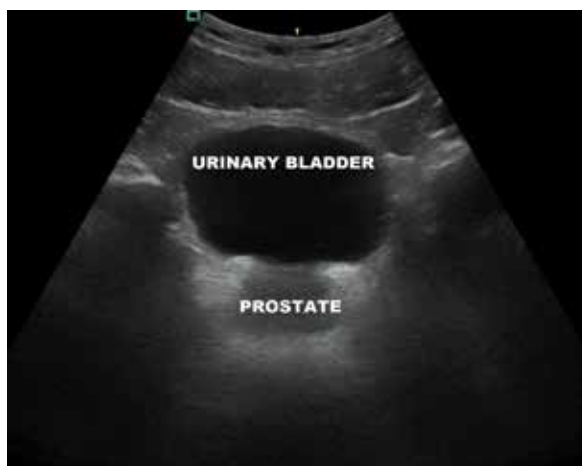
projection, also important here to check the entire peripheral area (Fig. 5). In order to do this accurately, we have to move the head in the direction to and from the center of the axillary line in the middle and posterior axillary line. Free liquid blood will be manifested on the screen of the ultrasound as black. If the patient is conscious and it is known that his lungs are not damaged (we do eFAST or BLUE protocol), we can ask him to take a deep breath, which will greatly facilitate the full depiction of this space.

Pelvis projection

Space under study: lower abdominal cavity, and smaller pelvis. The test is much easier to do when the patient's bladder is full. For this reason, we should do this procedure before assembling the catheter, you can also clamp the catheter and wait for the bladder to fill or fill it with saline [13]. As we wrote in the description of the projection, it consists

of two touchdowns, it does not matter much from which we start to remember both.
a) Head position: Transverse position — arrange the head above the pubic symphysis with the head marker pointing to the right (right side of the patient), heads lean towards the pelvis. In the picture, we try to visualize the bladder in the transverse plane of the Douglas pouch and pelvic organs (Fig. 6).
b) Head position: Arrow position — position the head above the pubic symphysis with the mark of the head directed in the sagittal plane in the sagittal plane. When moving from the transverse to the sagittal position, we rotate the head 90°, during rotation of the head we should keep the image of the bladder in the field of view (Fig. 7).

eFAST PROTOCOL

The eFAST (extended) study is an extended version of the FAST study [14]. To perform the eFAST test, add 3 positions of the head to the basic examination (Fig. 8). These items can be added anywhere in the study, but people with more experience recommend a method with the order of 1-6-2-3-4-5-7-8. It is logical because thanks to the similar positions of the head positioning, we can speed up the examination [15]. In the course of watching the lungs, we focus on two important phenomena, on the symptom of "sliding", or slipping the pleura, and viewing artifacts, or artificial creatures of the ultrasound device (Fig. 9). Physiologically, the lungs are filled with air, so we cannot visualize their flesh. Instead, we observe lines type A, B, C / Consolidation. The heads are placed in the left-collar, clavicular left and right positions 7–8 in 3–4th intercostal

FIGURE 5. Ultrasound left upper quadrant projection

FIGURE 6. Ultrasound pelvis projection — Transverse position
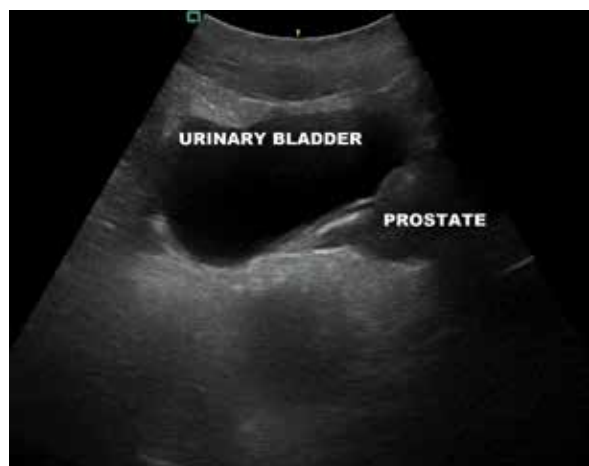
FIGURE 7. Ultrasound pelvis projection — Arrow position
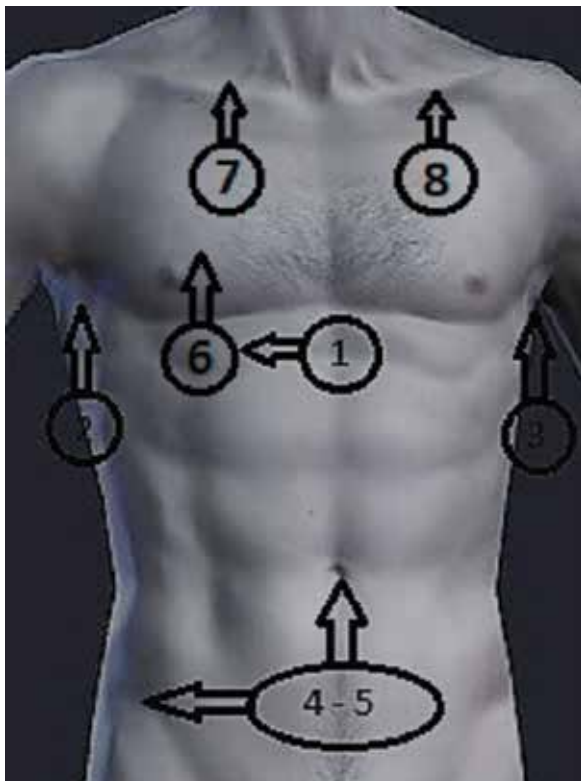
FIGURE 8. Ultrasound projections during eFAST protocol

FIGURE 9. Ultrasound symptom of "sliding"

and positions 6 in 8–9. Pictures are not able to present the full study. In the pictures above, only the starting positions are presented, as well as the structures and organs that we should show [16]. We remember that the head presents a two-dimensional image, and the test space is three-dimensional, which means that we have to move the head in specific directions to get full information.

BLUE PROTOCOL

The BLUE (Bedside Lung Ultrasound in Emergency) procedure is used to diagnose the acute respiratory failure, which is a life-threatening condition [17, 18]. This procedure can be performed both at the patient's home and in the hospital emergency department. The information we receive relates to the lungs and their condition: pneumothorax, pulmonary edema, or pulmonary embolism. The whole procedure should take up to three minutes. The test can be performed using any head, i.e., Phased Array, Convex, MicroConvex or Linear [19]. The recommended head for this procedure is the Microconvex or Phased Array. In the BLUE procedure, we view artifacts as in the case of e-FAST. At the same time, we should choose lung test applications (if we have

this option) or choose an abdominal application and turn off the options creating cross-linked beams on the device, because the device will create non-existent B lines.

During the examination, the ultrasound machine can display several types of "lines" on the screen during the procedure:

- Lines A — These are normal artifacts (horizontal, parallel) resulting from the reflection of the pleural line in the air in the lungs, such lines will repeat at regular intervals - it is important that the distance between lines A and the pleural line in the image must be constant otherwise, we may suspect Line C or Consolidation.
- Lines B — These are abnormal (vertical, perpendicular) artifacts that arise from small quantities of liquid in the pleural space. Under normal conditions, the fluid is hypoechoic (dark, black) on the ultrasound image, but when it is surrounded by air, it gives a hyperechoic effect (light, white) through the effect of signal amplification in the fluid space. Remember that the A lines do not coexist in the image with lines B.
- C-lines / Consolidations — These are lines created in a similar process to Line B, but in this case, the amount of fluid in the pleura is much greater. At the same time, the images appearing on the screen of the device do not have to come from the pleural space, but from the lungs themselves (Consolidations). We can observe such a picture when the lung parenchyma becomes visible during the examination.

The next and very important symptom observed on the screen during the lung examination is the "sliding symptom". It consists of checking the oc-

currence of pleural "slipping" movements [20]. We observe the presence of a symptom in each of the touchdowns, this is the correct symptom. Sliding we can observe both in the presentation B — Brightness and the presentation of M — Motion. In the B presentation, we obtain a position called "Bat Sign", which shows the image of the correct lung, and two adjacent intrapleural and shadows that they form. In this position, we also see visible pleural movement.

In the M presentation, we observe the "See Shore" Symptom — so-called the symptom of the beach, which similarly shows the correct image of the lungs, through the parallel arrangement of the lines that are the reflection of the pleura.

The test consists of three appendages on each side of the chest, the upper front point, the lower front point, and the PLAPS:

- The first point (front top) is between the third and fourth finger of the upper hand at their base
- The second front lower point is located at the height of the lower hand
- PLAPS point "posterior and/or lateral alveolar and/or pleural syndrome" — an intersection of the posterior axillary line and diaphragmatic/medial transverse line [21].

FATE PROTOCOL

The FATE (Focus Assessment Transthoracic in Emergency) protocol was created for the rapid assessment of hemodynamic disorders. It consists in the implementation of 4 touchdowns, of which 3 are closely related to cardiac imaging, sub-vertebral, apical and parasternal projection, and pleural projections in the middle axillary lines on both sides of the chest. This study will allow us to assess the condition of the pericardium: the presence of exudate, cardiac tamponade, cardiac assessment in patients with cardiac arrest, and the evaluation of the left ventricle systolic function [22, 23].

As in previous procedures, its execution time should not exceed 3 minutes. We do not have the ease of using any head for this protocol, we should use a Phased Array head because our projections are strictly echocardiographic [24]. As a last resort, we may try to use a Microconvex type head, but getting the correct image will be much more difficult.

- Substernal projection — this position offers excellent access to the heart in patients lying on the back. The head should be placed almost par-

allel to the patient's skin just under the sternum towards the heart. From this position, we have a four-chamber view. By turning the head, you can get a short axis view. This is an important projection for monitoring pericardial effusions.

- The apical projection — the transducer is placed over the apex of the heart and directed parallel to the long axis of the heart, we get a four-chamber apical view. If we have a problem with the placement of the head, we can use the palpation technique to locate the apex of the heart (palpable heartbeats in the intercostal space). From the four-chamber view, we go to the two-chamber view. For this purpose, the transducer is rotated counter-clockwise. Two-cavity projection is used to assess the left and front walls of the left ventricle. Further rotation of the head gives the view of the long axis.

- Parasternal projection — the head is placed paradigmatic on the line connecting the apex of the heart with the center of the right clavicle at the left edge of the sternum. From this position, we get a black/five-pointed view. By turning the head (directing the marker to the right arm) we obtain a short axis. Image quality can be improved by turning the patient to the left side. A parasternal position is often called classic because in it we check the basic dimensions of the heart.

- Projection of the pleura — this projection is performed in the middle axillary lines. The head marker is directed to the patient's head. In this projection, we use the same principles that we apply to the BLUE procedure [25].

RUSH PROTOCOL

The RUSH protocol (Rapid Ultrasound in Shock and Hypotension) was created in 2009 by Dr. Weingart. The protocol is intended for the assessment of patients in shock and hypovolemia. The ultrasound schema was based on the HI-MAP abbreviation, according to which the projection sequence is performed. For this test, we use Phased Array or Convex head, as well as abdominal or FAST applications [26, 27]. In RUSH protocol we distinguish the following projecttions:

- H — Heart (heart),
- I — Inferior vena cava (main lower vein),
- M — Morison's pouch,
- A — Aorta,
- P — Pneumothorax (pneumothorax).

The protocol starts with a heart projection (1,2) (H-Heart), we obtain parasternal and apical projections to assess the pericardial sac (fluid presence) and the function of both chambers. Next, we present the lower main vein (3) (I-inferior vena cava) in the substernal space with the head marker directed to the patient's head. The next projection (4,5) (M-Morison's Instruction) in this case means that we are looking at the spaces on both sides of the patient, both Morison's pouch and the kidney-spleen resection. While watching these spaces, we can move the head slightly in a cephalic way to visualize the basis of the lungs. The next projection (6,7) (A-Aorta) is a combination of two projections. We start at the bladder with the marker pointing to the left and see the pelvic space to exclude free fluid in the peritoneal cavity, and then move towards the patient's head, finding the aorta and assessing its condition up to the sternum. The last protocol point (8,9) (P-Pneumothorax) involves lung imaging to rule out pneumothorax, items as in the e-FAST study.

THE PROCEDURE FOR MEASURING THE OPTIC NERVE DIAMETER

The optic nerve is relatively easy to assess for the part of the nervous system that connects directly to the brain [28, 29]. The optic nerve is the second cranial nerve, it means it is surrounded by the same tires as the brain [30]. When the intracranial pressure increases, the cerebrospinal fluid flows into the subarachnoid space, causing the pressure of the optic nerve to increase (in diameter). Knowing this relationship, we can indirectly determine intracranial pressure (ICP).

The measurement is carried out using an 8–11 MHz high-frequency linear head [31, 32]. The structure of the eye is well-translucent for ultrasounds, so the test can be done with great accuracy every time. We perform the measurement when the patient has closed eyelids. The test time should not exceed one minute.

We measure the diameter of the optic nerve 3mm behind the eyeball (Fig. 10). If we have a problem with finding a nerve, we can use a colored Doppler [33]. Anatomically, the artery and vein of the retina run inside the optic nerve, information marked with color will allow us to precisely determine the position of the nerve. The correct diameter of the optic nerve for an adult does not exceed 5 mm, for a child 4.5 mm, and for an infant 4 mm.

ASSESSMENT OF IRRIGATION DEGREE — IVC/AO

A simple ultrasound procedure can also be used to assess the degree of filling of a vascular bed [34]. To determine its degree, we use the upper main vein, and more specifically its diameter (IVC; Fig. 11), which we compare with the width of the abdominal aorta (Ao; Fig. 12). This ratio is called the IVC/Ao index [35, 36].

For this measurement, we use a Convex type head. We position it in an anterior sagittal and axillary position with a marker directed to the patient's head. As the first we measure IVC at the height of the intrahepatic section, then we measure the aorta about 10 mm above the visceral trunk.

After obtaining the results, we substitute them for a simple IVC/Ao pattern where the standard deviation is SD = 1.2 +/- 0.2.

FIGURE 10. Optic nerve sheath diameter

FIGURE 11. IVC width measurement

FIGURE 12. Aorta width measurement

FEEL PROTOCOL

The most important POC protocol dedicated to the management of cardiac arrest is FEEL (Focused Echocardiographic Evaluation in Life Support). This protocol was introduced by Breitkreutz in 2007 [37]. We perform this test using a Phased Array type head, and the procedure consists of 4 positions of the head: substernal, apical and parasternal in two axes [38, 39]. We must remember that each of the POC procedures is used only to detect an abnormal assessment of organs, therefore we only have 10 seconds to perform the assessment of the heart. Teamwork is very important during the conduct of the procedure.

This procedure consists of 10 points thanks to which the resuscitation team and the person performing ultrasound imaging will be able to use the most efficient time:

1) The team starts BLS and ALS resuscitation procedures — at least 5 full cycles.
2) The investigator informs the team that he starts the preparation of the ultrasound scanner.
3) Preparing the ultrasound for performing the procedure. We check whether the device is working properly, check whether the right head and application are selected. Also, if we have the appropriate depth of imaging, and whether the gel is on the head.
4) Adapting to the situation. The idea is to prepare yourself and the patient for the procedure. We set the device in the right place (to see the picture), if the patient has clothes, we take them off.
5) We tell the resuscitation team to start counting from 10 to 1 (in seconds — at the end of the cycle) and then began to measure the pulse.

6) We inform the team to interrupt the compressions after the end of the cycle to perform echocardiography. During the ultrasound procedure, the ventilation is maintained.
7) We apply the head to the patient in the substernal position while we are compressing and look for the right image with a fan-shaped motion. If this position is not possible to obtain (injury, obesity), we use intercostal spaces and parasternal positions in the long axis.
8) When the team is finished counting from 10 to 1, the compression is interrupted, and the ultrasound scan begins. We have 3 seconds to find the heart and 3 seconds to evaluate it. If we do not find the heart, or we do not observe its movements, we inform the team about returning to full resuscitation for 5 subsequent cycles, after which we return with the head in the next position. Compressions cannot be interrupted for more than 10 seconds.
9) We inform the team about returning to resuscitation activities.
10) After the team returns to resuscitation, we inform the others about the conclusions we noticed during the test:
- Wall movement present / absent
- Pericardium tamponade
- Presence of PEA (pulseless electrical activity) / alleged PEA
- Poor image / no visibility
- etc.

This procedure gives us the opportunity to truly evaluate the performance of myocardium and the quality of its work and the effectiveness of resuscitation [40, 41].

DEEP VEIN THROMBOSIS DVT

We perform a test for the presence of deep vein thrombosis in a patient with swelling and/or pain in the calf area. A properly constructed vein collapses during compression, unlike arteries. When the venous vessel is destroyed, the walls become hardy and the functioning of the venous valves is impaired [42]. We will look for the first of these two symptoms during the procedure. The study is optimally performed using two heads: Convex type transducer for examination of iliac veins and Linear head for evaluation of the rest of the venous system of the lower limb. There are different methods of performing this test, but I think that the most accurate
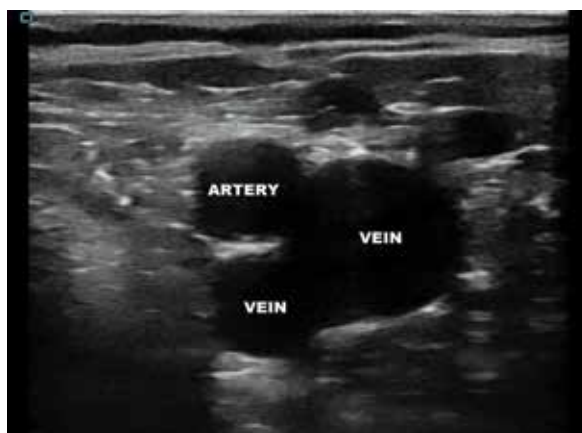
FIGURE 13. "Mickey Mouse" ultrasound image during deep vein thrombosis

and the fastest method is the 3-point compression method [43].

To perform this procedure, we lay the patient in a supine position and rotate the examined limb, about 10–15 ° outside. For the assessment of the popliteal segment, we can put the patient on the side and bend his leg in the knee joint by 12–30°.

The heads are applied transversely to the course of the vessel with the marker pointing to the left, i.e. to the right side of the patient. During each position, we must compress the venous vessel and assess its susceptibility to compression. If necessary, we should document our activities.

The procedure starts with the groin in which we are looking for the so-called "Mickey Mouse" image, i.e. the saphenofemoral runoff (Fig. 13). This is the first position. Then we go along the femoral vein to the next section, where I repeat the procedure. Next, we move to the height of the popliteal vein and perform a pressure test [44]. The whole process is repeated on the other limb.

SUMMARY

As presented in the above article, interventional ultrasonography and emergency procedures can help diagnose and implement treatment in patients with many disease entities that we will not be able to recognize during an interview or physical examination [45, 46]. The ultrasound machine gives us the possibility of a quick and non-invasive view of the problem directly, with the simultaneous possibility of indicating the cause of the ill condition of the patient without any doubts — especially in unconscious patients. The ultrasound machine is a small device that can be carried even in a pocket. Access to such devices for emergency medical services will not only increase the effectiveness in the diagnosis of injuries, but also enable continuous monitoring of the patient's condition, either in the ambulance or on the emergency department.

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