Chapter 4

Ultrasound-Guided Vascular Access during Cardiopulmonary Resuscitation

Anton Kasatkin, Aleksandr Urakov and
Anna Nigmatullina

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79400

Abstract

The chapter considers the possibilities for using ultrasound to increase the efficiency and safety of the intravascular access in patients during cardiac arrest, cardiopulmonary resuscitation, and advanced life support. It provides the grounds for the real-time use of ultrasound for ensuring satisfactory central vascular access; the main principles of this methodology and current recommendations are described as well. In addition, the article presents special aspects of visualization of ultrasound vessels in cardiopulmonary resuscitation, as well as puncture and catheterization techniques. It is crucial that resuscitators, who are often at the forefront of patient resuscitation, understand how to properly use this potentially life-saving procedure.

Keywords: cardiopulmonary resuscitation, advanced life support, ultrasound, vascular access, vascular visualization

1. Introduction

Providing satisfactory vascular access is still a critical part of resuscitation. Timely administration of drugs through intravenous access can improve the survival rate of patients after circulatory arrest. The time passed from the arrest to drug administration is an independent predictor of return to the spontaneous circulation [1]. In this regard, it is difficult to overestimate the importance of providing satisfactory vascular access for the patient with circulatory arrest. It is important to remember that the benefits of early vascular access must be considered together with the importance of uninterrupted cardiopulmonary resuscitation (CPR) [2]. When choosing vascular access, it is a common practice firstly to focus on visualization and palpation of the subcutaneous veins in the accessible parts of the body, as well as on the anatomical landmark (landmark technique). Subcutaneous veins in the extremities and the external jugular veins completely satisfy these requirements. The insertion of the catheter into visualized subcutaneous vein is considered to be quick and safe. It should be remembered that visualization and palpation of the subcutaneous veins can be difficult in patients in critical condition (bleeding, hypovolemic shock, burns of limbs, or hypothermia). In this case, infrared thermography [3] and near-infrared vein visualization [4] can be applied. If the catheterization of the subcutaneous veins is difficult or impossible, then intraosseous access (IO) is recommended by current clinical guidelines [5]. Nowadays, IO route is proved to be quite effective in adults and children with out-of-hospital cardiac arrest [6]. It is assumed that insertion of a central venous catheter requires the interruption of CPR and can be technically challenging and associated with complications. However, the introduction of real-time ultrasound-guided central venous catheter (CVC) insertion into clinical practice significantly increased its safety, accuracy, and effectiveness compared to the conventional landmark technique [7, 8]. It is known that central venous access is required for administering drug solutions, monitoring venous pressure, and for performing extracorporeal oxygenation and detoxification, which cannot be achieved by other types of access. In addition, ultrasound-guided catheterization of the internal jugular (IJV) and femoral veins (FV) may not require the cessation of chest compression and placing a patient in a forced position (head-down tilt positions) during CPR. It is critical that resuscitators, who are often at the forefront of patient resuscitation, understand how to properly use this potentially life-saving procedure.

2. History

The use of ultrasound imaging support for IJV location was first described in 1978 [9]. The use of ultrasound for real-time CVC insertion was reported in 1984. Legler and Nugent [10] showed that Doppler localization of the IJV facilitates central venous cannulation. Later, the results of studies showing the advantage of using ultrasound for catheterization of subclavian (SV) and FV were published [11]. The first results of studies on the use of ultrasound for catheterization of the central vein during CPR were published in 1997. Hilty et al. [12] showed that real-time ultrasound-guided FV catheterization was faster and produced a lower rate of inadvertent arterial catheterization and a higher rate of success during CPR than the standard landmark-oriented approach. Benassi et al. [13] showed the benefits of the real-time ultrasound cannulation of the femoral vessels for establishing venoarterial extracorporeal membrane oxygenation in acute cardiopulmonary failure.

3. Principles of vessel visualization using ultrasound

Two-dimensional (2D) gray-scale imaging (**Figure 1**), color (**Figure 2**), and spectral Doppler (**Figure 3**) ultrasonography are used for ultrasonic visualization of vascular structures, surrounding tissues, and anatomical formations [14]. The best resolution of surface structures in the immediate vicinity of the skin surface is provided by high-frequency (>7 MHz) linear ultrasonic sensors. The operator must have an idea of the probe orientation, the image on

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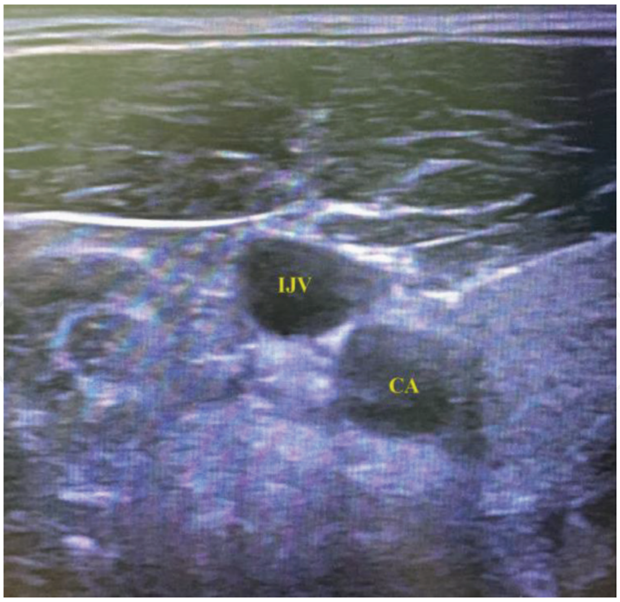

Figure 1. Ultrasound 2D image of the right internal jugular vein (IJV) and carotid artery (CA).

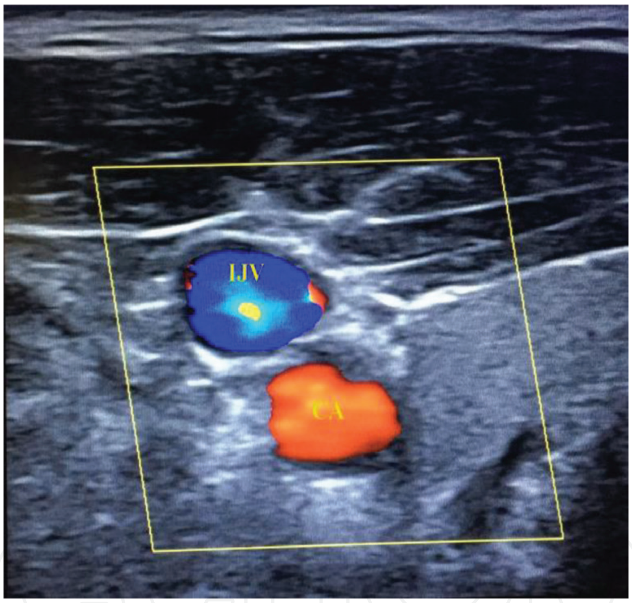

Figure 2. Ultrasound color Doppler imaging of the right internal jugular vein (IJV) and carotid artery (CA).

the display, the physics of ultrasound, the mechanism of image generation, and the artifacts, and be able to interpret 2D images of the vessel lumen and surrounding structures. A two-dimensional image of a blood vessel is usually displayed either along the long axis (**Figure 4**), the short axis (**Figure 5**) or the oblique short axis (**Figure 6**).

3.1. Ultrasonic visualization of blood vessels in people with spontaneous circulation

The basic differences between a vein and an artery in an ultrasound 2D image are the irregular form of the vein (the artery is generally round) and the wall thickness (the arterial walls are

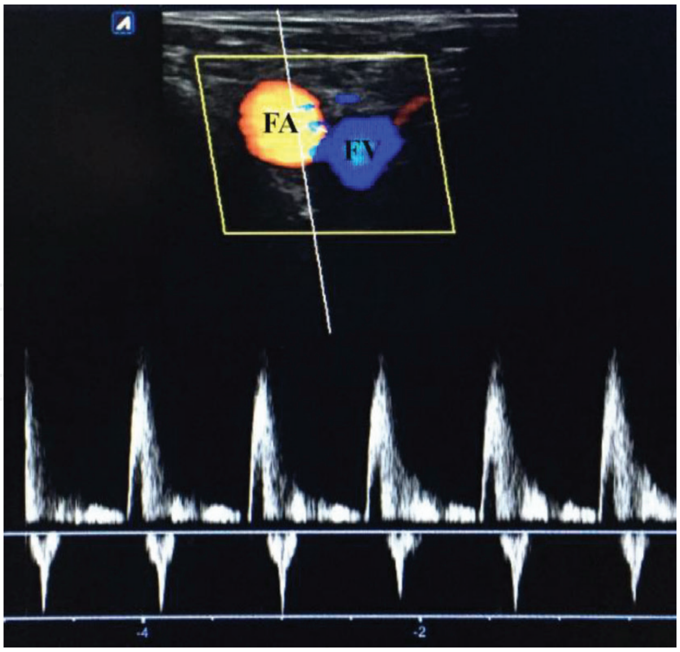

Figure 3. Ultrasound color Doppler and spectral Doppler imaging of the right femoral artery (FA) and femoral vein (FV).

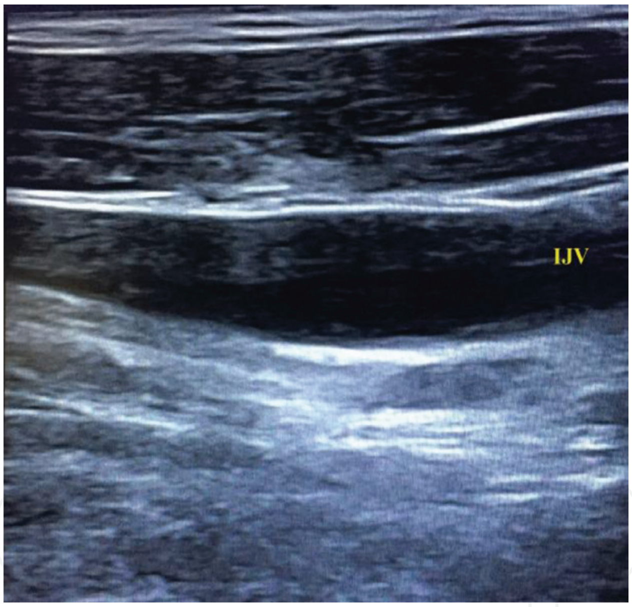

Figure 4. A two-dimensional image of the right internal jugular vein (IJV) along the long axis view.

thicker), but the major difference is vein compressibility under a slight external surface pressure (**Figures 7** and **8**). The lack of vein compressibility may indicate the presence of a thrombus. Using Doppler also helps to distinguish a vein from an artery. Respiratory-based vein excursion may also allow us to distinguish it from the artery [15]. Respiratory-based vein excursion is a change in its diameter based on the respiration phase. It is known that, in contrast to the arteries, the IJV, SV, and FV diameter decreases during inhalation and increases during exhalation [16]. In patients with hypovolemia, the IJV may completely collapse during inhalation

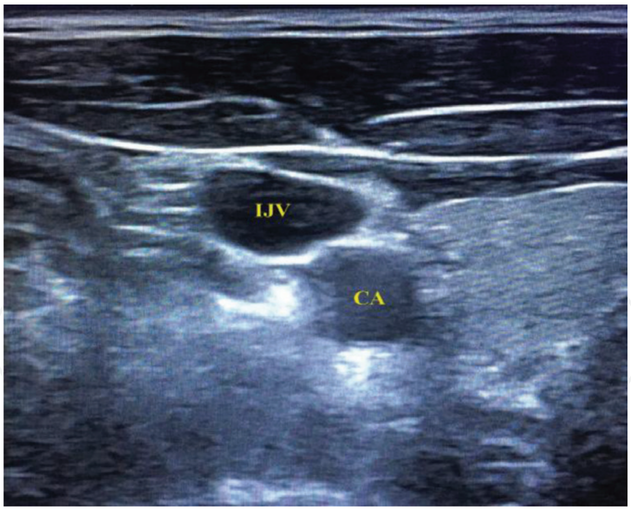

Figure 5. A two-dimensional image of the right internal jugular vein (IJV) and carotid artery (CA) along the short axis view.

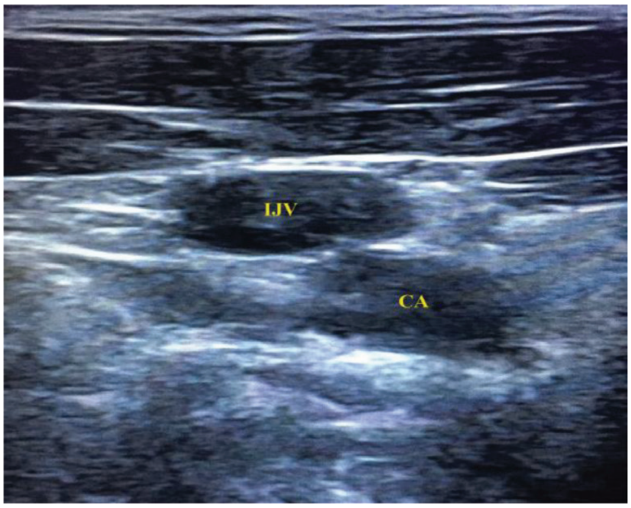

Figure 6. A two-dimensional image of the right internal jugular vein (IJV) and carotid artery (CA) along the oblique short view.

(**Figure 9**). It must be remembered that the color does not determine the nature of the blood flow (venous or arterial), but depends on the flow direction (from the probe or to the probe). By default, the device marks the blood flow directed toward the probe as red, and the blood flowing away from the probe is marked as blue. The change in the inclination of the probe can lead to the change in the vessel color on the screen of the ultrasonic device.

3.2. Special aspects of ultrasound imaging of vessels during cardiac arrest and CPR

During circulatory arrest, the blood pressure on the walls of arteries decreases; they lose elasticity and are compressed together with veins when external surface pressure is applied by the ultrasonic probe. In this regard, compressibility during cardiac arrest is characteristic of both the vein and the artery. When performing chest compression, the blood pressure on the

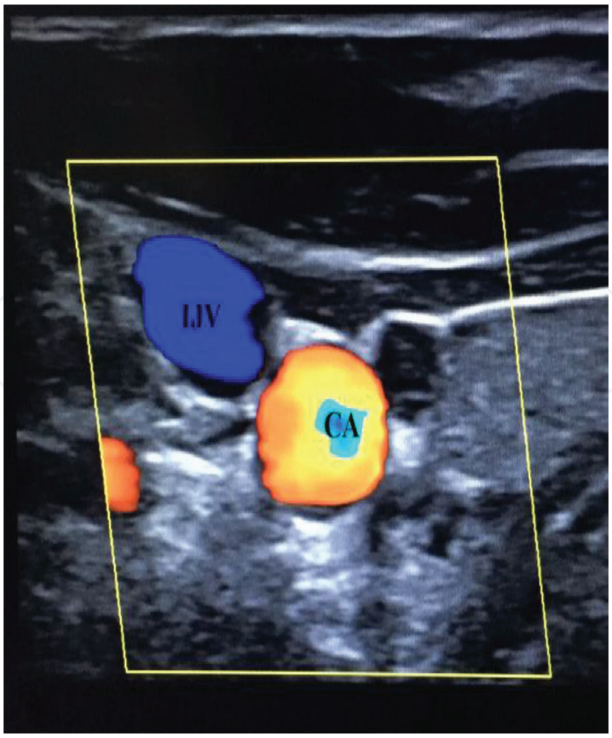

Figure 7. Ultrasound color Doppler imaging of the right internal jugular vein (IJV) and carotid artery (CA) before external surface pressure.

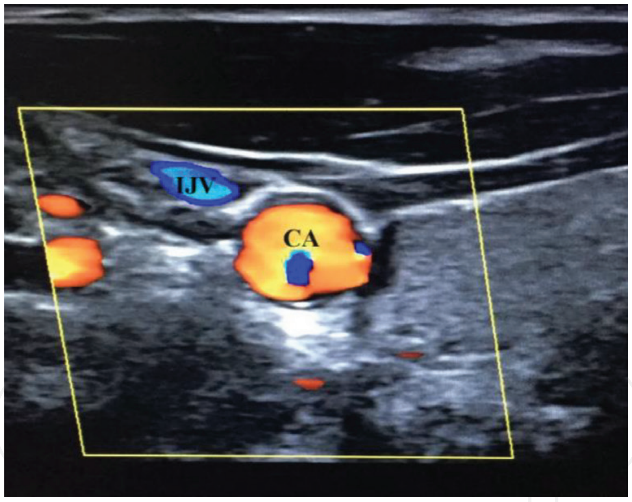

Figure 8. Ultrasound color Doppler imaging of the right internal jugular vein (IJV) and carotid artery (CA) after external surface pressure.

walls in the arteries increases. An increase in blood pressure (more than 60 mmHg) leads to an increase in the elasticity of the arteries walls, which again makes them noncompressible when pressed [17]. During CPR rhythmic change in diameter is typical for both veins and arteries due to compression and decompression of the chest with a frequency of 100–120 per minute (diameter of the CA may change by 30–40% and IJV by 50–60%). Using a Doppler is a reliable way to distinguish the artery from the vein by the flow direction.

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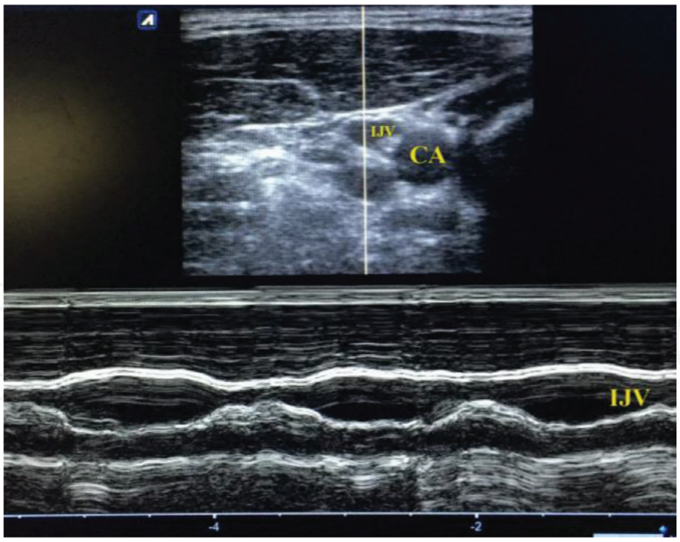

Figure 9. Measuring right internal jugular vein (IJV) diameter in healthy volunteer using M-mode ultrasonography.

The ratio of the sizes (diameters) of IJV, SV, and FV veins in patients with cardiac arrest may vary. If the cause of cardiac arrest is hypovolemia (blood loss), then the ratio of the veins diameter will be as follows: IJV < SV > FV. If the cause of cardiac arrest was thromboembolism, acute myocardial infarction or tamponade, the ratio of the veins diameter will be different: FV < SV > IJV.

4. IJV anatomy, access, and catheterization technique

IJV emerges from the outer jugular opening at the base of the skull posterior to the internal carotid artery (CA), then proceeds caudally, and shifts, taking anterolateral position in regards to CA. Denys and Uretsky [18] showed that the IJ was located anterolateral in regards to CA in 92% (**Figure 7**), >1 cm lateral to the carotid in 1%, medial to the carotid in 2%, and outside of the path predicted by landmarks in 5.5% of patients. Preliminary ultrasound evaluation of the vein patency, size, location, and possible anomalies is mandatory, it ensures avoiding futile attempts as in patients whose IJV is absent or thrombosed or who have congenital anomalies. Surrounding structures (subcutaneous tissue, carotid artery, thyroid, and lymph nodes) must also be analyzed. The properly trained clinicians use real-time ultrasound during IJV cannulation whenever possible to improve cannulation success and reduce the incidence of complications associated with the insertion of large bore catheters. Before the procedure, a patient should be placed in position on his back. The head can be turned to the contralateral side from 0 to 40°. The head-down tilt position should be used, when possible, for increasing the vein size, eliminating the vein respiratory excursion, reducing the risk of air embolism during IJV cannulation, and consequently improving the success of CVC insertion. For more than 65% of patients requiring CVC, the 10° head-down tilt position is sufficient to increase the size of IJV. In certain clinical situations, the head-down tilt position may not be applied.

4.1. Approach to vein puncture

Currently, three types of approach for real-time ultrasound-guided IJV catheterization are described: central (classical), lateral, and lateral oblique.

For classical IJV approach, one can use short or long axis vein visualization and in-plane (when included in the plane of the ultrasound beam) or out-of-plane (only a very limited part of the needle can be visualized by the ultrasound beam) needle visualization [14]. The long axis view of the IJV can be obtained by positioning the ultrasound probe in longitudinal orientation on the patient's neck. This view shows the course of the IJV, and with this probe positioning, the needle is inserted in-plane at the level of the cranial edge of the ultrasound probe; this allows the operator to visualize the entire length of the needle through the soft tissue and into the IJV [19]. With this type of technique, the information of the carotid artery, lymph nodes, and thyroid may be lost. In addition, the IJV access will be at least 3 cm cranial from the upper margin of the clavicle, for the limitation imposed by the ultrasound probe length. This fact makes it difficult to apply this kind of approach in patients with a short neck. The short axis view of the vein can be obtained by positioning the ultrasound probe in a transverse orientation (90° rotation from the long axis) on the patient's neck (the ultrasound probe is perpendicular to the course of the IJV). This view allows the visualization of the carotid artery, lymph nodes, and thyroid. With this position of the ultrasound probe, the needle is usually inserted vertically (vertical out-of-plane technique) above the middle part of the ultrasound probe in a position 1–1.5 cm cranial from the upper margin of the clavicle. This allows the operator to simultaneously visualize the IJV and all surrounding structures and ensures a caudal vein access [20]. With this type of technique, the operator has a very limited view of the needle (**Figure 10**).

The lateral short axis in-plane technique is a combination of the advantages of both previously mentioned conventional techniques, but without their limitations [21]. The ultrasound probe is positioned in a transverse orientation (short axis), with a good view of the IJV and its surrounding structures. The needle is inserted at the level of the lateral edge of the ultrasound probe [22]. This guarantees the visualization of the entire length of the needle during vein access (**Figure 11**).

This allows the operator to avoid iatrogenic puncture complications, such as arterial puncture and pneumothorax. The ultrasound-guided lateral short axis in-plane technique for percutaneous IJV cannulation can be successfully applied in patients without hypovolemia. Using this method for patients with hypovolemia and veins with a small diameter (less than 7 mm) may result in vein perforation [23].

The real-time ultrasound-guided lateral oblique short axis in-plane technique may be successfully applied in patients with hypovolemia and a small IJV size. The lateral oblique short axis view of the vein can be obtained by positioning the ultrasound probe rotated in 10–50° from the short axis. This method can be applied as follows: set the sensor so that the vein image in the transverse axis is located in the middle of the screen of the ultrasound scanner and measure the maximum distance between the lateral and medial walls at the time of inspiration of the patient. If this distance is less than 7 mm, the sensor is rotated by moving

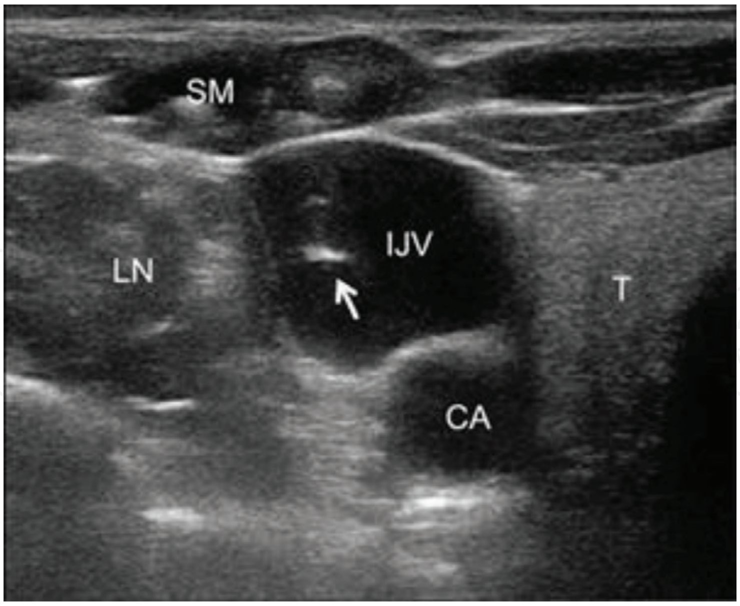

Figure 10. Short axis vertical out-of-plane technique ultrasound image of the right neck area showing the internal jugular vein (IJV), carotid artery (CA), lymph nodes (LN), sternocleidomastoid muscle (SM), and the thyroid (T). The needle is visible in a limited fashion into the internal jugular vein as a bright dot (arrow). From J Vasc Access [22].

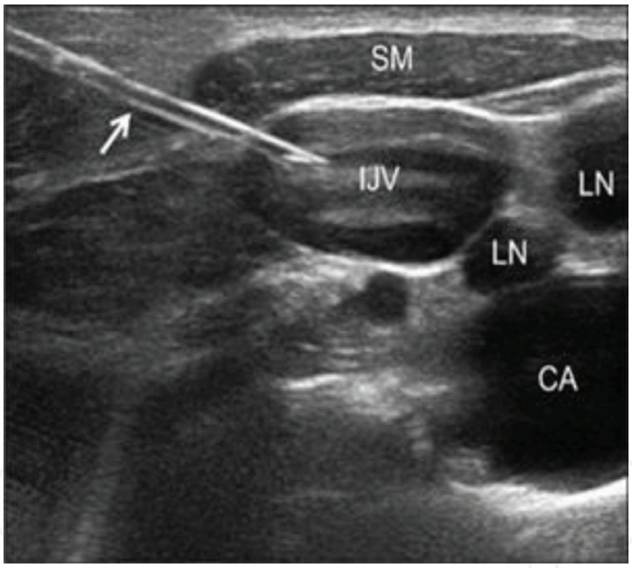

Figure 11. Short axis, lateral in-plane technique ultrasound image of the right neck area showing the internal jugular vein (IJV), carotid artery (CA), lymph nodes (LN), and the sternocleidomastoid muscle (SM). The needle is visible in its entire length with the full tip into the internal jugular vein (arrow). From J Vasc Access [22].

its lateral part upwards and the medial part downwards, and the rotation of the sensor is stopped when the distance between the walls of the vein is more than 7 mm. Fix the sensor in this position. Puncture needle is then inserted, and the vein is punctured in the sensor plane. [24]. This maneuver allows us to increase the size of the vein compared to the size in short axis (**Figure 12**).

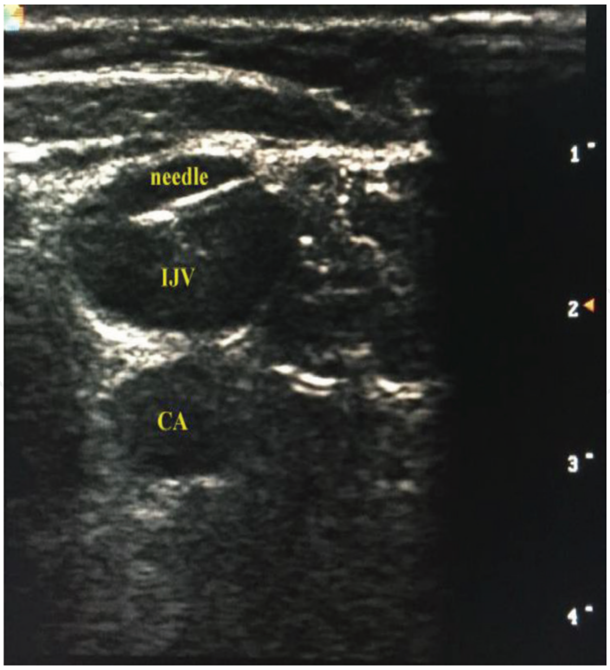

Figure 12. Lateral oblique short axis in-plane technique ultrasound image of the internal jugular vein (IJV), carotid artery (CA), and needle is visible in its entire length with the full tip into the internal jugular vein.

5. FV and FA anatomy, access, and catheterization techniques

Common femoral vein and common femoral artery (FA) lie within the femoral triangle formed by the inguinal ligament, the long adductor muscle, and the sartorius muscle. An important landmark for determining the location of the femoral vein in patients with spontaneous circulation is the femoral artery pulsation, since the vein is usually located medial to the artery in the vascular lacuna of the femoral triangle. This vascular interposition is constant only under the inguinal ligament (**Figure 13**). Change in the relative location of the vessels occurs in the caudal direction. In particular, the FA may overlap the femoral vein at a level of 1 cm below the inguinal ligament. In this regard, ultrasound imaging will accurately localize the FV and differentiate it from the femoral artery (**Figure 14**).

During CPR, it is possible to reliably distinguish the artery from the vein during the chest compression in the direction of the flow with the help of the Doppler. The advantages of choosing a femoral vein are the possibility to perform its catheterization without disrupting the CPR, lack of control devices in this area, and the ability for the resuscitator to access the patient's chest and airways. In addition, this access prevents pneumo- and hemothorax. Well-known complications of catheterization are vascular damage, bleeding, and arteriovenous fistulas.

Before the catheterization, the patient should be placed on his back, with his thigh slightly retracted, and rotated outwards. This technique allows us to increase the accessibility of the common femoral vein in 70–80% of adults [25]. It is possible to increase the cross-sectional

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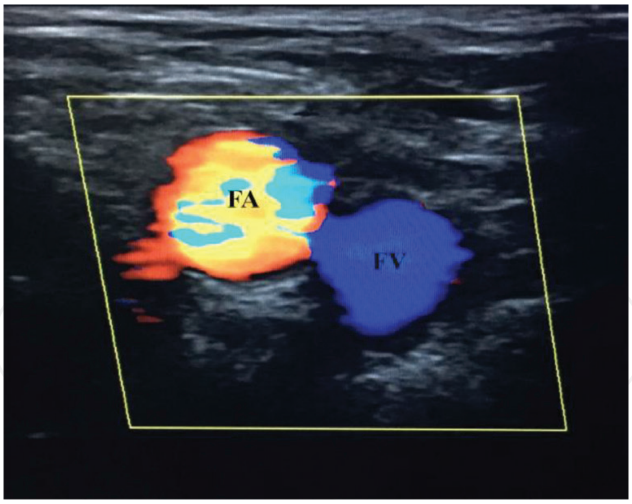

Figure 13. Ultrasound color Doppler imaging of the right femoral artery (FA) and femoral vein (FV). The US probe is installed under the inguinal ligament.

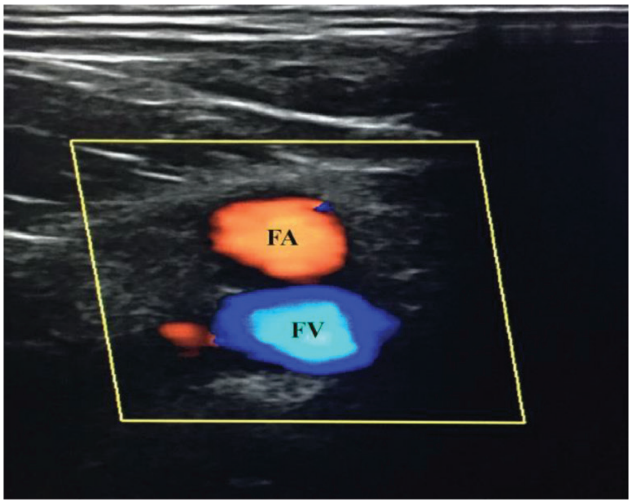

Figure 14. Ultrasound color Doppler imaging of the right femoral artery (FA) and femoral vein (FV). The US probe is installed at a level of 1 cm below the inguinal ligament.

area of the common femoral vein by more than 50% by using head-elevation tilt positions [26]. However, no data on the safety of this maneuver in patients with cardiac arrest and CPR are currently available. First, the femoral vessels in the transverse plane are visualized using a real-time 2D ultrasound, placing an ultrasonic probe under the inguinal ligament. The differentiation between the vein and artery during CPR is performed with a Doppler. The short axis out-of-plane technique is often used for the catheterization of the FV and FA. The long axis in-plane technique is preferable when longitudinal scanning of the femoral vessels is possible. The real-time ultrasound-guided lateral oblique short axis in-plane technique can also be applied. At the same time, no evidence of its preference is available.

Nowadays, femoral vessels are chosen for inserting venoarterial extracorporeal membrane oxygenator devices for extracorporeal CPR and extracorporeal life support [27]. The research results reveal promising outlook of this area of research aimed at saving human life.

6. SV catheterization techniques

The use of a subclavian vein for central venous access during CPR surgery cannot be recommended due to certain limitations. Providing access to the vein may require CPR interruption, and in particular, thorax compression. Besides, a defibrillation electrode may be located in the subclavian area. During CPR, there is a risk of post-puncture pneumo- and hemothorax during SV catheterization. Compared to IJV and FV, the SV anatomical location and its course under the clavicle bone may challenge ultrasound imaging and are accompanied by various artifacts (**Figure 15**).

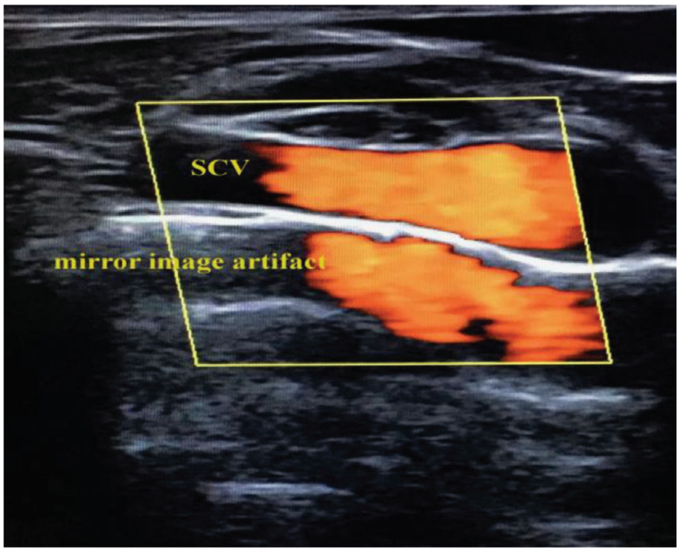

Figure 15. Ultrasound color Doppler imaging of the right subclavian vein (SV) with mirror image artifact.

7. Advantages of ultrasound-guided vascular access during CPR

It can be argued that the use of ultrasound facilitates the identification of the insertion site anatomy, localization of the vessels and their sizes, and differentiating between veins and arteries. Real-time US guidance for puncture allows us to confirm patency of the vessel, as well as needle, wire, and catheter position in the vessel. In addition, ultrasound can be used to determine the change in the filling, and thus, the cross-sectional lumen of the patient, depending on the change in the patient's position (head-down or head-elevation tilt position). In the clinical setting, these advantages allow us to choose the most secure access for puncture and the catheterization of the targeted vessel without interrupting the CPR, reduce the time of intravascular access, minimize the number of unsuccessful catheterization attempts, and reduce the risk of post-puncture complications.

8. Limitations of ultrasound-guided vascular access during CPR

The operator performing ultrasound-guided vascular access is certainly required to have special knowledge and practical skills in visualization of anatomical structures, in particular, blood vessels, during CPR. We assume that anesthesiologists, intensivists, and emergency physicians must be educated about it. To ensure this, special training of operators involved in CVC insertion should be organized. In addition, an intensive care unit must be equipped with US machines to exclude procedural delays. Ultrasound-guided vascular cannulation proved to be effective for cardiopulmonary resuscitation during in-hospital cardiac arrest. This method, however, is not to be recommended during out-of-hospital cardiac arrest, since nowadays there are no data proving its safety and efficiency.

9. Conclusions

Providing satisfactory intravascular access remains an important component of the CPR. Taking into account the advantages of ultrasound-guided central vascular access, it should be considered along with other types of access (peripheral and intraosseous) in patients with in-hospital cardiac arrest.

Conflict of interest

None declared.

Author details

Anton Kasatkin*, Aleksandr Urakov and Anna Nigmatullina

*Address all correspondence to: ant-kasatkin@yandex.ru

Izhevsk State Medical Academy, Izhevsk, Russia

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