# 1.1

# Cardiovascular ultrasound in the emergency–urgency: ultrasound anatomy, inferior vena cava, pericardial effusion

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Cardiovascular emergencies consistently rank among the top challenges encountered by healthcare professionals.[1] Patient outcomes often depend on swift and precise assessments. Over time, the medical community has experienced a significant shift in diagnostic methodologies. Echocardiography, a branch of ultrasound techniques, stands out as one of the most transformative tools. This noninvasive imaging technique has revolutionized how clinicians address cardiovascular emergencies, providing a real-time glimpse into the heart's complex dynamics and the surrounding vasculature.[2] This chapter serves as a comprehensive guide, highlighting the essential equipment for cardiovascular ultrasound anatomy and clarifying the clinical implications of various findings.

## Cardiac ultrasound in emergencies

Traditionally, the diagnosis of cardiovascular pathologies has relied heavily on clinical symptoms, invasive procedures, and basic imaging techniques. The introduction of cardiac ultrasound marked a pivotal moment. Today, it is more than just a diagnostic tool; it is a fundamental component of modern cardiology.[3] Its applications range from diagnosing life-threatening conditions to guiding complex surgical procedures and monitoring treatment efficacy.[4] Over the years, cardiac ultrasound equipment has also undergone significant advances.

In the demanding realm of emergency medicine, clinicians often work with limited information. In such scenarios, cardiac ultrasound shines as a beacon, offering swift insights into a range of severe and potentially fatal pathologies.[5, 6] Its noninvasive nature ensures patients are not exposed to unnecessary risks, making it a top choice in emergencies. Furthermore, it facilitates a prompt diagnostic evaluation of critically ill patients. It is advisable to perform focused cardiac ultrasound on any critically ill patient to assist with diagnosis and guide management.[7]

Transthoracic echocardiography remains the primary information source in emergency settings. Recent publications have provided appropriateness criteria for it, detailing indications for specific clinical scenarios, including acute settings.[8] Notably, emergency cardiac ultrasound can enhance survival rates in various conditions and can precisely calculate essential heart parameters (Table 1.1.I).[9] Two-dimensional, spectral, and color Doppler techniques are foundational for evaluations in cardiac emergencies. However, newer techniques like tissue Doppler imaging, myocardial deformation imaging, and three-dimensional echocardiography currently play a limited role in emergency scenarios.[9-13]

Emergency cardiac ultrasound potentially improves survival in several conditions,[9] such as penetrating cardiac injuries. It can accurately measure systolic function, identify pericardial effusions, diagnose acute heart failure, pinpoint right heart strain, predict fluid responsiveness, and forecast short-term outcomes in cardiac arrest. Mastery in many of these areas does not require advanced training.

**TABLE 1.1.I.**
Clinical scenario and conditions where echocardiography is of paramount importance in the acute setting.[8]

| SCENARIO | CONDITIONS |
|---|---|
| Circulatory compromise/shock | Ischaemic LV/RV dysfunction |
| Cardiac arrest | Cardiomyopathies (DCM, HCM, Takotsubo) |
| Chest pain | Myocarditis |
| Chest/cardiac trauma | Cardiac tamponade |
| Respiratory compromise | Pulmonary embolism |
| | Hypovolemia |

LV: left ventricle; RV: right ventricle; DCM: dilated cardiomyopathy; HCM: hypertrophic cardiomyopathy

## Ultrasound of the cardiac anatomy

Understanding the heart's anatomy is essential to interpret ultrasound images accurately. The heart's position and orientation can differ based on individual anatomy and underlying pathologies. Typically situated in the left thorax, its apex points downwards and angles approximately 60° to the left.[14] However, conditions like cardiomegaly or chronic lung disease can shift this orientation, requiring tailored approaches during ultrasound examinations.

Echocardiography vividly captures the heart's rhythmic contractions, known as the cardiac cycle. By observing the movement of the valves, clinicians can gain insights into the heart's functional status, underscoring its diagnostic significance.[15]

There are distinct differences between the left and right ventricles (LV and RV, respectively). The LV is more substantial, with thicker walls and a rounded apex. Its contraction is torsional, moving toward the apex. In contrast, the RV tapers toward the apex, and its contraction is linear.[16]

The appearance of cardiac anatomy varies based on the imaging plane, and once the indication has been recognized, images can be acquired.[17] This process involves optimizing the probe, patient, and image quality. To visualize the heart between the ribs, transducers with smaller footprints and low frequencies (2-4 MHz) are preferred. Phased or microconvex arrays are commonly used. A curvilinear transducer can also be employed, especially for the subxiphoid view, but rib shadows might obstruct clear views on the chest. The depth should be increased to 20-24 cm to detect pericardial and pleural effusions and reduced to 14-16 cm

**TABLE 1.1.II.**

Details of cardiovascular ultrasound.[18]

| VIEW | WHAT TO EVALUATE | PATIENT POSITION | TRANSDUCER PLACEMENT |
|---|---|---|---|
| Subcostal | IVC collapse, LV and RV size and function, pericardial effusion, right pleural effusion | Supine with a pillow under knees to relax the abdominal wall | Transducer at the subxyphoid position, angled slightly medially, pointing the soundwave beam to the patient's left side<br>Transducer marker at approximately 3 o'clock<br>Transducer almost flat against the abdominal wall, at about a 15-degree angle |
| PLAX | LV size and function, RV size, RV wall motion, pericardial effusion, left pleural effusion, mitral and aortic valve thickening, significant valvular regurgitation | Far left lateral, when possible | Second or third ICS, as close to the sternum as possible, with the transducer "marker" directed at approximately 11 o'clock (towards the right shoulder) |
| PSAX | LV size, wall thickness, and function, RV size and function, main pulmonary artery (dilated or not), pericardial effusion, aortic valve thickening, significant valvular regurgitation | Far left lateral, when possible | Second or third ICS, as close to the sternum as possible: from the PLAX view, rotate the transducer clockwise or to your right until the transducer "marker" is at approximately 2 o'clock |
| A4C | LV size and function, RV size and function, pericardial effusion, RV/LV ratio, left pleural effusion, aortic and mitral valve thickening, significant valvular regurgitation | Far left lateral, when possible | Start at the apex and then rotate the transducer clockwise with the transducer marker at approximately 3 o'clock and angle the transducer or sound wave beam up through the apex of the heart or right |

PLAX: parasternal long axis; PSAX: parasternal short axis; A4C: apical four chambers; LV: left ventricle; RV: right ventricle; ICS: inter-costal space for a full-screen cardiac image. Adjusting the gain is crucial to clearly visualize endocardial borders.[18]

Cardiac ultrasound has four main views: parasternal long-axis (PLAX), parasternal short-axis (PSAX), apical four-chamber (A4C), and subcostal/subxiphoid (Table 1.1.II).[6, 18]

Below in detail the cardiac ultrasound view:

- subxiphoid or subcostal view – start by palpating the xiphoid process and placing the probe inferiorly with the indicator pointing to the patient's right. Initially, orient slightly toward the right shoulder to use the liver as an acoustic window. The liver appears on the screen's left side and near field. Tilt toward the left shoulder until the heart is visible. The RV, being the most anterior, is adjacent to the liver. A deep patient inhalation may enhance visualization, especially for viewing the inferior vena cava (IVC) in the short axis. Rotate the transducer 180° clockwise to see the IVC in the long axis. Note the overall diameter and collapsibility with respirations, approximately 2-3 cm distal from the right atrium or just after the hepatic vein insertion. The hepatic veins can often be seen in the liver draining into the IVC (Figure 1.1.1);
- PLAX view – this view captures the blood flow through the heart's left side. The apex appears on the screen's left. The mitral valve leaflets, and often the chordae tendinae connecting them to the papillary muscles, are visible. Two cusps of the aortic valve (typically the non-coronary and right coronary cusp) are seen. The left ventricular outflow tract (LVOT) refers to the aortic root and proximal ascending aorta. A portion of the RV is visible in the near field. Initially, the indicator should point to the patient's left hip, but adjust as needed to best visualize the aortic valve, mitral valve, and cardiac apex. Move the transducer in large circular motions on the left anterior chest to find the patient's optimal window, usually in the third or fourth intercostal space (Figure 1.1.2);

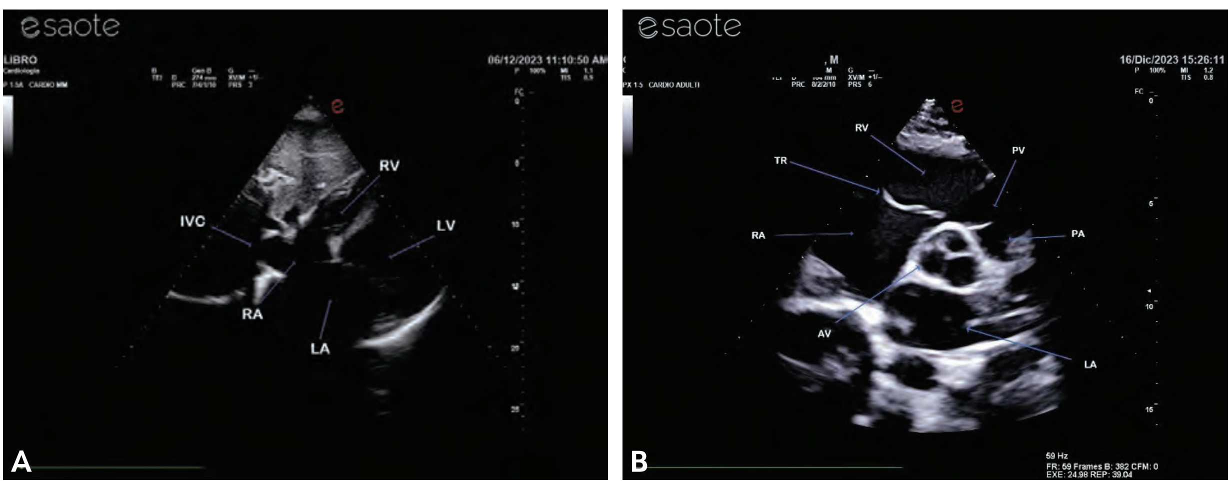


**FIGURE 1.1.1.**

A) Subcostal long axis view (also known as the subcostal coronal view). B) Parasternal sax view at level of aorta.

IVC: inferior vena cava; LV: left ventricle; RV: right ventricle; RA: right atrial; LA: left atrial; TR: tricuspid valve; PV: pulmonary valve; PA: pulmonary artery; AV: aortic valve.

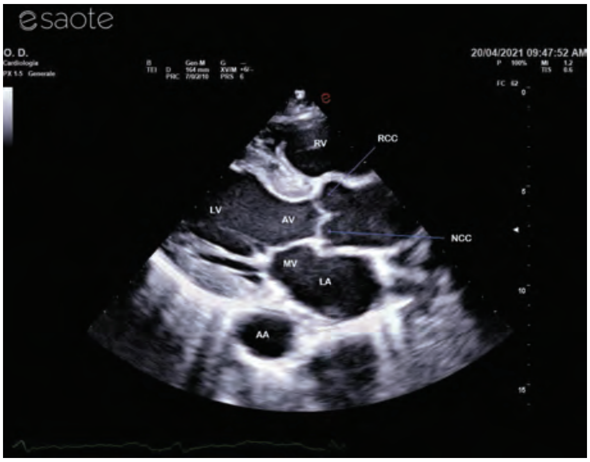


**FIGURE 1.1.2.**

Parasternal long axis.

LV: left ventricle; LA: left atrial; AA: ascending aorta; RV: right ventricle; MV: mitral valve; RCC: right coronary cusp; NCC: non-coronary cusp.

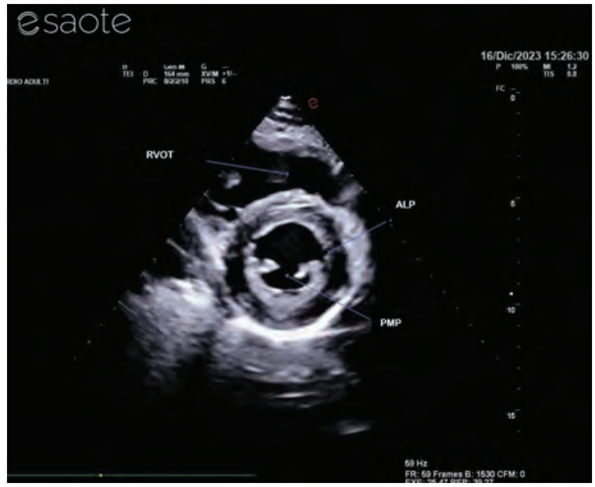


**FIGURE 1.1.3.**

Parasternal sax view at mid left ventricle.

RVOT: right ventricle outflow tract; ALP: antero-lateral papillary; PMP: postero-medial papillary.


**FIGURE 1.1.4.**

4-chamber apical view.

RA: right atrial; LA: left atrial; RV: right ventricle; LV: left ventricle; MV: mitral valve; TR: tricuspid valve.

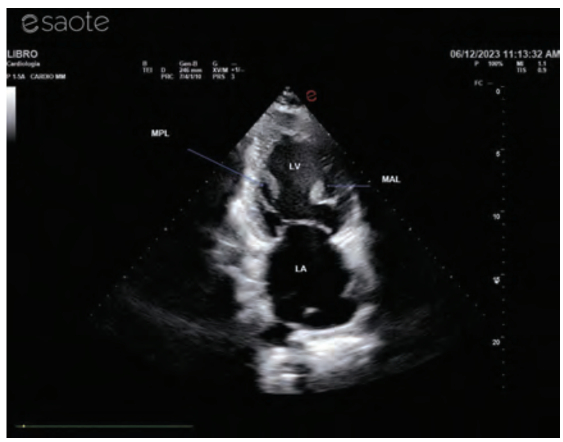


**FIGURE 1.1.5.**

2-chamber apical view.

LA: left atrial; LV: left ventricle; MAL: anterior leaflet of mitral valve; MPL: posterior leaflet of mitral valve.

- PSAX view – this view provides a cross-sectional perspective of the heart's left and right sides. These can be "sliced" at various levels between the base and the apex. From the PLAX view, rotate the transducer 90° clockwise so that the indicator points to the right hip. By tilting the probe toward the right shoulder, the aortic valve in cross-section becomes visible, showcasing all three leaflets in the "Mercedes Benz" sign. The right ventricular outflow tract (RVOT) and pulmonary valve are also visible. At the base, the mitral valve is inside the LV. At the mid-ventricular level, the papillary muscles are within the LV. In point-of-care ultrasound in acute care settings, the PSAX view is the most common. At the apex, the LV is tapered, and no structures are visible within (Figure 1.1.3);

- A4C view – this view displays all four heart chambers. Locate the point of maximal impulse and place the transducer over it, generally at the inframammary fold or under the left breast in women, with the indicator pointing to the patient's right side. Adjust the probe to ensure the interventricular septum is approximately at the 12 o'clock position. The apex is near the field, with the interventricular septum pointing to around the 12 o'clock position. By tilting the probe superiorly, the apical five-chamber view can be obtained, with the "fifth chamber" being the LVOT with the aortic valve (Figures 1.1.4-1.1.6).

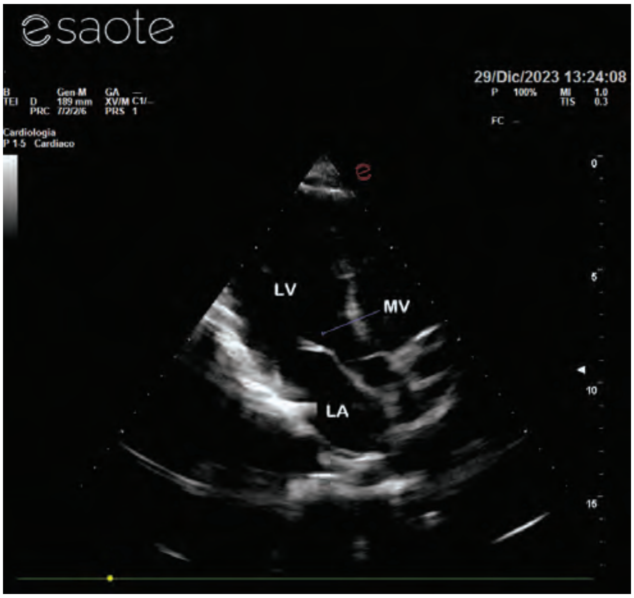


**FIGURE 1.1.6.**
3-chamber apical view.

LA: left atrial; LV: left ventricle; MV: mitral valve.

## Focused cardiac ultrasound

In 2001, the American College of Emergency Physicians (ACEP) introduced the first emergency ultrasound guidelines. They were designed to outline the primary point-of-care ultrasonography (POCUS) applications and to emphasize the significance of ongoing education and training in emergency ultrasound usage. As the utilization of focused ultrasounds grew, so did these guidelines.[19] POCUS serves as a vital diagnostic instrument, offering bedside evaluations, enabling physicians to swiftly assess patients in the emergency department and to make informed clinical decisions.[20]

The principal role for POCUS is the time-sensitive assessment of the symptomatic patient.[9] This evaluation primarily includes assessment of pericardial effusion and evaluation of the relative chamber size, global cardiac function, and the patient's volume status (Table 1.1.III). The intravascular volume status may be assessed based on LV size, ventricular

**TABLE 1.1.III.**
Aims of the focused cardiac ultrasound in the symptomatic Emergency Department patient.

| AIMS OF THE FOCUSED CARDIAC ULTRASOUND |
| --- |
| Assessment for the presence of pericardial effusion |
| Assessment of global cardiac systolic function |
| Identification of marked RV and LV enlargement |
| Intravascular volume assessment |
| Guidance of pericardiocentesis |
| Confirmation of transvenous pacing wire placement |

LV: left ventricle; RV: right ventricle.

function, and IVC size and respiratory change. Moreover, POCUS aids in guiding urgent invasive procedures like pericardiocentesis or verifying the position of transvenous pacemaker placement.[9]

While POCUS might hint at certain pathologies (*e.g.*, intracardiac masses, LV thrombus, or valvular dysfunction), comprehensive echocardiography or a cardiology consultation is advised for a definitive diagnosis. Detailed hemodynamic assessments of intracardiac pressures and diastolic function necessitate further training in comprehensive echocardiography techniques.[9]

Whenever there is a discrepancy between focused findings and clinical presentations, a comprehensive echocardiographic examination or the use of other imaging modalities is recommended. The scenarios and information derived from focused cardiac ultrasound in urgent situations differ significantly from those where comprehensive echocardiography is employed. Both study types play a role in enhancing patient care.[9]

## Pericardial effusion

Pericardial effusion, a potential life-threatening condition, pertains to fluid accumulation in the pericardial sac surrounding the heart. On ultrasound, it appears as a dark (anechoic) space encircling the heart.[21] On the other hand, epicardial fat pads are localized anteriorly to the heart and often exhibit increased echogenicity. The PLAX view can help differentiate between pericardial effusion (anterior to the descending thoracic aorta) and pleural effusion (posterior to the descending thoracic aorta). Swift identification and differentiation from conditions like cardiomyopathy or aortic dissection are crucial. Small or localized pericardial effusion might be challenging to detect with POCUS. If clinical suspicion for effusion is high and POCUS does not confirm it, then a comprehensive echocardiogram or other diagnostic imaging is warranted.[9]

Research indicates high sensitivity and specificity in detecting pericardial effusions in both medical and trauma patients using POCUS.[22-24] For the most accurate detection of pericardial effusion, imaging in multiple views or windows is recommended. The subcostal view, easily performed in supine patients, is the most suitable for diagnosing pericardial effusion, which appears as an echo-free space between the heart and the parietal layer of the pericardium.[6]

In cases of significant effusion, the heart may appear to "swing" or "wobble" within the accumulated fluid.[25] This phenomenon, combined with other clinical signs, can suggest cardiac tamponade, where the accumulated fluid compresses the heart, affecting its function. Recognizing that pericardial tamponade is a clinical diagnosis is vital. It includes visualizing pericardial fluid, blood, or thrombus, in addition to clinical signs like hypotension, tachycardia, pulsus paradoxus, and distended neck veins.[26] The pericardial tamponade diagnosis encompasses hemodynamic instability, pulsus paradoxus, jugular distension,[27] and echocardiographic evidence of pericardial effusion associated with diastolic right chamber collapse and a dilated, hypo-collapsing IVC. When emergency pericardiocentesis is necessary, ultrasound can the fluid collection from the subxiphoid/subcostal or other transthoracic windows to determine the best needle trajectory. If pericardial effusion requiring percutaneous drainage is diagnosed promptly at the bedside, ultrasound-guided pericardiocentesis in these critically ill patients has fewer complications and a higher success rate than procedures done without ultrasound guidance.[28, 29] Agitated saline injection can help localize needle placement during this procedure.[28] If emergency pericardiocentesis is required, POCUS can assist in guiding the needle into the pericardial space and verifying the needle's position in the pericardial cavity after agitated saline solution infusion.[30] Echo-guided pericardiocentesis has a higher success rate and reduced complication risk compared with non-echo-guided pericardiocentesis.[31]

## Left chamber size and function

POCUS can evaluate LV systolic function globally. This assessment is based on the overall evaluation of endocardial excursion and myocardial thickening, using various windows, including parasternal, subcostal, and apical views.[9] It is essential to understand that POCUS assesses global function and categorizes patients into "normal" or minimally impaired function *versus* "depressed" or significantly impaired function. This descriptive terminology, when used by non-echocardiographers, aligns well with echocardiographic interpretations.[32, 33] The goal of the focused exam is to aid clinical decision-making, determining whether a patient with acute shortness of breath or chest pain has impaired systolic contractility, and thus would benefit from pharmacologic therapies or other interventions.[34] Identifying reduced LV systolic function can guide the physician toward diagnosing cardiogenic shock, indicating the need for inotropes, mechanical support, and an urgent coronary angiographic evaluation.[33] Evaluating segmental wall motion abnormalities and other shortness of breath causes (*e.g.*, valvular dysfunction) can be challenging and should be assessed by a comprehensive echocardiogram.[35]

The LV's diastolic function can be roughly evaluated in the A4C view by focusing on the left atrium's dimensions and analyzing the pulsed-wave Doppler of the transmitral diastolic flow, positioning the volume sample at the mitral leaflet tip.[36] The ratio between the protodiastolic E wave and the end-diastolic A wave provides preliminary information on the heart's diastolic function. The mitral, annular, septal, and lateral protodiastolic mean velocity evaluation through the tissue Doppler technique allows estimating the LV diastolic filling pressures using the E/e' ratio.[6] This information is valuable in guiding patient treatment because, in diastolic dysfunction, fluid administration might yield little to no response, while diuretic therapy to unload left heart filling pressures could be beneficial. Additionally, the interatrial septum's position can be informative: if it bulges toward the right, then it indicates elevated filling pressures in the left cardiac chambers.[6]

## Right ventricle parameters

POCUS can identify hemodynamically significant pulmonary emboli by observing RV dilatation (RV:LV ratio >1), decreased RV systolic function, or occasionally by spotting a free-floating thrombus.[9] When evaluating the RV, it is crucial to focus on the chamber dimensions (typically two thirds of the LV size in the A4C view) and shape. A D-shaped appearance, combined with septal systolic bulging toward the LV, suggests a high-pressure regimen in the right heart, potentially linked to severe pulmonary hypertension or a pulmonary embolism.[37]

Tricuspid annular plane systolic excursion (TAPSE) measures right-sided systolic function. In the emergency department, it is primarily used to check for signs of right heart strain in patients with suspected or confirmed pulmonary embolism.[38] Although it is a good prognostic test, it is not sensitive enough for diagnosing pulmonary embolism. On the A4C view, place the M-mode cursor