

GUIDELINE

Instructions for the use of critical care ultrasound in Dutch daily practice: the Rijnstate ICU manual, ready for broad acceptance?

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Basic cardiac ultrasound and lung ultrasound

Introduction

The use of ultrasonography in the diagnosis and treatment of critical illness has increased extensively. Critical Care Ultrasound (CCUS) has become an important tool for intensivists. CCUS is easily accessible and is a rapid diagnostic bedside tool that should be considered as an extension of the physical examination. The answers to many clinical questions can be found through a focused CCUS investigation. This manual has been developed to address the requirement of intensive care physicians to rapidly identify cardiovascular and respiratory problems by using basic cardiac ultrasound (BCU) and lung ultrasound (LUS) in order to apply appropriate therapy – especially in life threatening situations. We want to emphasize that BCU is not intended to replace transthoracic echocardiography (TTE) performed by cardiologists; as well as LUS, it is meant as a targeted examination to find answers to specific clinical questions. However, it is not feasible to have a cardiologist or radiologist available on call on a 24-hour basis to perform bedside ultrasound in the ICU.¹ Recently the term *binary ultrasound* was introduced by Bosch et al.² to emphasize that ultrasound should be used to answer clinical questions with a yes or a no. With proper training, intensive care physicians can achieve a high level of competence in all aspects of ultrasonography; the intensivist ultrasonographer has to be proficient to be qualified. Proficiency includes the knowledge of when to ask for expert advice.

According to the 2009 La Société de Réanimation de Langue Française (SRLF) / American College of Chest Physicians (ACCP) “Statement on Competence in Critical Care Ultrasonography” CCUS is divided into General Critical Care Ultrasonography (GCCUS) (pleural/lung, abdominal and vascular) and Critical Care Echocardiography (CCE) or cardiac

ultrasound (CU) basic and advanced.³ This manual will discuss “the Arnhem protocol” of BCU and LUS through stepwise instructions and illustrations supported by internet-based video demonstrations.

Daily practice in the Netherlands

One of the difficulties in Dutch daily practice is that physicians who want to become skilled in CCUS have limited access to training. Although local training programs have been developed, specific training programs designed for intensivists at national level are not yet widely available. The RACE (*Rapid Assessment of Cardiac Echo*) course,⁴ currently organized by the Netherlands Society of Intensive Care, is the national basic ultrasound course. There are also other courses organized by various hospitals.

Training programs

Focused bedside ultrasonography by intensivists is feasible and can be performed safely and rapidly in order to guide the diagnosis and management of critically ill patients. However, false interpretation or application of data obtained by a poorly skilled ultrasonographer may have adverse consequences.⁵ To avoid misuse, adequate training is essential.¹ Maintaining good levels of competence in staff is also a key element of the successful use of CCUS. Inappropriate use or misapplication of CCUS could potentially slow the acceptance of bedside ultrasound performed by intensivists.¹

Training requirements

According to the 2009 European Society of Intensive Care Medicine (ESICM) annual meeting “Expert Round Table on Ultrasound in ICU”, the following minimal requirements leading to competence in GCCUS and basic CCE/CU have been defined as follows.

For theoretical training: a minimum of 10 hours is required to be divided between lectures and didactic cases with image-based training, in which both internet-based learning and lecture format should be available to trainees in a blended fashion.

For practical training: there was no consensus regarding the required number of examinations to be performed by the trainee. However, a review of the literature suggests that 30 fully supervised transthoracic echocardiography studies is a reasonable training target for people to achieve competence in image acquisition. The trainee should maintain a logbook of his/her scanning activities including reports of ultrasound examinations performed and/or interpreted and co-signed by both trainee and supervisor.⁶

Future developments

At present we are at the beginning of the development of CCUS in the Netherlands. The challenge is to provide adequate training to every intensive care physician. This will enable them to perform BCU and LUS at point of care in order to guide the diagnosis and management of patients with cardiopulmonary failure.⁷ In the near future, it will be possible to expand competence to all aspects of CCUS such as bedside diagnosis of deep venous thrombosis, identification of intra-abdominal fluid, or diagnosis of hydronephrosis. We recommend that the initial training of Dutch intensivists should focus on BCU and LUS.

Basic cardiac ultrasound

The aim of BCU is to provide answers to a limited number of clinical questions frequently encountered by intensive care physicians. BCU is a qualitative and targeted tool that can be repeated in order to evaluate specific therapeutic interventions, such as, whether to choose between fluids or diuretics, vasodilators or vasopressors. Because specificity is favoured over sensitivity, well-defined results will lead to changes in patient regimen, whereas indeterminate results will require consultation with a more experienced echocardiographer.³ Competence in BCU requires intensive care physicians to integrate echocardiographic results into management strategy after cognitive training. The goals of training are as follows.

Goals

1. Through BCU, an intensive care physician is able to identify normal cardiac images together with their adjacent structures and accessory anatomy.
2. Through BCU, an intensive care physician is able to recognize and apply the five standard basic cardiac ultrasound views (PLAX, PSAX, A4C, SC, SC-IVC).
3. Through BCU, an intensive care physician is able to identify and interpret aberrant phenomena, especially hemodynamic disturbance (LV-dysfunction, RV-dysfunction, tamponade

and intravascular volume status). The results of the examination are translated into daily clinical practice in order to apply focused therapy.

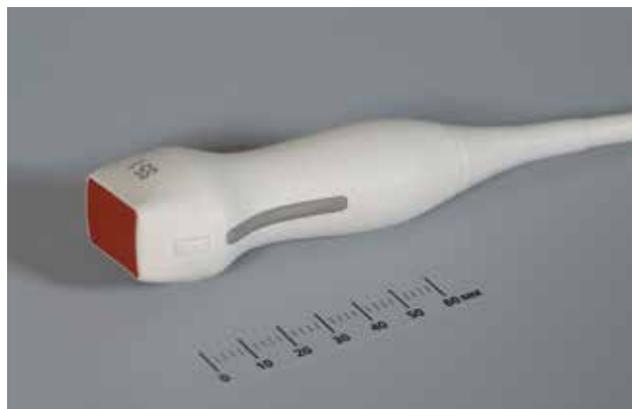
Type of transducer

A BCU examination is performed with a phased array transducer (1.5 - 4 MHz) (figures 1, 2) that has a small footprint to fit between the ribs, thus making it best suited for cardiac imaging. Because of low frequency, it has good penetration but poor axial resolution. In terms of electronic steering, it has a better lateral resolution than the curvilinear probe.⁴

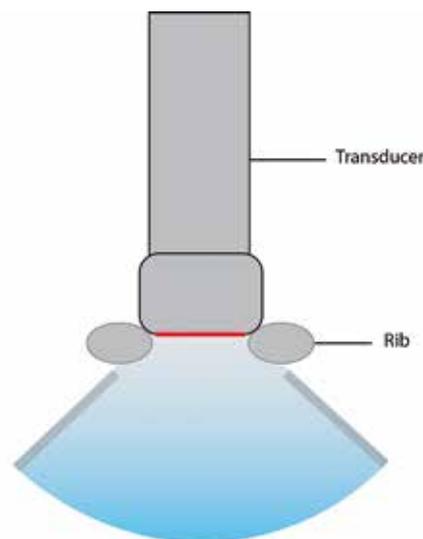
Positioning and preparation

1. The patient is placed in the left lateral position, if possible, with the left arm abducted (figure 3).
2. The patient's details are entered into the machine.
3. The ECG is connected to the ultrasonography machine.

1. Phased-array transducer.



2. Schematic phased-array characteristics.



Standard views⁴

1. Parasternal Long Axis (PLAX) view

- Probe position: normally, 2nd to 4th intercostal space, left of the sternum (*figure 3*).
- Pointer direction: at around 11 o'clock (*figure 3*).
- View: longitudinal section of the heart (*figure 4*).
 - Optional: link to internet-based video demonstration of PLAX⁸

2. Parasternal Short Axis (PSAX) view

- From the PLAX position to PSAX (*figure 5*): rotate the transducer 90° clockwise.
- Tilt the transducer superiorly and inferiorly to obtain the three levels of the left ventricle (LV):
 - a. Basal: mitral valve (*figure 6*)
 - b. Mid: papillary muscles (*figure 7*)
 - c. Apical (*figure 8*)
- Tilt the transducer superiorly and angle medially to obtain the aortic valve level (*figure 9*).
 - Optional: link to internet-based video demonstration of PSAX⁹

Apical 4 Chamber (A4C)

- The transducer is placed directly on the area where the apical pulse is palpable (*figure 10*). This position is usually located at the 5th intercostal space and in the mid-axilla area.
 - The pointer is directed towards the 3 o'clock position (posteriorly).
 - The transducer is tilted superiorly.
 - The A4C view can be obtained (*figure 11*).

The apical 5 chamber (A5C) and apical 2 chamber (A2C) views and their accessory measurements, determination of stroke volume and detailed analysis of segmental function, respectively, will be covered in the advanced ultrasound course. However, recognizing these views in BCU can contribute to the process of understanding the potential obtained views in the A4C position.

- Optional: the transducer is tilted anteriorly from the A4C view; the A5C view can be obtained (*figure 12*).
- Optional: to switch from the A4C view to the A2C view (*figures 13, 14*) rotate the transducer approximately 60° counter-clockwise. The pointer is at approximately 12 o'clock (superiorly).
 - Optional: link to internet-based video demonstration of apical view (A4C, optional: A5C and A2C)¹⁰

3. Subcostal (SC) view

- The transducer is placed in the subxiphoid position along the midline of the patient and tilted slightly anteriorly.
- The transducer is pointed at the left mid-clavicular region or left shoulder (*figures 15, 16*).
- The pointer is at approximately 3 o'clock.

3. PLAX positioning: the patient is placed in the left lateral position, if possible, with the left arm abducted.

Probe position: 2nd to 4th intercostal space, left of the sternum. Pointer direction: at about 11 o'clock.

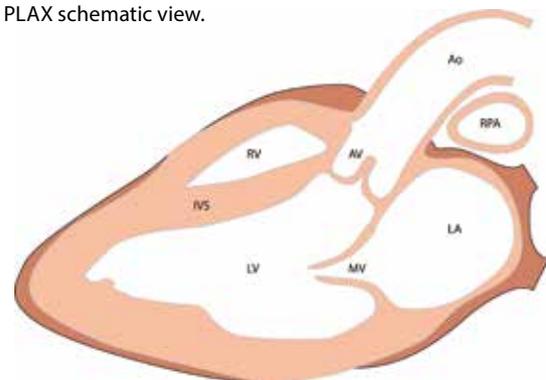


4A. PLAX view.



RV: right ventricle. IVS: interventricular septum. LV: left ventricle. LA: left atrium. MV: mitral valve. AV: aortic valve.

4B. PLAX schematic view.

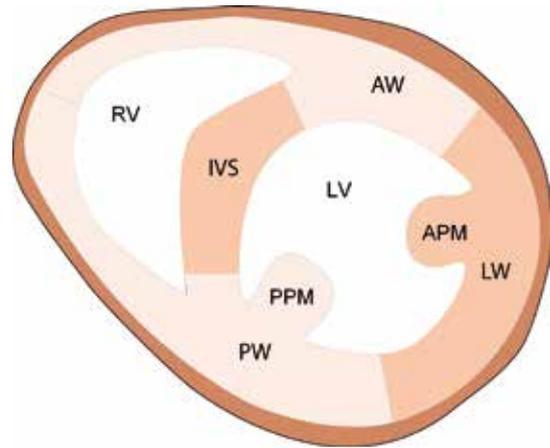


RV: right ventricle. IVS: interventricular septum. LV: left ventricle. LA: left atrium. MV: mitral valve. AV: aortic valve. Ao: aorta. RPA: right pulmonary artery.

5. PSAX positioning; rotate the transducer 90° clockwise.

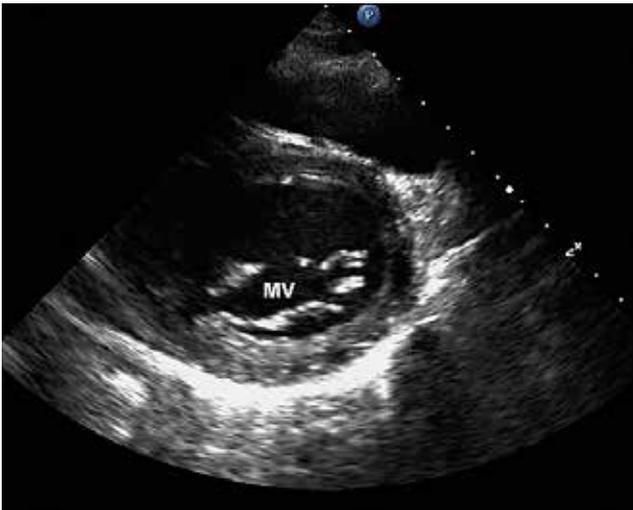


7B. Schematic PSAX view.

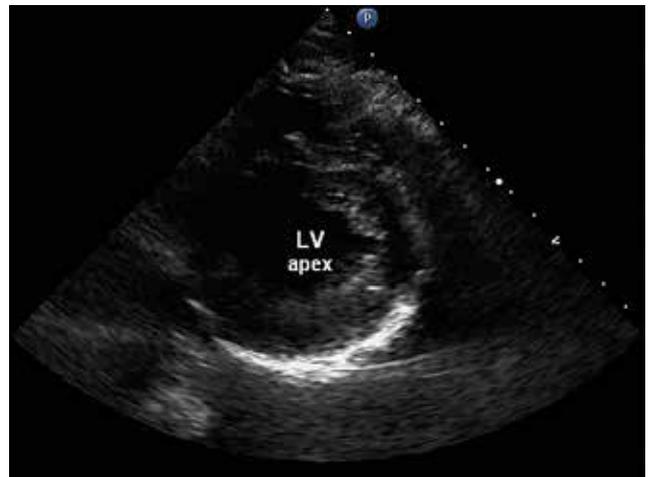


LV: left ventricle. RV: right ventricle. IVS: interventricular septum. AW: LV anterior wall. PW: LV posterior wall. LW: LV lateral wall. PPM: posterior papillary muscle. APM: anterior papillary muscle.

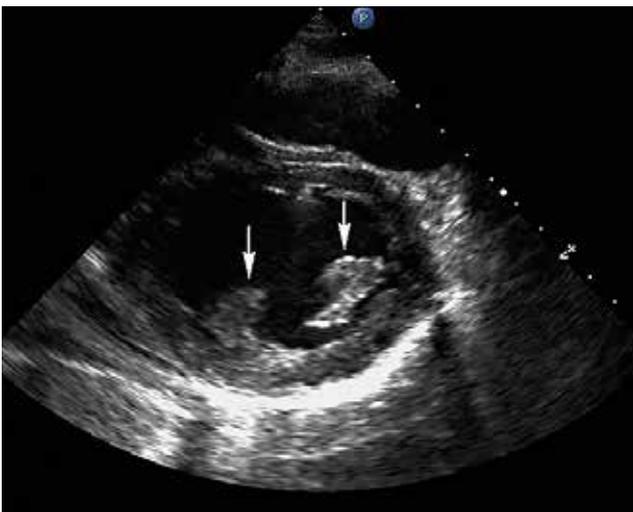
6. PSAX view, basal level. MV: mitral valve.



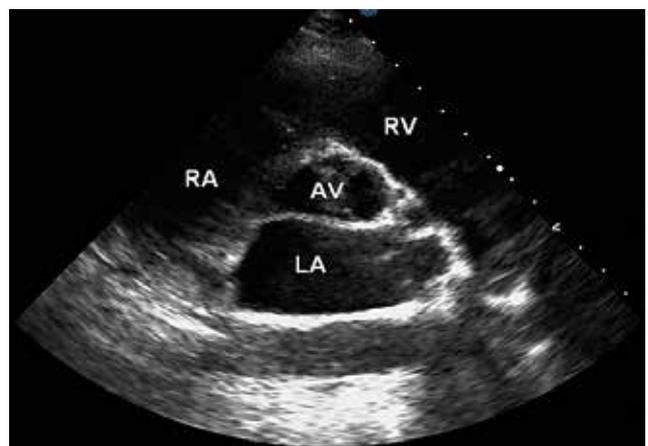
8. PSAX view, apical level.



7A. PSAX view mid level. Arrows: papillary muscles.



9A. PSAX view.

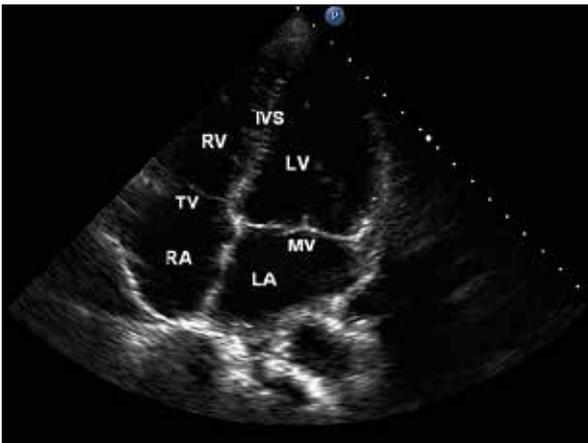


RA: right atrium. AV: aortic valve. LA: left atrium. RV: right ventricle.

10. To obtain the A4C view: the transducer is placed directly on the area where the apical pulse is palpable.

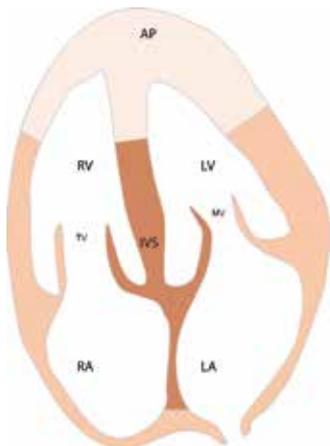


11A. A4C view.



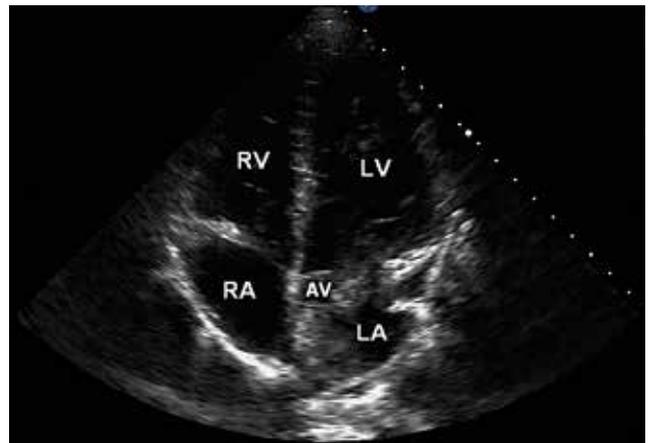
RV: right ventricle. LV: left ventricle. TV: tricuspid valve. MV: mitral valve. RA: right atrium. LA: left atrium. IVS: interventricular septum.

11B. Schematic A4C view.



RV: right ventricle. LV: left ventricle. TV: tricuspid valve. MV: mitral valve. RA: right atrium. LA: left atrium. IVS: interventricular septum. AP: apex.

12. A5C view.

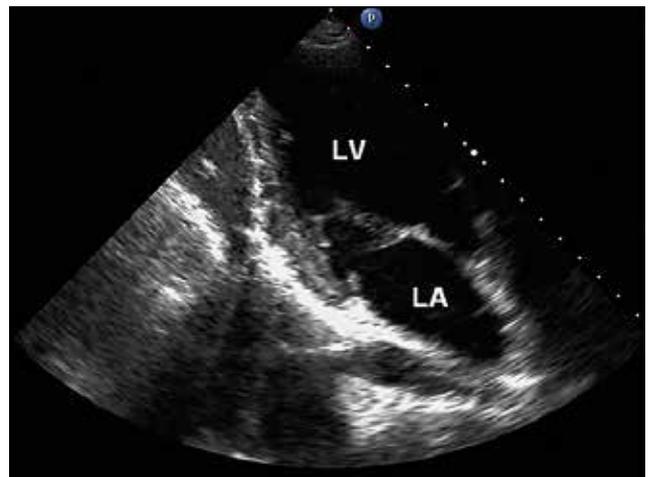


RV: right ventricle. LV: left ventricle. RA: right atrium. LA: left atrium. AV: aortic valve.

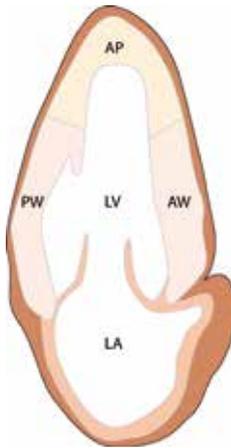
13. A2C view: to switch from A4C to A2C view: rotate the transducer 60° counter-clockwise. The pointer is at approximately 12 o'clock.



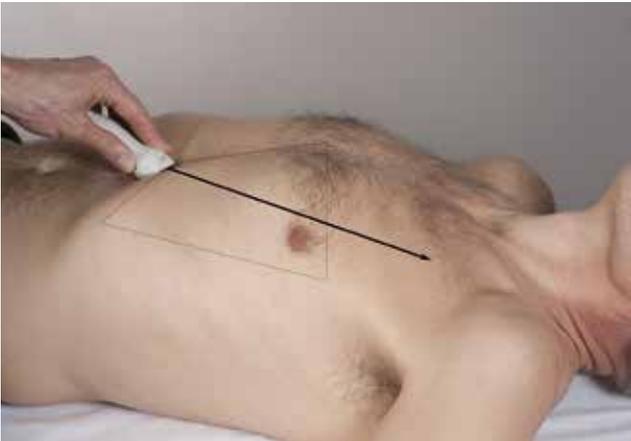
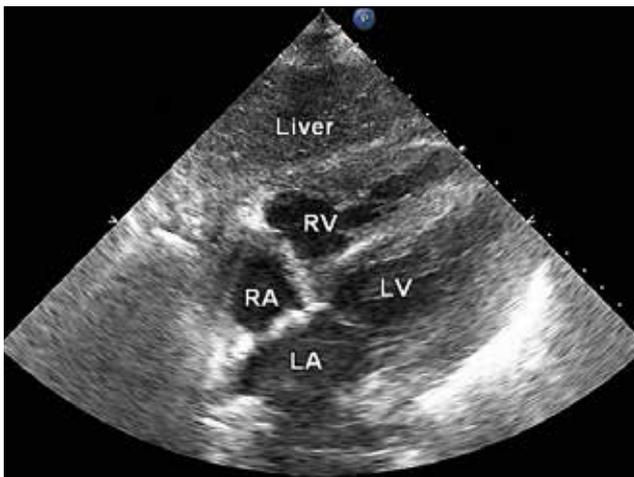
14. A2C view.



LV: left ventricle. LA: left atrium.

14B. Schematic A2C view.

LV: left ventricle. LA: left atrium. AW: anterior wall. AP: apical wall. PW: posterior wall.

15. SC view: the transducer is pointed at the left mid-clavicular region or left shoulder. The pointer is at approximately 3 o'clock.**16.** SC view.

RV: right ventricle. RA: right atrium. LV: left ventricle. LA: left atrium.

This view is often the best quality view in a critically ill patient. It provides a good view for the assessment of cardiac function in order to rapidly identify imminently life-threatening causes of shock (e.g. pericardial tamponade, acute cor pulmonale, profound hypovolemia with LV end systolic effacement, or thrombus in transit).

- Optional: link to internet-based video demonstration of subcostal view¹¹

4. Subcostal Inferior Vena Cava (SC-IVC) view

- From the SC position the transducer is angled towards the patient's right side and is subsequently rotated counter-clockwise until the transducer marker is at the 12 o'clock position. This results in a long axis view of the IVC, as it passes through the liver and terminates at the IVC-right atrium junction (*figures 17, 18*).
- Optional: link to internet-based video demonstration of SC-IVC view¹²

Left heart assessment

In the acute clinical setting, an assessment of LV function is a key part of the BCU examination. The high prevalence of coronary artery disease and associated ischemia often affects LV contractility, acute or chronically. This can result in compensatory LV dilatation and regional wall motion abnormality.⁴

Basic questions about LV function

- What is the global LV function?
- Presence of dilatation? *Answer: yes/no/not sure.*

Right heart assessment

Right heart failure should always be considered as a possible cause for hemodynamic failure.

- It can be a source of primary pathology.
- It can reflect circulatory changes as a result of LV pathology.
- It can provide information concerning major respiratory pathophysiology.⁴

The subcostal (SC) view is often most suitable, especially where obese, mechanically ventilated patients or patients with chronic pulmonary disease are concerned.⁴

In right heart assessment, the size and contractibility of the RV are examined. Tricuspid Annular Plane Systolic Excursion (TAPSE) measurement can assess RV contractility without the need for sophisticated machines or Doppler studies. TAPSE reflects the longitudinal motion of the tricuspid annulus and correlates with RV systolic function. It is measured in the A4C view by placing an M-mode cursor along the lateral tricuspid annulus and is defined as the peak-to-peak distance of the total excursion during systole (*figure 19*). A greater distance travelled implies greater RV systolic function. The normal reference limit is a TAPSE of > 17 mm.¹³

17. SC-IVC view: the transducer is rotated approximately 90°. Point posteriorly. Pointer upward.

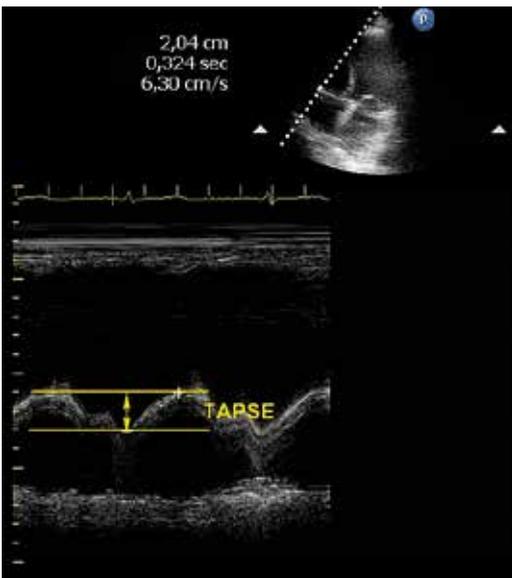


18. SC-IVC view.



IVC: inferior vena cava. RA: right atrium.

19. TAPSE.



Basic questions about RV function

- What is the global RV function?
- Presence of dilatation? *Answer: yes/no/not sure.*

*Pericardial effusion*⁴

Normally 5-10 ml of fluid is present in the pericardial space. Various pathophysiologic processes can cause either slow or rapid accumulation of fluid in the pericardial space.

- The pericardium can be a source of primary pathology (e.g. infection, inflammation) gradually resulting in pericardial effusion.
- Acute accumulation of pericardial fluid or blood in the pericardial space can cause cardiac tamponade resulting in hemodynamic failure.

The PLAX and subcostal views are often most suitable in this condition. Pericardial effusion can be seen as an echo-free space. In the case of an echo-free space, it is important to rule out the presence of a fat pad and pleural effusion. Fat pads can be seen in obese patients and are, in contrast to pericardial effusion, not completely echo-free. Furthermore, a fat pad moves in concert with heart motion and is only present anteriorly, not posteriorly. Pleural effusion can be seen as an echo-free space posterior to the descending aorta.⁴

Pericardial effusion is anterior to the descending aorta, while pleural effusion is posterior to the descending aorta (figure 20)
Severity of pericardial effusion (*table 1*): the largest epi- and pericardial separation (echo-free space) is measured at end-diastole.

Basic questions about pericardial effusion

- Is pericardial fluid present? *Answer: yes/no/not sure*
- If yes: significant quantity (> 20 mm)? *Answer: yes/no*

Note 1: Tamponade is considered a clinical diagnosis. Ultrasound is an important aid to making the diagnosis of tamponade.

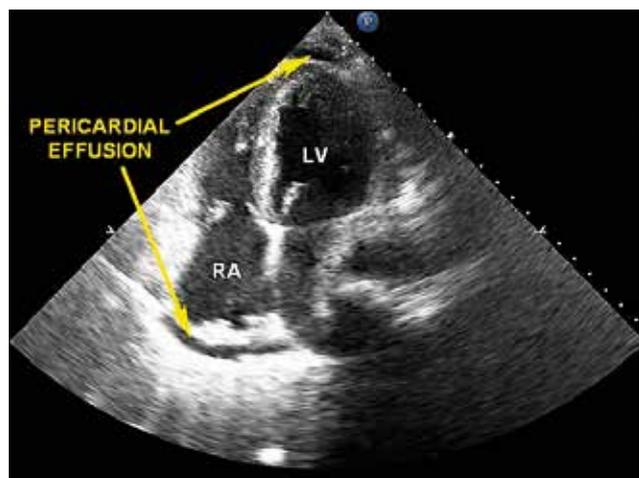
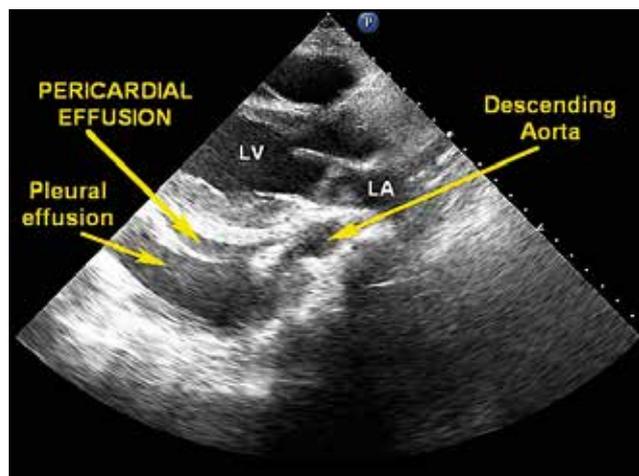
Note 2: The diagnosis of pericardial effusion/tamponade in post-cardiothoracic surgery patients can be more difficult than in non-operated patients. This may require expert level assessment with transoesophageal echocardiography.

Volume status

Maintaining adequate circulation in patients is one of the main tasks of intensivists, especially in cases of shock. However, assessing intravascular volume remains one of the most challenging jobs in intensive care medicine.⁴

The methods that are currently available, such as respiratory IVC diameter variation (Δ IVC) and right atrial pressure correlation, have their limitations as interpretation is often influenced by the existence of comorbidity and mechanical ventilation.⁴

20. Pericardial effusion.



A. in PLAX view. LA: left atrium. B. in A4C view. RA: right atrium. LV: left ventricle.

Table 1.⁴

Severity	Characteristics
Minimal / physiological	End-systolic separation of epicardium and pericardium posteriorly
Small	<ul style="list-style-type: none"> Echo-free space in both anterior and posterior space Echo-free space appears throughout the cardiac cycle Echo-free space: < 10 mm
Moderate	<ul style="list-style-type: none"> Echo-free space: 10-20 mm Surrounds the entire heart
Large	<ul style="list-style-type: none"> Echo-free space: > 20 mm Swinging heart motion

Recently Muller et al. emphasized that Δ IVC, being a dynamic preload index, cannot reliably predict fluid responsiveness in patients with acute circulatory failure (ACF) who are breathing spontaneously.¹⁴ In contrast to findings reported in mechanically ventilated septic patients, dynamic parameters

have been shown to be an ineffective fluid responsiveness predictor in patients breathing spontaneously.¹⁵ In patients with spontaneous ventilation, respiratory variations are highly variable from one cycle to another in any given patient and between different patients. As a result, the influence of the breathing pattern on Δ IVC is also variable. In addition, Δ IVC may be influenced by the magnitude of respiratory movements, especially in cases of dyspnoea in patients with circulatory failure and/or shock.¹⁵ In summary, Δ IVC should be interpreted with caution in patients breathing spontaneously with ACF. In general it can be stated that high Δ IVC values (> 40%) are usually associated with fluid responsiveness, while low values (< 40%) cannot exclude fluid responsiveness.¹⁴ More studies are needed to further evaluate ultrasound and fluid responsiveness.

In the case of mechanical ventilation, predicting fluid responsiveness is also difficult.

In the future it would be conceivable to incorporate an assessment of intravascular volume and fluid responsiveness as a substantial subject in an advanced ICU ultrasound course. In BCU, fluid responsiveness and/or assessing volume status might be the most difficult part. However, having said this, it is also possible for less experienced doctors to assess volume status and fluid responsiveness on both ends of the volume spectrum: massive overload versus extreme fluid depletion.

Inferior Vena Cava (IVC)⁴

The IVC diameter and its changes are measured during respiration in patients who are breathing spontaneously. The most suitable probe position is the subcostal view. The patient is in the supine position.

IVC is significantly affected by the patient's position, being largest in the right lateral position, intermediate in the supine and smallest in the left lateral position.

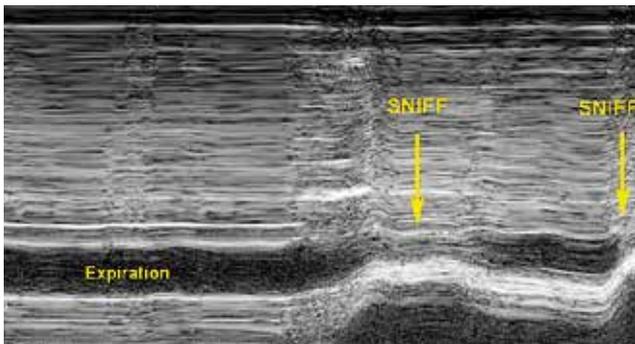
2-D

- The transducer is tilted and pointed to obtain the largest IVC diameter.
- The 2-D images are frozen at both end-expiration and end-inspiration.
- The IVC diameter is measured at a distance of 2 cm (point of maximal collapse) from the IVC-RA junction.

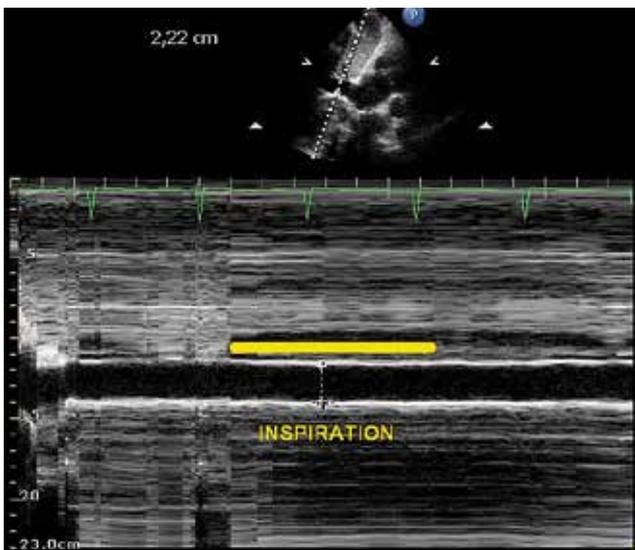
M-mode (time-motion)

- Tilt and point the transducer to obtain the largest IVC diameter.
- Place the cursor perpendicular to the IVC at a distance of 2 cm (point of maximal collapse) from the veno-atrial junction.
- Start M-mode and ask the patient to "sniff" (the *sniff manoeuvre*) (figures 21, 22).

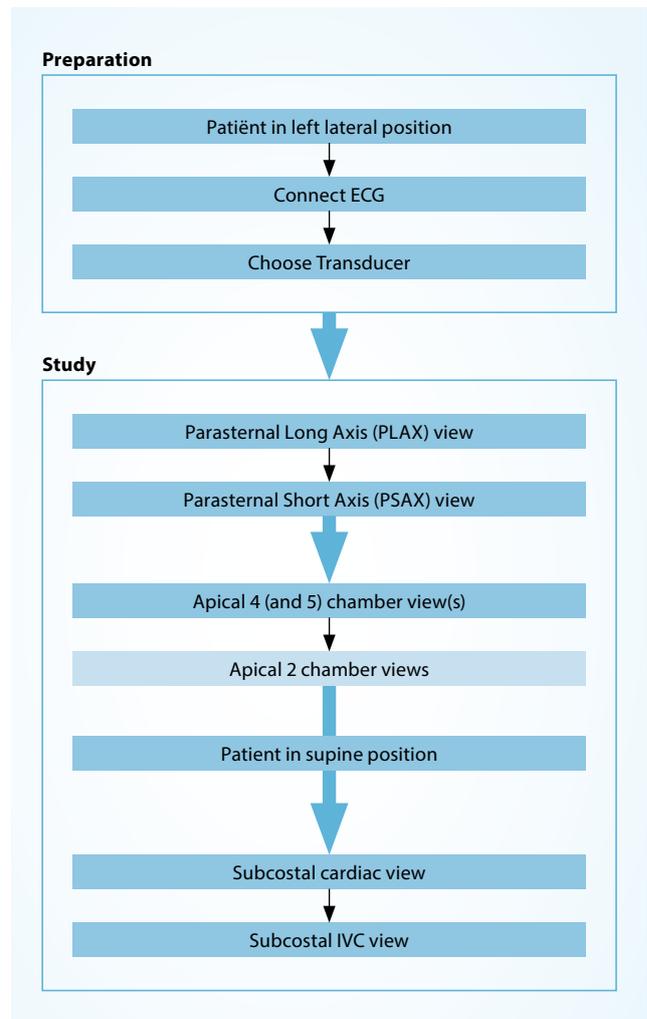
21. Normal IVC response to sniff manoeuvre.



22. Non-collapsing and dilated IVC in a spontaneously breathing patient.



Flowchart 1.⁴



Summary basic cardiac ultrasound
(Flowchart 1)⁴

Template report BCU

1. LV function characteristics?

- Size (diastole): *small/normal/dilated* (through ‘eyeballing’).
- Contractility: *normal/decreased/hyper-dynamic*.

2. RV function characteristics?

In general terms the RV must be smaller than the LV. When the RV size is similar to or larger than the LV size it indicates the presence of underlying disease. Additional quantitative ultrasound by a cardiologist is recommended.

- Size: *small/normal/dilated*.
- Contractility: *normal/decreased/hyper-dynamic*.
- TAPSE: ≤ 17 mm: abnormal, indicates reduced RV systolic function¹³, > 17 mm: normal RV function.¹³

3. Tamponade?

Signs of tamponade:

- Right atrium: early systolic collapse.
- Right ventricle: early diastolic collapse.
- IVC diameter and collapsibility (in mechanical ventilation)
 - dilated and/or fixed: True Tamponade;
 - non-dilated and collapsible: fluid depletion resulting in low diastolic pressure.

4. Intravascular volume status?

Be careful with the interpretation of the assessment of volume status and/or fluid responsiveness in spontaneously breathing patients. In the absence of accurate universal ultrasonographic methods, we suggest using Δ IVC.

In spontaneously breathing patients:

Δ IVC: $(D_{max} - D_{min}/D_{max}) \times 100$. Where D = IVC diameter.^{4,14}

Cut-off values:

Δ IVC > 40% is usually associated with fluid responsiveness, while Δ IVC < 40% cannot exclude fluid responsiveness.¹⁴

Lung ultrasound (LUS)

The major advantage of pleural- and lung ultrasound is its immediate bedside availability. Several recent publications demonstrate that ultrasound is more reliable than bedside chest radiography, and that it is similar in performance characteristics to computed tomography (CT) scan for critical care applications.¹⁶⁻²⁰ LUS is a non-invasive and straightforward method that allows the frontline clinician to identify important findings such as pneumothorax, normal aeration pattern, interstitial abnormality, consolidation, and pleural effusion. At a more advanced level, it allows regional assessment of lung recruitment and close monitoring of treatments and manoeuvres aimed at improving lung aeration. Bouhemad et al. correlated bedside LUS with pressure-volume curves for the assessment of PEEP-induced lung recruitment.²¹

Learning LUS is straightforward. Competence requires the intensive care physician to integrate ultrasonographic results into management strategy after cognitive training and requires the following goals.

Goals

1. Through LUS, an intensive care physician is able to identify normal images of pleura and adjacent structures/phenomena (parietal and visceral pleura, *bat sign*, A-lines, B-lines, lung sliding).
2. Through LUS, an intensive care physician is able to recognize aberrant images/phenomena (absent lung sliding, lung point, lung pulse, pleural effusion, PLAPS).
3. Through LUS, an intensive care physician is able to interpret aberrant images/phenomena and translate them into daily clinical practice (e.g. absence of ventilation, pleural effusion).

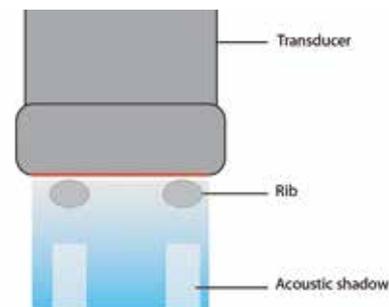
Type of transducer

The LUS examination is performed with a Linear transducer (5-12 MHz) (figures 23, 24). This transducer has a large footprint. Because of high frequency it has good axial resolution for structures closer to the body surface. It has poor penetration. As an alternative, the cardiac transducer may be used if deeper thoracic structures are to be imaged, or if the patient has a thick chest wall (due to obesity, oedema, heavy musculature). Use of the lower frequency transducer improves penetration but at the expense of reduced resolution.

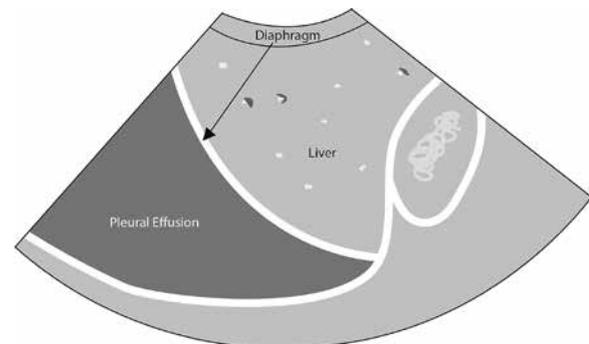
LUS: Schematic anatomy of patient's right side (figure 25)

Positioning and preparation

1. The patient is placed in the supine position, if possible.
2. The patient's details are entered into the machine.

23. Linear- array transducer.**24. Schematic linear-array characteristics.**

25. Patient's right side in LUS: schematic anatomy. Note: the patient's left side in LUS represents a similar schematic anatomy, only instead of the liver the spleen can be identified.



26. The transducer is moved towards the lateral thorax, checking for lung sliding at different locations (asterisks).



Probe position: on both sides of the thorax (figure 26).

- Third to fourth intercostal space between parasternal and midclavicular line.
- The transducer is moved transversely on two ribs from medial to lateral.

To obtain a structured examination, both sides of the thorax are divided into three zones (figure 27) as follows: 1) anterior, 2) subaxillary, 3) dorsal. In all of these zones two scans are performed, upper and lower half. The examination can be completed in a few minutes.^{16,20}

The normal ultrasound image

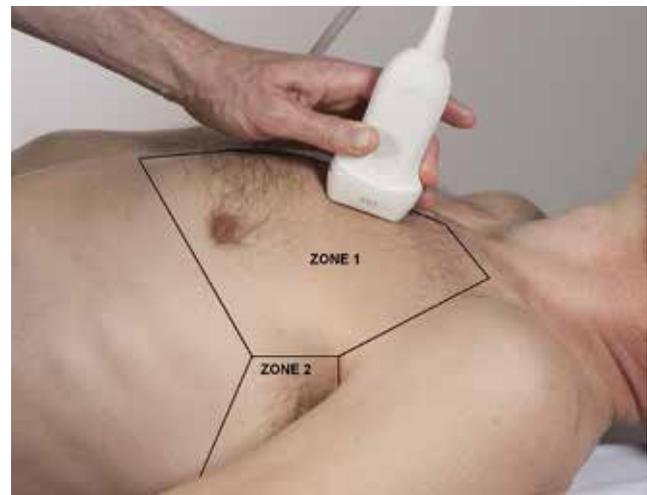
First, it is important to make a reference image in order to recognize the structures. The transducer is placed perpendicular to the ribs so that two ribs are represented. The echographic shadow of both ribs produces the characteristic image called *bat sign* (figure 28). Approximately 0.5 cm deep to the periosteal line, a white line is visible. This represents the pleural interface (figures 28, 29).¹⁶

Bat sign (figures 28, 30)

Subsequently, the next normal structures can be perceived:

- **A-lines**
A-lines arise as artifacts from reflections of the pleural line in reference to the skin and are at the same distance from one another (figure 31).¹⁷
- **B-lines**
B-lines or *comet tails* arise from the pleural line (figure 32). B-lines have seven characteristics: a) comet-like, b) arise from the pleural line, c) hyperechoic, d) well-defined, e) spreading to the lower edge of the screen, without fading, f) synchronous with lung sliding, g) are generated by elements with a high acoustic impedance gradient from the surrounding structures; such as fluid and air.¹⁷ More than three B-lines in one intercostal space is abnormal and indicates the presence of an alveolar or interstitial process.
- **Lung sliding**
 The movement of visceral pleura in reference to parietal pleura produces the image called *lung sliding* (figure 33). This physiologic and dynamic sign can be checked in a few seconds; it is identified as respirophasic movement of the pleural line during respiration.¹⁸ It is an indirect sign indicating the presence of the visceral pleura that is in apposition to the parietal pleura.¹⁸ The presence of lung sliding indicates that there is no pneumothorax at the site of the examination.
 The *Seashore sign* refers to the image of lung sliding by using M-mode scanning: the outer motionless part of the chest wall generates horizontal lines, ‘the waves’, and the deep motion artifacts below the pleural line generate ‘the sandy pattern’ (figure 34).^{16,17,20}
- Optional: link to internet-based video demonstration of *Lung Sliding (shimmering line)* and *Seashore sign*²²

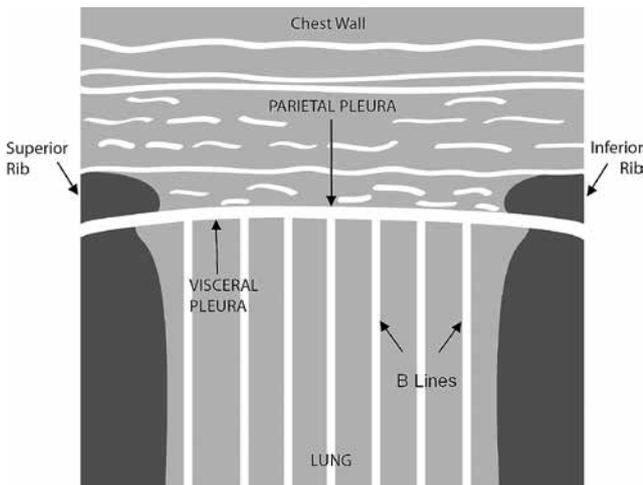
27A./27B. Ultrasound areas. Zone 1: investigation of the anterior chest wall. Zone 2: lateral wall. Zone 3: posterolateral chest wall. Each zone is divided into upper and lower halves, resulting in six areas of investigation.



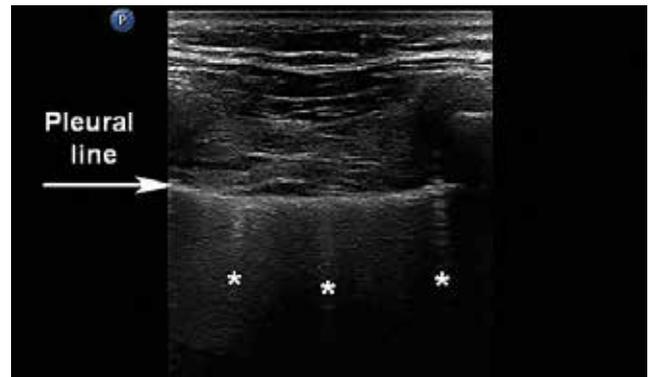
28. Normal LUS image with characteristic *bat sign*.



29. Schematic image of normal LUS.



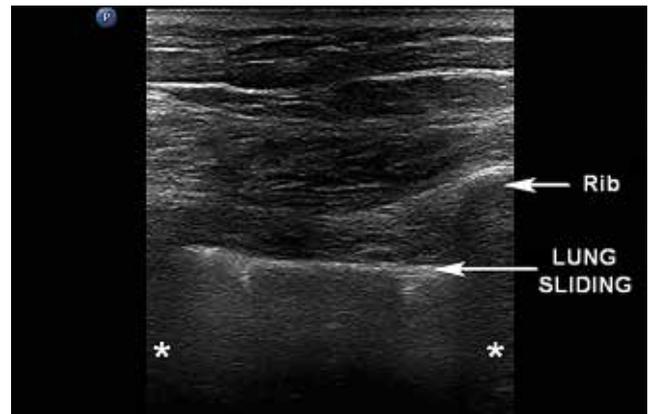
32. B-lines (asterisks) arising from the pleural line.



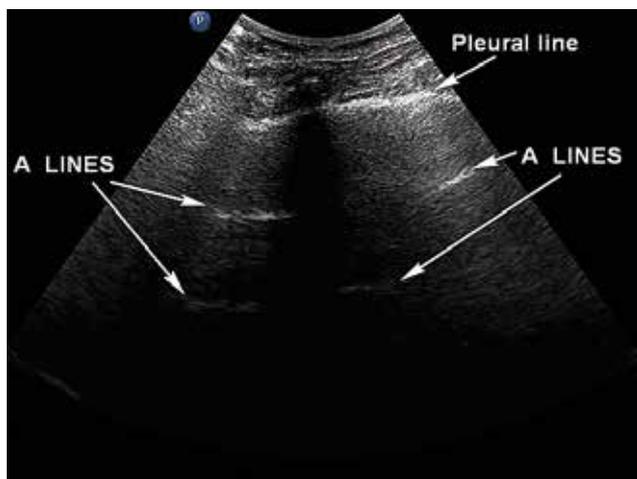
30. Bat sign: rib's shadow (asterisks).



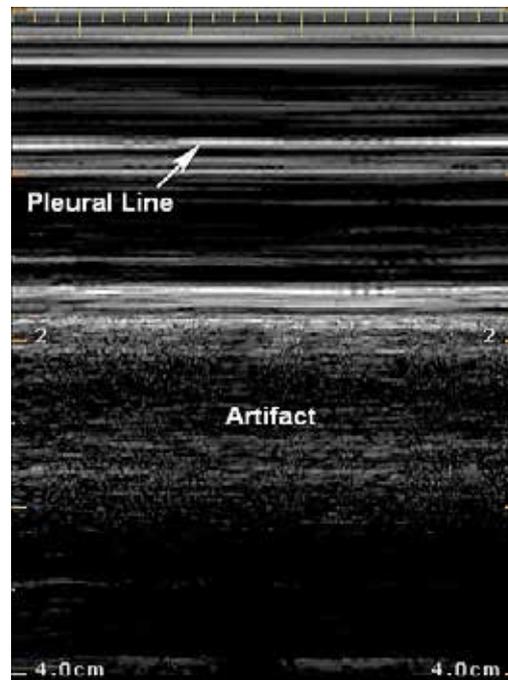
33. Lung sliding: horizontal movement or shimmering of the pleural line. Rib's shadow (asterisks).



31. A-lines.



34. Seashore sign in M-mode scanning: excludes pneumothorax.



Aberrant images

Pathology

Pneumothorax results in loss of lung sliding, as the visceral and parietal pleural surfaces are not in apposition. However, there are other causes for loss of lung sliding such as:

- atelectasis
- main-stem intubation
- ARDS
- pleural adhesions
- pulmonary contusion

Pneumothorax (PNX)

Through LUS, the diagnosis of pneumothorax is quickly excluded by the identification of lung sliding. The anterior thoracic areas should be scanned first in the supine patient, as the pneumothorax space will be anterior in location. Absent *lung sliding* is the basic and initial step for the diagnosis,¹⁶ and strongly suggests pneumothorax (*figure 35*). However, the clinician must consider other causes for the absence of lung sliding, so that clinical correlation is always required. Absent lung sliding is associated with a characteristic M-mode pattern called *Barcode sign* (*figure 36*).

- Optional: link to internet-based video demonstration of pneumothorax²³
- Optional: link to video with absent lung sliding in pneumothorax²⁵

Other definitions

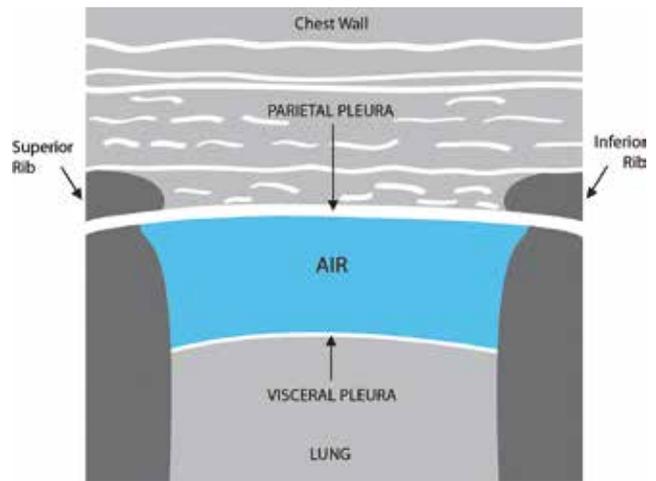
- *Lung point* the point where the tip of the collapsed lung adheres again to the parietal pleura. The *lung point* allows confirmation of PNX with 100% specificity.¹⁸ Although some pneumothoraces are total, i.e. the lung is completely collapsed, most are partial with some remaining apposition of the visceral and parietal pleura at some point in the lateral or posterior thorax. The lung point is found where there is respirophasic movement of the partially collapsed lung in and out of the pneumothorax space.
- *Lung pulse* a vertical movement of the pleural line synchronous to the cardiac rhythm. Occasionally it can be detected in the absence of *lung sliding*. It is caused by the transmission of the heart beat through a consolidated motionless lung or during apnoea. Visualization of *lung pulse* rules out PNX.¹⁸

The following diagram describes the steps after finding absent *lung sliding* (*flowchart 2*)¹⁸

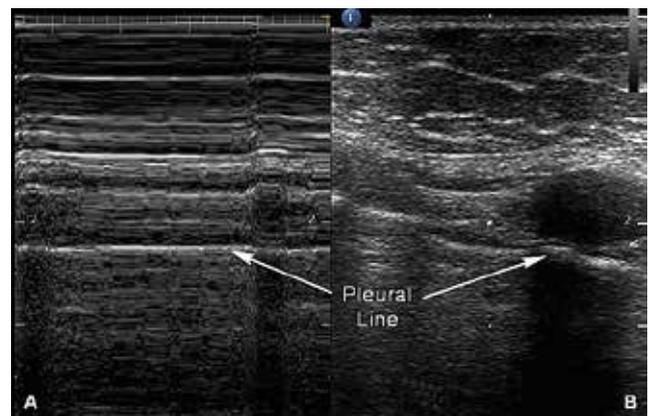
Pleural effusion

Pleural effusion is a disorder containing exclusively fluid and no air.¹⁶ Pleural fluid, unless loculated, assumes a dependent position in the thorax in the supine patient. Pleural fluid has characteristic findings on ultrasonography:

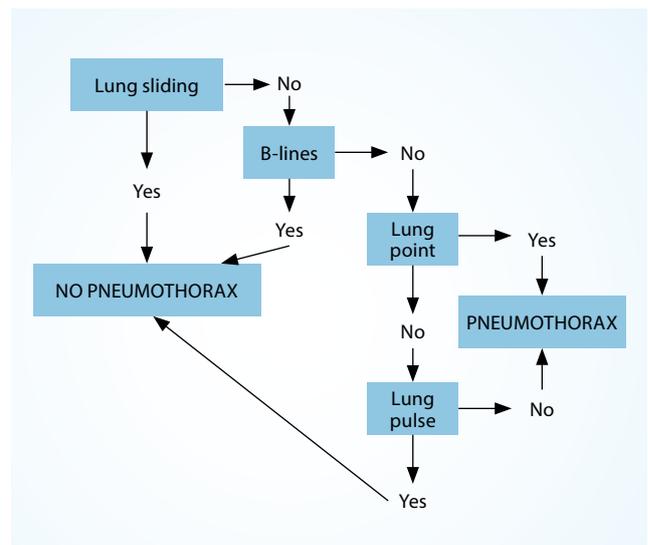
35. Schematic image of PNX.



36A. Barcode sign in PNX at M-mode: no motion of chest wall and lung.
36B. Accessory 2-D image.



Flowchart 2.¹⁸



- Typical anatomic boundaries: this requires definitive identification of the chest wall, the surface of the lung, and the diaphragm.

LUS does not only detect effusion, it can also provide information on its nature. Theoretically, a transudate is hypoechoic, while an exudate is hyperechoic with mobile particles or septa.¹⁶

- Hypoechoic or hyperechoic space: this requires definitive identification of either a relatively hypoechoic space or hyperechoic space that is the pleural effusion which is surrounded by the typical anatomic boundaries.
- Dynamic changes: this requires definitive identification of dynamic changes that are characteristic of a pleural effusion such as diaphragmatic movement, movement of atelectatic lung, and movement of echogenic material within the effusion.

Identification of the diaphragm is a key element for safe performance of thoracentesis using ultrasonographic guidance. This requires the examiner to positively identify the diaphragm and subdiaphragmatic organs (spleen or liver, on the left and right respectively), in order to avoid inadvertent subdiaphragmatic device insertion when performing thoracentesis. During respiration it is possible for consolidated or atelectatic lung tissue to move into the image plane.

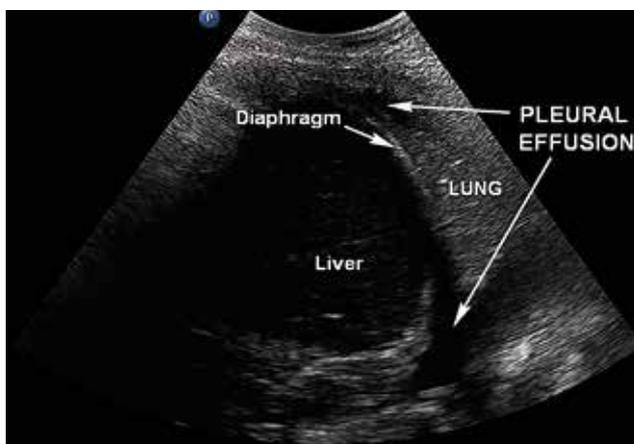
Various quantities of pleural effusion (*figure 37*):

- *Posterolateral alveolar and/or pleural syndrome (PLAPS)*: pleural effusion visible as a black shadow just beyond the pleura, often accompanied with atelectasis; visible as a lung part with a higher density (*figure 38*).¹⁷
 - Optional: link to internet-based video demonstration of ultrasound detection of pleural fluid²⁴

Consequences of LUS examination

- In case of CPR: acute drainage at the side of suspected PNX.
- In cases of dyspnoea but clinically stable patients: bedside chest radiograph, CT-scan.

37A. Small quantity of pleural effusion.



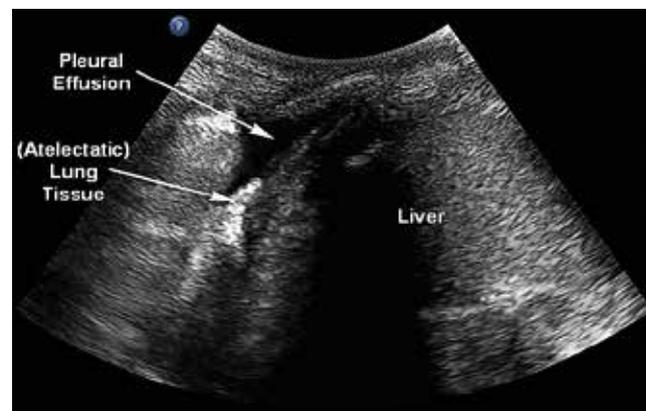
37B. Large quantity of pleural effusion.



37C. Loculated pleural effusion.



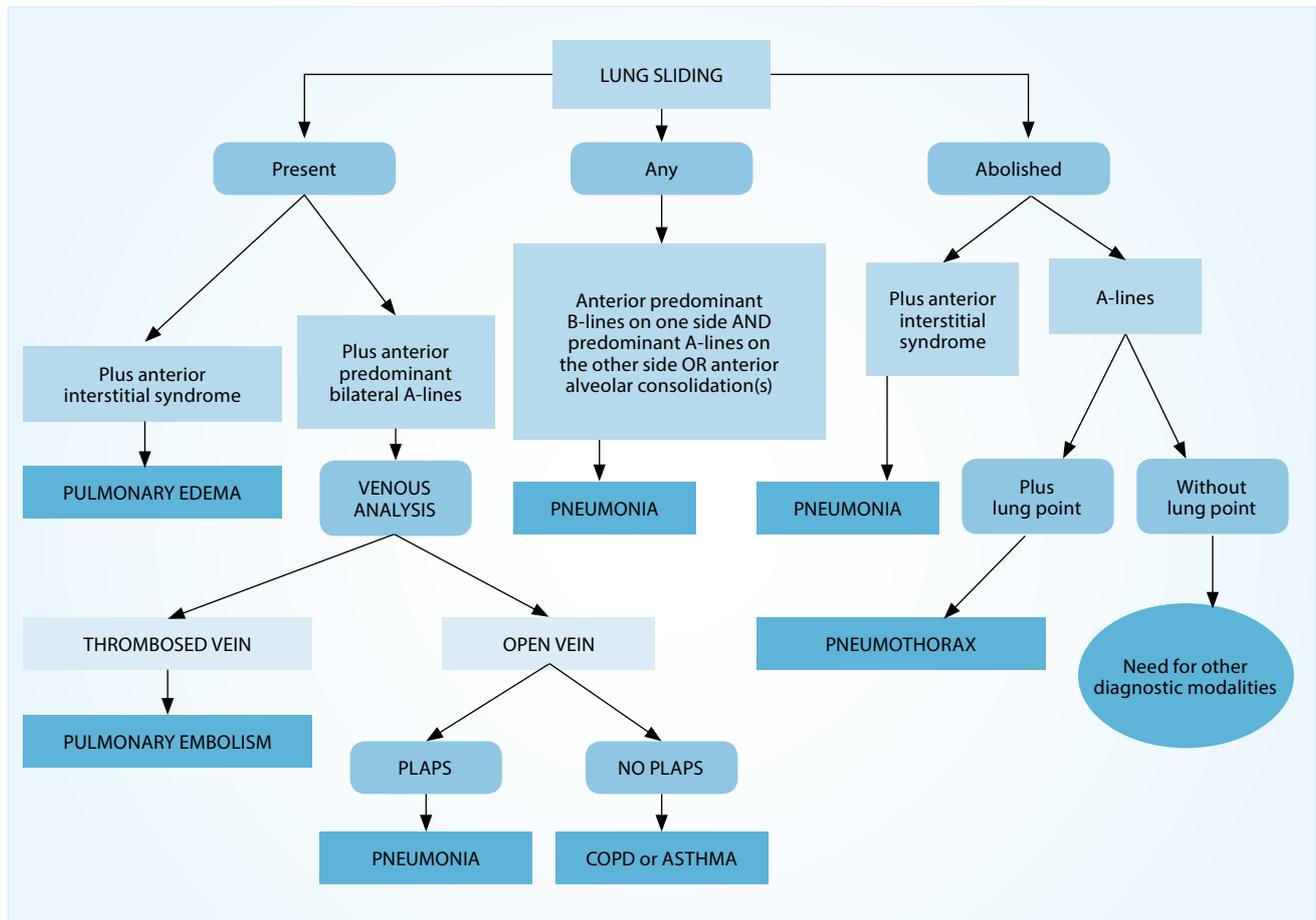
38. Posterolateral alveolar and/or pleural syndrome (PLAPS).



Summary lung ultrasound

Ultrasound of pleura and lungs is a technique that can be learned easily and can be applied instantly and at the bedside. In patients with acute dyspnoea a potential lethal condition like pneumothorax can be excluded quickly. Moreover, other diagnoses can be made by ultrasound (*flowchart 3*).

Flowchart 3. Utilizing LUS to guide diagnosis of severe (acute) dyspnoea according to the BLUE protocol of Lichtenstein et al.²⁰ (with the minor adjustment of translating the profile characters into possible obtainable ultrasound patterns).



References

1. Beaulieu Y, Marik PE. Bedside ultrasonography in the ICU: part 2. Chest 2005;128:1766-81.
2. Bosch FH, ter Maaten JC, Geers ABM, Gans ROB. Binary Ultrasonography for the internist: yes or no, that's the question! Neth J Med. 2012;70:473-5.
3. Mayo PH, Beaulieu Y, Doelken P, et al. American College of Chest Physicians/ La Société de Réanimation de Langue Française statement on competence in critical care ultrasonography. Chest 2009;135:1050-60.
4. McLean AS, Huang SJ. The RACE Manual, 2nd edition. Sydney 2010.
5. Seward JB, Douglas PS, Erbel R, et al. Hand-carried cardiac ultrasound (HCU) device: recommendations regarding new technology. A report from the Echocardiography Task Force on New Technology of the Nomenclature and Standards Committee of the American Society of Echocardiography. J Am Soc Echocardiogr. 2002;15:369-73.
6. Expert Round Table on Ultrasound in ICU. International expert statement on training standards for critical care ultrasonography. Intensive Care Med. 2011;37:1077-83.
7. Cholley BP, Vieillard-Baron A, Mebazaa A. Echocardiography in the ICU: time for widespread use! Intensive Care Med. 2005;32:9-10.
8. Internet-based video demonstration of PLAX: SonoSite Inc. http://www.youtube.com/watch?v=H_3V9xIDMA0.
9. Internet-based video demonstration of PSAX: SonoSite Inc. <http://www.youtube.com/watch?v=B731sgCuZU4>.
10. Internet-based video demonstration of Apical view: SonoSite Inc. <http://www.youtube.com/watch?v=4vBJoWP-zBM>.
11. Internet-based video demonstration of Subcostal view: SonoSite Inc. <http://www.youtube.com/watch?v=ew6uJvZDhmw>.
12. Internet-based video demonstration of SC-IVC: SonoSite Inc. <http://www.youtube.com/watch?v=ci9W4MvyMHl>.
13. Narasimhan M, Koenig S, Mayo P. Advanced echocardiography for the critical care physician Part 2. Chest. 2014;145:135-42.
14. Muller L, Bobbia X, Toumi M, et al. Respiratory variations of inferior vena cava diameter to predict fluid responsiveness in spontaneously breathing patients with acute circulatory failure: need for a cautious use. Critical Care. 2012;16:R188;1-7.
15. Soubrier S, Saulnier F, Hubert H, et al. Can dynamic indicators help the prediction of fluid responsiveness in spontaneously breathing critically ill patients? Intensive Care Med. 2007;33:117-24.
16. Barillari A, Fioretti M. Lung ultrasound: a new tool for the emergency physician. Intern Emerg Med. 2010;5:335-40.
17. Bosch FH, Blans MJ, van der Hoeven HG. Echografie van de pleura en de longen. Ned Tijdschr Geneesk. 2011;155:A2531.
18. Volpicelli G. Sonographic Diagnosis of pneumothorax. Intensive Care Med. 2011;37:224-32.
19. Lichtenstein DA, Menu Y. A bedside ultrasound sign ruling-out pneumothorax in the critically ill. Lung sliding. Chest. 1995;108:1345-48.
20. Lichtenstein DA, Mezière GA. Relevance of Lung Ultrasound in the diagnosis of acute respiratory failure. The BLUE Protocol. Chest. 2008;134:117-25.
21. Bouhemad B, Brisson H, Le-Guen M, Arbelot C, Lu Q, Rouby J. Bedside ultrasound assessment of Positive End-Expiratory Pressure-induced lung recruitment. Am J Respir Crit Care Med. 2011;183:341-7.
22. Internet-based video demonstration of Lung sliding and Sea-shore sign: SonoSite Inc. <http://www.youtube.com/watch?v=D3mm9wwlw7g>.
23. Internet-based video demonstration of Pneumothorax: SonoSite Inc. <http://www.youtube.com/watch?v=Xxdedx1HtHo>.
24. Internet-based video demonstration of ultrasound detection Pleural fluid: SonoSite Inc. <http://www.youtube.com/watch?v=X1E7OgOLzw0>.
25. Video link in pdf NJCC 3, www.nvic.nl.