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Basic concepts in the use of thoracic and lung ultrasound

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Title:

Basic concepts in the use of thoracic and lung ultrasound

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Purpose of review

Recent advances were made in the field of point-of-care ultrasound. Thoracic and lung ultrasound have become a rapid and accurate method of diagnosis of hypoxic diseases. The purpose of this article is to review the recent literature on point-of-care ultrasound, emphasising on its use in the operating room.

Recent findings

Many international critical care societies published guidelines on the use of ultrasound in the installation of central venous access. More recently, evidenced-based guidelines on the use of point-of-care lung ultrasound were published. Lung ultrasound has shown it's superiority over conventional chest radiography in the diagnosis of many pathologies of significant importance in anesthesiology, particularly the pneumothorax.

Summary

Point-of-care thoracic and lung ultrasound is used in many critical medicine fields. The aim of this review is to describe the basic lung ultrasound technique and the knowledge required in order to diagnose and treat the hypoxic patient. Emphasis is on pathology such as pleural effusion, alveolar interstitial disease as well as pneumothorax, which is of particular important in the field of anesthesiology.

Key words: Lung ultrasound, pneumothorax, pleural effusion, alveolar interstitial disease

Introduction

Point-of-care ultrasound (POCUS) in critical care medicine and anesthesiology is rapidly evolving and becoming the standard of care in multiple clinical situations, such as central venous access.[1] The American Society of Anesthesiology, the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists have recently published specific guidelines, following the 2001 report of the Agency for Healthcare Research and Quality.[1, 2] Multiples international critical care societies established guidelines concerning the use of ultrasound in their various fields of expertise as well as part of residency training.[3-8] Ultrasound is a widespread tool in the evaluation of the hypoxic patient. Indeed, multiple studies have been published in the last 20 years on the subject. Most of the literature on lung ultrasound is based on studies done in intensive care suites as well as in emergency departments, but more recently, anesthesiologists have reported their experience using lung ultrasound in the operating room.[9, 10] A recent editorial article stressed the need to implement POCUS in the operating room (OR).[11] Evidenced-based recommendations have been published on point-of-care lung ultrasound.[12] The current article will describe the basic lung ultrasound technique and the knowledge required in order to diagnose and treat the hypoxic patient. We will stress the role of lung ultrasound in the diagnosis of pneumothorax, alveolar and interstitial lung disease and pleural effusion.

How to proceed

All portable ultrasound machines permit to evaluate the hypoxic patient. Recent guidelines recommended the use of an abdominal or microconvex probe, but a linear high frequency probe can also be used.[12] In the OR, as we will see, transoesophageal echocardiography (TEE) can also be used in patients in whom the chest is not accessible such as during cardiac surgery (Figure #1).

Lung ultrasound can be done in a sitting or supine patient. There are generally 2 imaging planes that are used: the sagittal and the coronal plane (Figure#2). As most patients the OR are in a supine position, this approach will be discussed here. A recent scanning protocol suggests a 4 zones division of each hemithorax in order to expedite lung ultrasound in critical situations.[13, 14] Volpicelli's zones are shown in figure #3. Different imaging modalities are used depending on expected pathology. Most of the scanning is done in 2D, but motion mode (M-Mode) as well as color Doppler can be used.

Each thoracic zone should be scanned individually. The transducer is apposed perpendicular to the long axis of the ribs in order to obtain an image of 2 ribs cut in a transverse fashion (Figure#4). The hyperechogenic linear structure between the 2 ribs is the pleural interface. The parietal and visceral pleura creating this interface move in a synchronous fashion with spontaneous respiration or mechanical ventilation. This movement, called "Lung Sliding" (LS) , described originally in veterinary medicine, is one of the most important findings during any ultrasound examination of the lung.[15] LS identification is the most commonly used artefact in the exclusion of pneumothorax as well as in the confirmation of endotracheal intubation (discussed latter). The lung parenchyma located under the pleural interface is where artefacts are observed. All zones on each hemithorax must be scanned in order to obtain a complete examination. Both abdominal lateral upper quadrants can also be examined in search of pleural effusions. In the OR, TEE use will be useful in order to detect pleural fluid, atelectasis or pneumonia but is more limited in the detection of LS.[16] Basic ultrasound principles in the identification of specific pathologies are discussed in the next section.

Basic ultrasound principles

Ultrasounds are sound waves with a frequency higher than what can be perceived by the human ear. An ultrasound wave travels at approximately the same speed in all human tissue which absorbs and reflects part of it. Depending on the amount of energy absorbed as well as the time between the emission and reception of the ultrasound wave by the transducer, the software is able to generate an image depicting the underlying structures. Ultrasounds are completely reflected by air, so it is impossible in theory to see the air filled lung parenchyma. In both normal and abnormal conditions, the thoracic cavity and the lungs may contain some physiologic or pathologic fluid. This fluid changes the relation between the ultrasound wave and the air contained in the alveolar interstitial space of the parenchyma or in the pleural space and creates particular artifacts. It is often quoted that lung ultrasound makes facts out of artefacts. After lung sliding, the most common artefacts in lung ultrasound are named A lines and B lines.

As mentioned earlier, air will reflect entirely ultrasounds as a mirror does with light. The A line artefact is the single or multiple horizontal reflections of the pleural interface similar to the reflections of two mirrors in front of each others. The emitted ultrasound wave is reflected multiples times by the pleural interface. This back and forth phenomenon gives a false impression to the imaging software that the pleural interface is deeper. Each A line is separated by a distance equivalent to the thickness of the subcutaneous tissue between the ultrasound probe and the pleural interface. A lines are present in a normal lung as well as in the presence of a pneumothorax (Figure#5).

The most useful artefact, created by the reflection on air of the ultrasound wave, is known as the B line, also called comet-tail artefact or lung rocket. This artefact is created by repetitive reflections of the ultrasound wave within the lung parenchyma because of a higher concentration of physiologic or pathologic fluid.[13, 17] This artefact is a vertical white line, originating from the visceral pleura, and reaching the bottom of the screen (Figure#6). The presence of B lines will erase the A lines on their passage. Few B lines can be seen in a healthy lung typically in the dependent regions.

The presence of B lines is used in the diagnosis of alveolar interstitial syndrome. The presence of B lines will automatically exclude the presence of a pneumothorax.

M-Mode is used in thoracic and lung ultrasound. In the presence of a normal lung, the movement of the underlying lung will create a fuzzy image under the fixed subcutaneous tissue. This pattern is often referred to as the "seashore" sign. This image has two portions. The superficial part is typically composed of multiple horizontal lines that correspond to the motionless soft-tissue. This image ends on the pleural line. The other portion corresponds to the motion of the normal lung. This motion will generate an artefact that originates from the pleural line and looks like sand on a beach. This double image artefact looks like water waves in the ocean and is called the seashore or beach sign (Figure#7).

Using two-dimensional imaging, the "lung pulse" artefact is a small to and fro movement of the visceral on the parietal pleura induced by the heartbeat that can be confused with a normal LS. Although it does not constitute a normal LS, it implies an intact pleural interface. It can also be identified on M-Mode imaging as an intermittent vertical artefact synchronous with the electrocardiogram. The use of color Doppler can facilitate recognition of this artefact (Figure#8). The presence of a lung pulse artefact excludes a pneumothorax.

Basic pathology

This section will describe the most common pathologies encountered in critical care.

Normal lung

A normal lung is usually characterised by the presence of the following artefacts : lung sliding, A lines, less than 3 B-lines per Volpicelli's sonographic zone as well as absence of pleural effusion.[18, 19]

Alveolar interstitial disease

B lines are the major characteristic of alveolar interstitial disease. Previous studies showed that B lines separated by less than 3 millimetres are a sign of alveolar as opposed to interstitial lung disease.[18, 20] Alveolar interstitial disease can be diffuse as in cardiogenic (Figure#9) or non cardiogenic pulmonary oedema such as acute respiratory distress syndrome (ARDS) (Figure#10), interstitial pneumonias and pulmonary fibrosis. They can be bilateral or limited to one part of the lung and associated with lobar pneumonia, pulmonary contusion or atelectasis. The same constellation of artefacts will be seen for each of these pathologies, but their distribution will vary depending on the spread of the disease. In the presence of ARDS as well as pneumonia, impaired lung sliding is possible. This finding can help make the difference between cardiogenic pulmonary oedema where sliding will be preserved and ARDS where it can be altered. In the presence of pneumonia or atelectasis, consolidated lung parenchyma can also be seen, having a similar aspect to liver parenchyma (Figure#11).

Pneumothorax

Pneumothorax is the pathology that made lung ultrasound gain so much popularity in the recent decade. Lung ultrasound is mostly useful in excluding the presence of pneumothorax by detecting normal lung sliding, a lung pulse and if present, B lines. A recent case report describes the diagnosis of an intraoperative pneumothorax using lung ultrasound in two different patients. This diagnosis had a significant impact on the intraoperative course of these patients.[10] Ruling out a pneumothorax in a hypoxic mechanically ventilated patient who underwent central venous access is critical. A complete bilateral lung ultrasound in search of pneumothorax can be done in less than 3 minutes.

The diagnosis of pneumothorax is fairly simple. The pleural interface must be identified and examined in search of lung sliding. In the presence of a pneumothorax, air will be present between the parietal and the visceral pleura. Since air completely reflects ultrasound waves, the visceral pleura will not be seen and there will be no lung sliding. At the border of the pneumothorax, the pleural interface should be intact and normal lung sliding should be present. This transition point between the intermittent presence and absence of a lung sliding is called the “lung point”. This is a pathognomonic sign of the presence of pneumothorax (Figure#12).[21]

Use of M-Mode facilitates exclusion of a pneumothorax. If the seashore sign is present, there is no pneumothorax in the part of the lung scanned.[21] If there is a pneumothorax, the absence of a lung sliding will create a series of black and white horizontal lines, called the “stratospheric or barcode” sign. The lung point can also be identified on M-Mode as a transition between a seashore sign and a barcode sign (Figure#13). The lung point, seen on M-Mode or conventional 2D, is 100% specific for pneumothorax.[21] It is important to keep in mind that lung ultrasound is more useful in excluding that confirming a pneumothorax.

Caution must be taken if a lung point is identified in the lower parts of the lungs. The excursion of the diaphragm, for instance above the liver, can give a false impression of lung point. This phenomenon can be called the “abdominal point” (Figure #14). Absent lung sliding can also be encountered in an unventilated lung, severe ARDS or lung atelectasis. Caution must also be taken if a lung pulse is identified close to the sternum since pulsation of a mammary artery could lead to false exclusion of pneumothorax.

Color Doppler and pulsed-wave Doppler interrogation can confirm the arterial origin of this structure.

If A lines are seen with no lung sliding, no B lines, no lung pulse and no lung point is identified, a pneumothorax is probable. However, the identification of a lung point is essential to confirm the presence of a pneumothorax. In the absence of the lung point alternative methods of diagnosis are suggested in a non life-threatening situation, remembering that supine chest x-ray in not very sensitive to detect a pneumothorax.

A rapid scanning protocol concentrating on the 2nd intercostal space on the mid-clavicular line, the 4th intercostal space on anterior axillary line, the 6th intercostal space on the mid-axillary line and the 8th intercostal space on the posterior axillary line showed a sensitivity of 98.1% and specificity of 99.2% in the diagnosis of pneumothorax with lung ultrasound.[22]

Pleural effusions

Thoracic ultrasound can rapidly identify simple or complex pleural effusions. In a supine patient, using a microconvex, phased array or convex transducer, both abdominal upper quadrants on the middle or the posterior axillary line should be scanned in order to view the interface between the diaphragm and the lung, just above the liver and the spleen.[12] The air contained in a normal lung parenchyma will reflect the ultrasound waves bouncing off the liver or the spleen and create an image identical to these structures. In the presence of a pleural effusion, this normal mirror image is lost and liquid is seen. Through this effusion, parts of the lung can be visualised. A simple effusion will be homogeneous, but a complex effusion, such as a hemothorax or an empyema, will be heterogeneous (Figure#15). Caution must be taken not to mistake free peritoneal fluid, located under the diaphragm, as a pleural effusion.

Other uses of thoracic and lung ultrasound

Point of care thoracic and lung ultrasound is a very useful tool in critical care medicine. It can be used to confirm endotracheal intubation, the correct placement of a double lumen endotracheal tube or identify a mainstem intubation.[9, 23] Methods used to confirm endotracheal intubation by ultrasound include lung sliding identification, visualisation of diaphragm movement and direct endotracheal tube visualisation in the trachea or oesophagus.[24-30] Ultrasound can also be used to confirm endotracheal intubation in pediatric patients.[31, 32]

Diaphragmatic movement identification in a breathing patient also permits to exclude a complete diaphragmatic paralysis after procedures such as interscalene block, high abdominal surgery or internal mammary artery manipulation in a coronary bypass surgery.

Limitations

As air creates significant impedance to ultrasound penetration, thoracic and lung ultrasound is impossible in patients with subcutaneous emphysema. Deeper lung pathology is not adequately investigated because only superficial portions of the lung are accessible to ultrasound. In addition, in severely obese patient or women with large breasts, ultrasound examination might be limited. Pulmonary embolism is also not easily identified by lung ultrasound. In massive pulmonary embolism, the lung ultrasound examination will be typically normal. Complementary POCUS of the heart and lower extremities will be necessary. Finally POCUS remains operator dependent and a structured formation is needed such as the one proposed by the American College of Chest Physician.[33]

Approach of the hypoxic patient

Depicted in figure #16 is a rapid thoracic and lung ultrasound protocol for the hypoxic patient. This protocol contains the basic lung and thoracic ultrasound elements discussed in the previous paragraphs.

Conclusion

Thoracic and lung ultrasound are very useful tools in the evaluation of the hypoxic patient. This situation can occur in the operating room, recovery room, the intensive care unit and the emergency ward. It's ease of access, mobility, rapidity, repeatability and lack of radiation gives it an advantage over chest x-rays and computed tomography. Bedside ultrasound is already used for central venous accesses and nerve blockade. Expansion of its use in the thoracic region and the abdomen is a natural evolution. Combined with pulse oximetry, end-tidal carbon dioxide monitoring, mechanical ventilation monitors and bronchoscopy, thoracic and lung ultrasound will allow investigating almost every cause of hypoxemia. Training guidelines have already been published. Structured curriculum in anesthesiology, critical care and emergency medicine will enable a safe and precise use of thoracic and lung ultrasound.

Key points:

Lung ultrasound is a rapid and easy way to diagnose serious thoracic pathology as pneumothorax.

Its use has been shown to significantly change the diagnosis and treatment of the hypoxic patient in the operating room.

Although being fairly simple, a structured curriculum is necessary in order to perform thoracic and lung ultrasound accurately and safely.

Acknowledgement:

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Figure legends

Figure 1. Different ultrasound transducers used to perform thoracic and lung ultrasound. The linear array (A), the phased-array (note the simple pleural effusion) (B), the convex (C) and the transesophageal echocardiography (TEE) transducer (note the complex pleural effusion) (D).(See attached videos)

Figure 2. Imaging plane used in lung ultrasound scanning. A combination of sagittal (A) and coronal (B) views are used. (Image obtained from of CAE Healthcare Vimedix Simulator)

Figure 3. The four Volpicelli's zones. (AAL, anterior axillary line; PAL, posterior axillary line)

Figure 4. Typical lung ultrasound image obtained with a linear transducer at 4 cm deep. The main components are identified.

Figure 5. Typical lung ultrasound image obtained with a linear transducer at 6 cm deep. Note the horizontal A lines that were present in this patient. In the absence of lung sliding, this would be suggestive of a pneumothorax.

Figure 6. Typical lung ultrasound image obtained with a linear transducer at 4 cm deep. Note the vertical B lines. These are white vertical white lines originating from the pleural interface and reaching the bottom of the screen. (See attached video)

Figure 7. Typical lung ultrasound image obtained with a linear transducer at 6 cm deep. A normal M-Mode is shown with the seashore sign.

Figure 8. Typical lung ultrasound image obtained with a linear transducer at 5 cm and 6 cm deep. The M-mode shows regular artefact. This corresponds to lung pulse (white arrows) (A). Adding color Doppler to the M-Mode image and the electrocardiogram facilitates lung pulse identification (white arrows) (B).

Figure 9. 83 year-old man with heart failure before cardiac surgery. Thoracic examination using a phased array transducer shows B lines on the chest wall (A). The same artefact is also present on the transesophageal echocardiographic (TEE) examination at the aortic arch level (B). Corresponding chest radiograph (C). (Ao, aorta)

Figure 10. Bilateral B lines (A,B) in a patient with acute respiratory distress syndrome. The corresponding chest radiograph (C) and computed tomography of the chest are shown (D). (See attached video)

Figure 11. Patient with left lower lobe pneumonia. The lung parenchyma has the same aspect as liver on ultrasound hence the word lung hepatisation used in pathology. However hyperechoic elements corresponding to air bronchograms are present (A). Corresponding chest radiograph (B) and computed tomography (C). (See attached video)

Figure 12. 47 year-old man with a right sided pneumothorax after liver transplantation. Thoracic ultrasound on the anterior chest (Zone 1 and 2) shows A lines with no sliding lung (A). A more lateral position (Zone 3 and 4) reveals normal sliding lung with B lines (B). The patient had no right superior vena cava which explains the unsuccessful attempt in inserting the right internal jugular. Note on the chest radiograph (C) the position of the pulmonary artery catheter in the left superior vena cava and through the coronary sinus. Note also the transesophageal echocardiography probe used for post-op monitoring.

Figure 13. Same patient as in Figure 12. The post-operative right sided pneumothorax is seen on the chest x-ray (A). The barcode (or stratospheric) aspect of the M-Mode followed by the normal seashore sign. This transition is called a lung point and is diagnostic of the pneumothorax (B).

Figure 14. Saggital view at the level of the interface between the lung and the liver. This interface corresponds to the abdominal point (A). Corresponding M-Mode view. Note the transition points (white arrows). During inspiration the M-Mode artefact are seen. They correspond to the normal lung (between the arrows). During expiration, the M-Mode aspect of the liver is seen. (lateral portion of the image outside the arrow). This can be easily seen also using two-dimensional echocardiography. (See attached video)

Figure 15. A 67 year-old woman presented with sudden hypotension and shortness of breath. She was started on low-molecular weight heparin 3 days ago for lower extremity deep venous thrombophlebitis. Upon examination breath sound were reduced on the left side. Bedside cardiac function was normal with signs of hypovolemia. Thoracic ultrasound revealed an isoechoic mobile mass corresponding to an hematoma (A) which was confirmed on chest radiograph (B) and computed tomography (C). A chest tube was inserted.

Figure 16. Thoracic and lung ultrasound protocol to investigate the hypoxic patient.

Figure 1

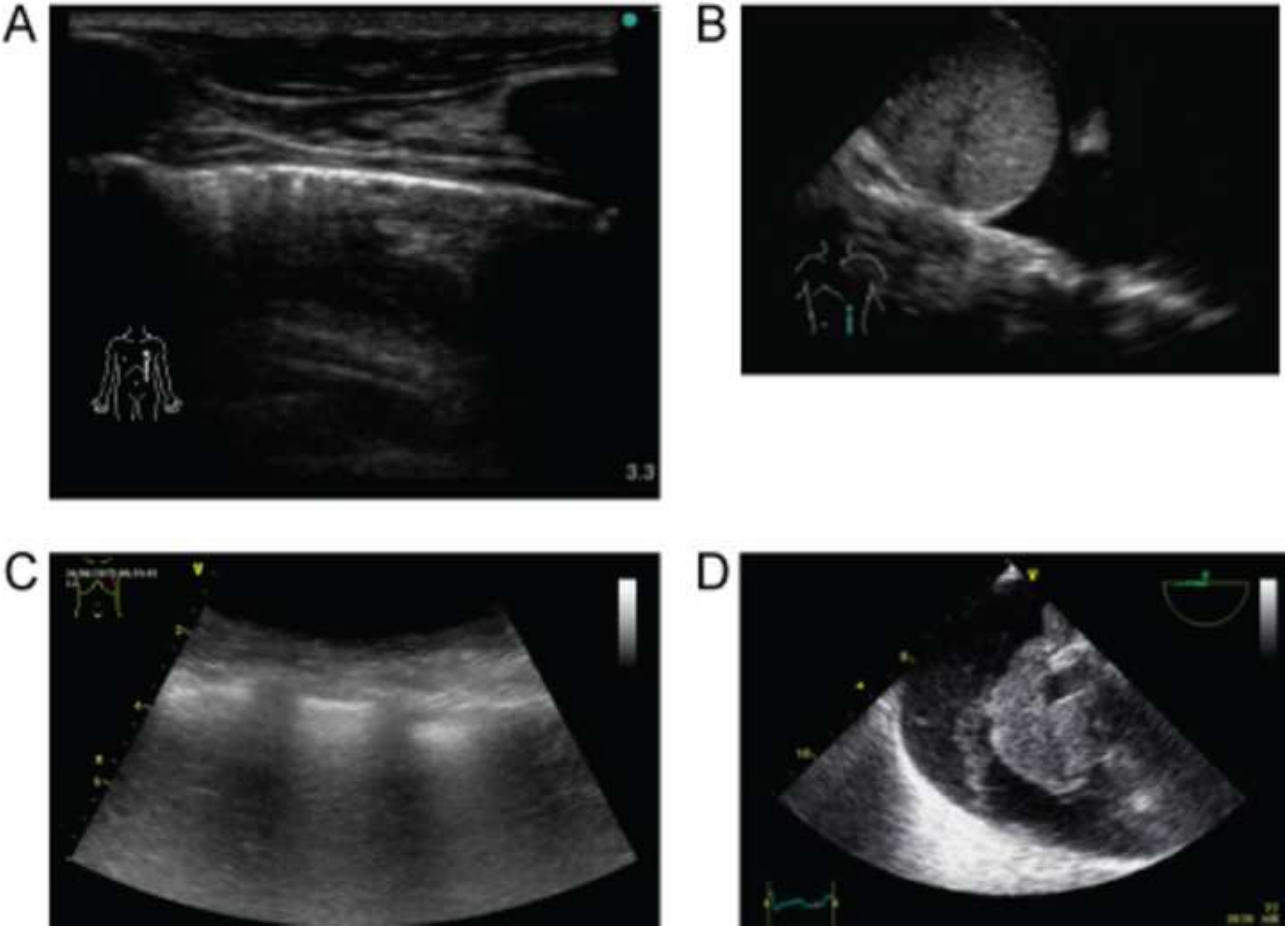
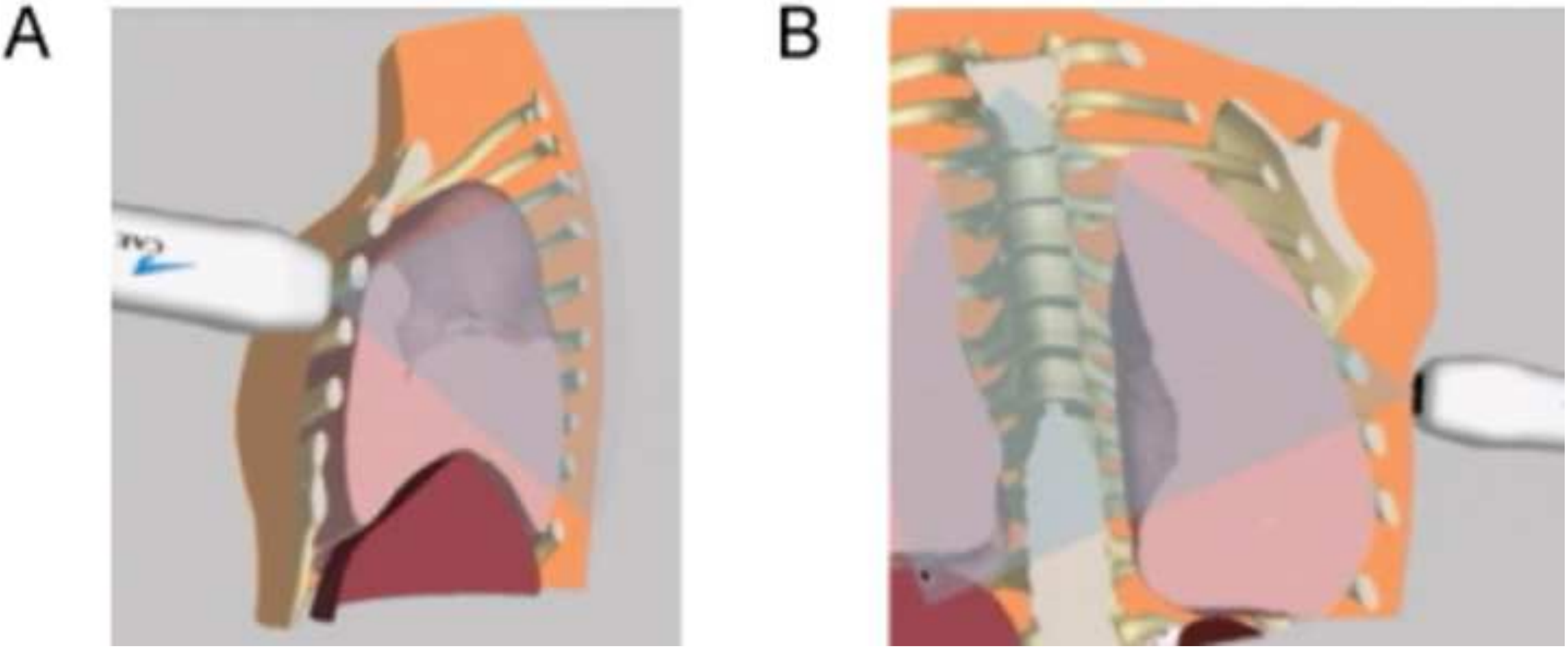


Figure 2



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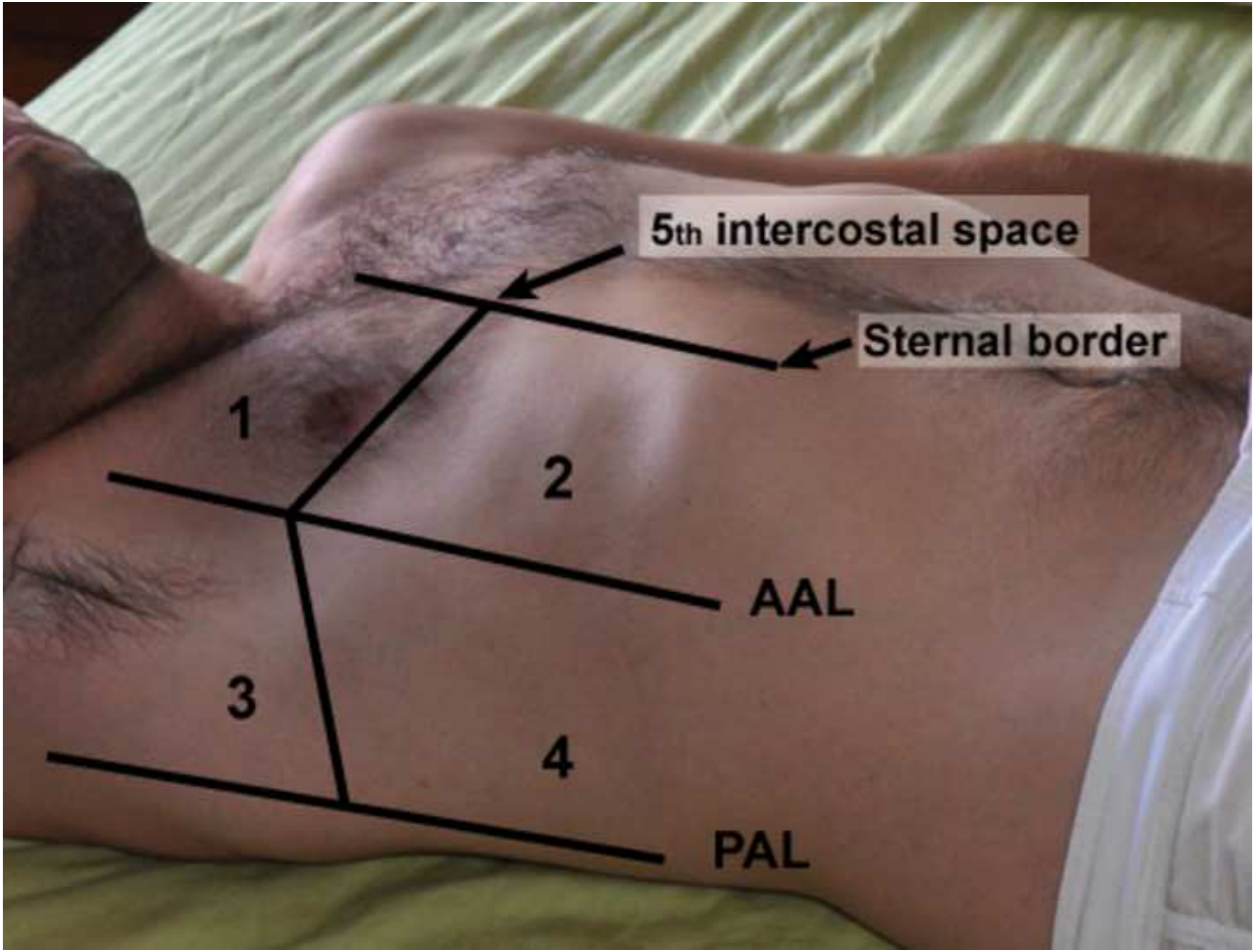
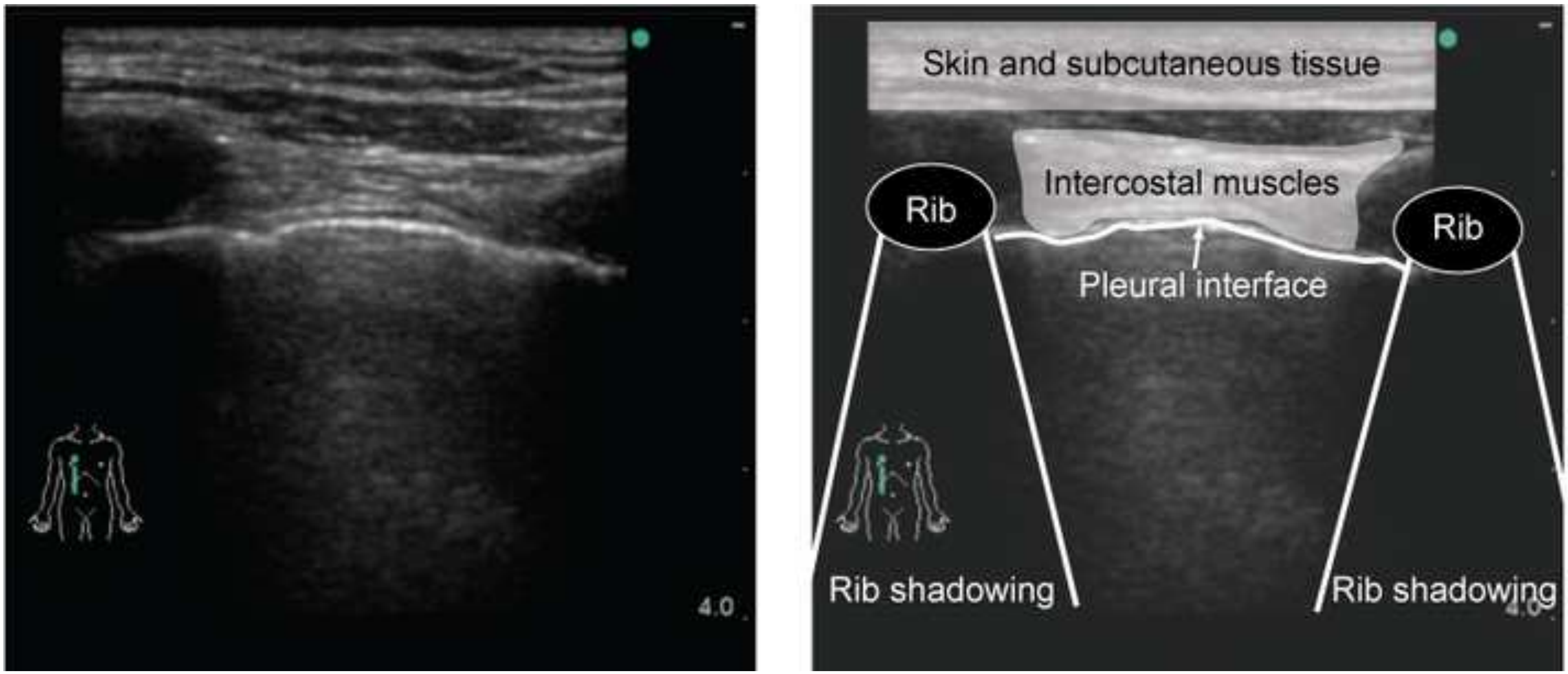


Figure 4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Intercostal muscles
Rib
Rib
Pleural interface
Rib shadowing
Rib shadowing

Figure 5

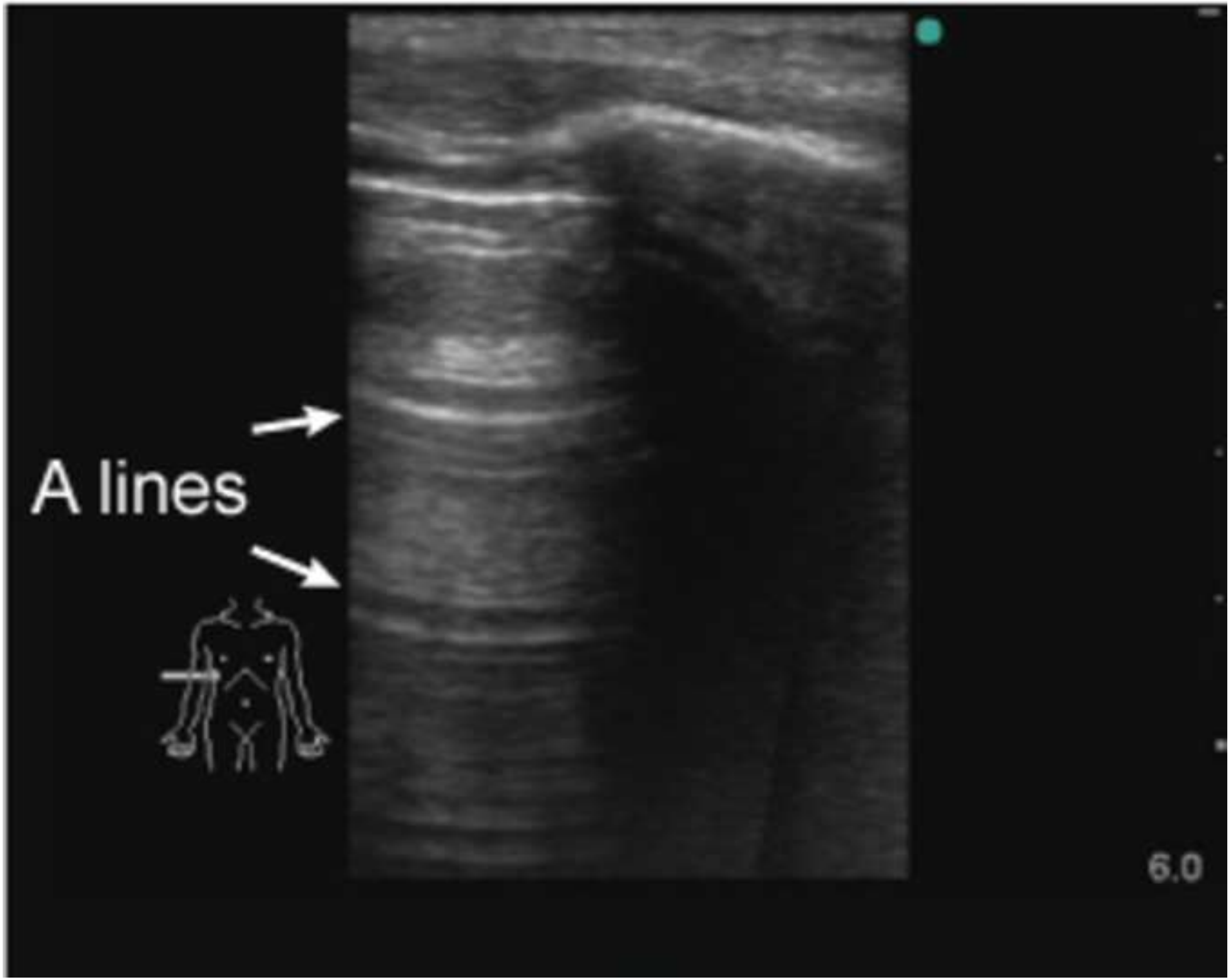
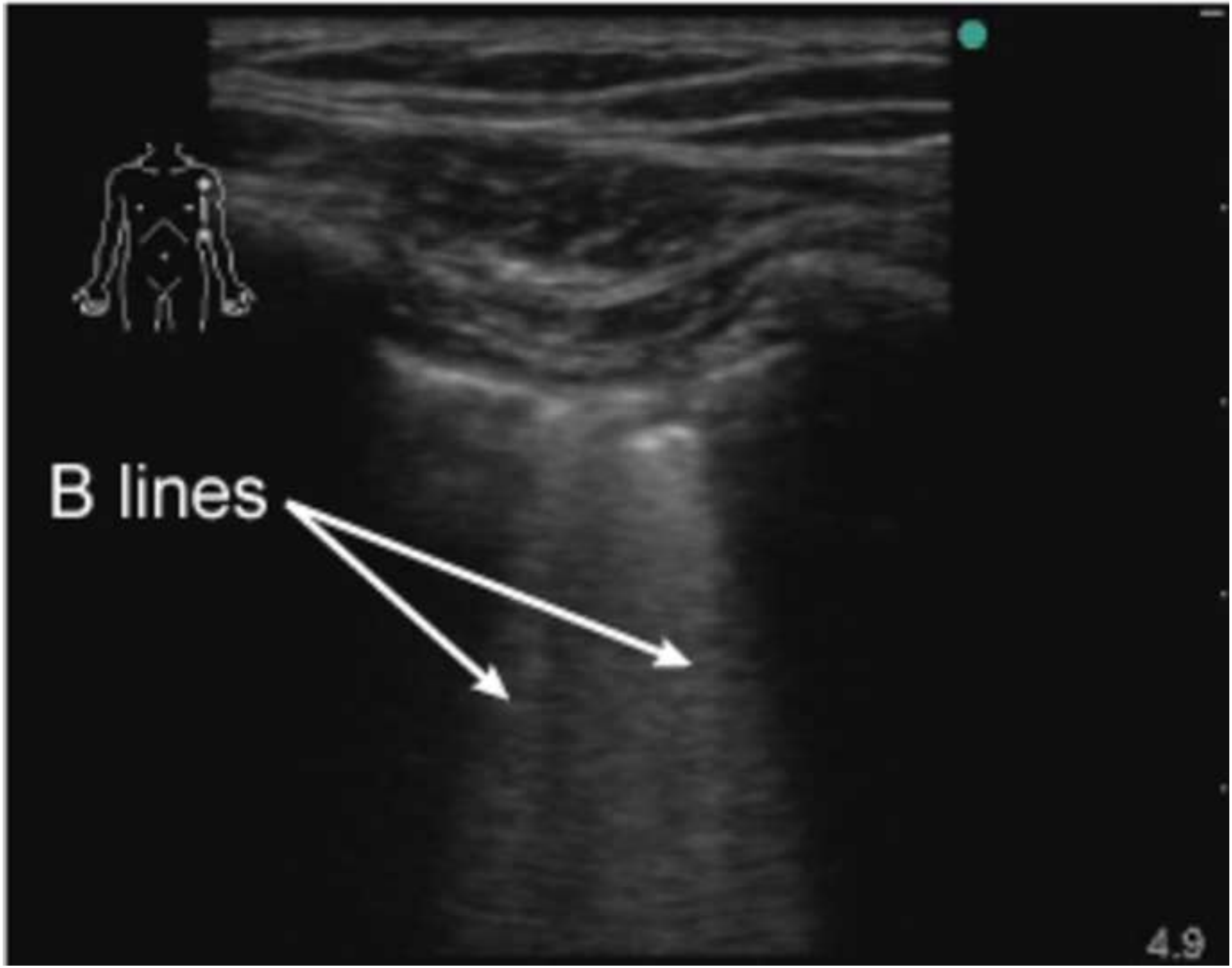


Figure 6



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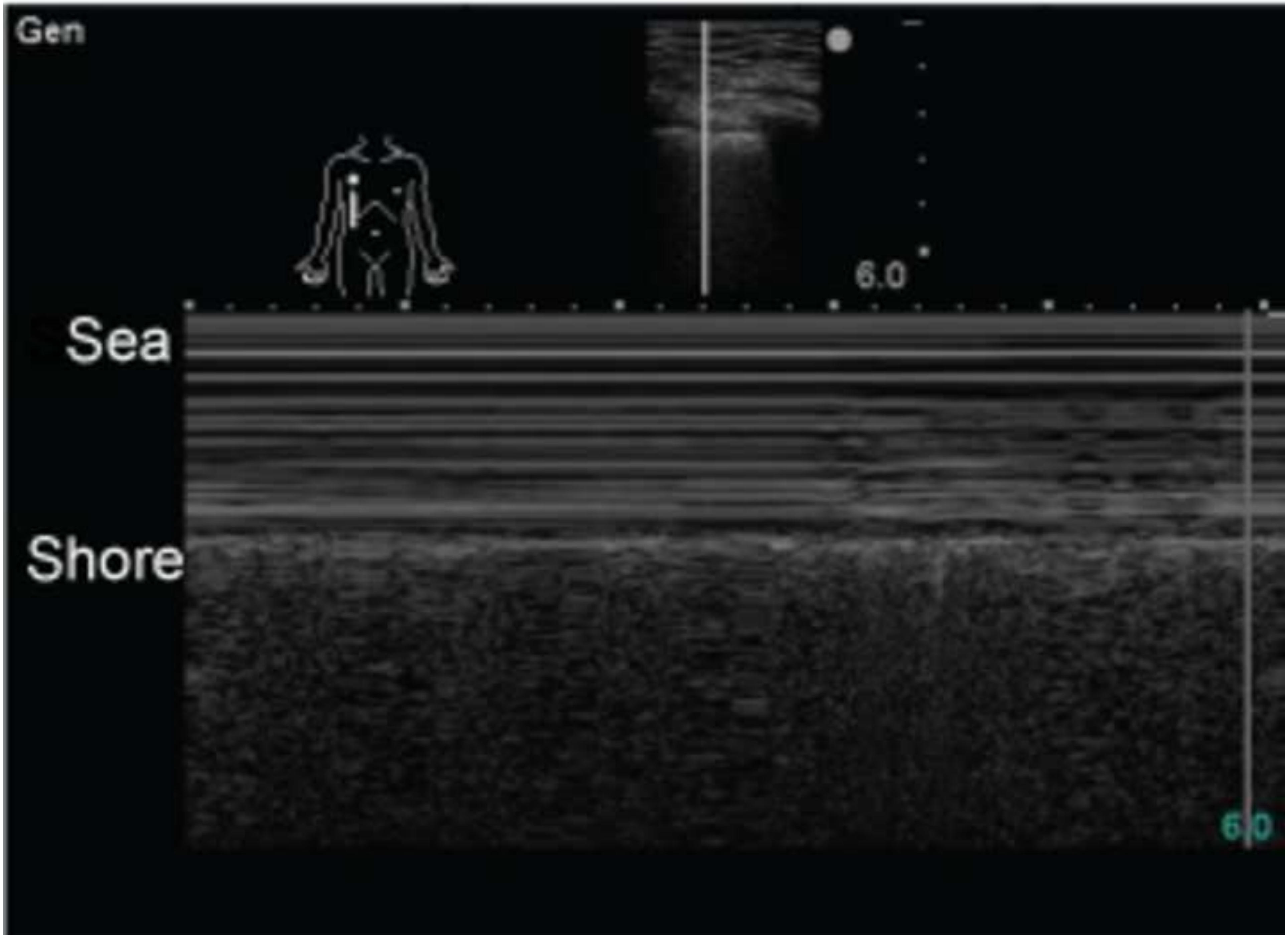


Figure 8

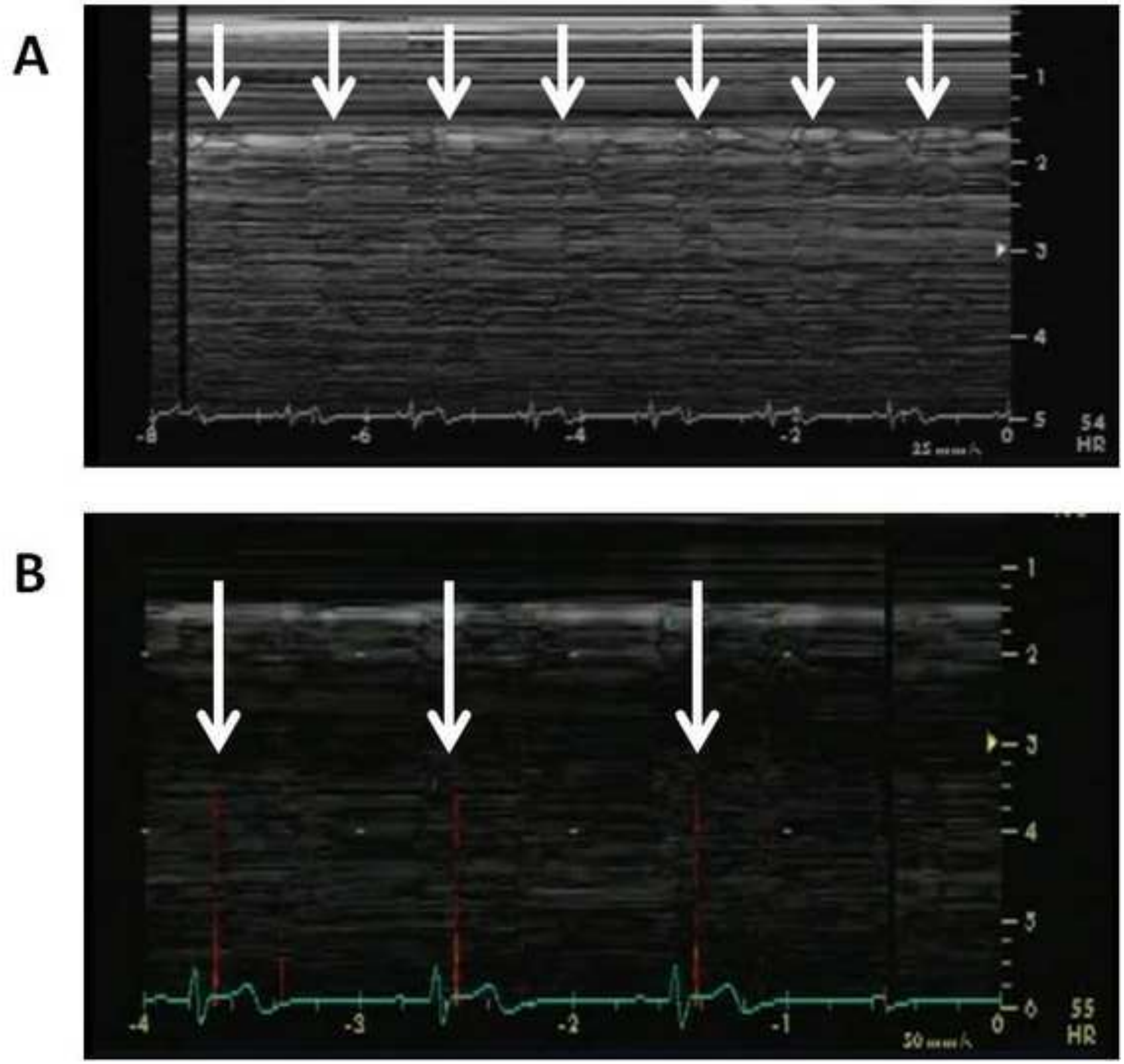


Figure 9

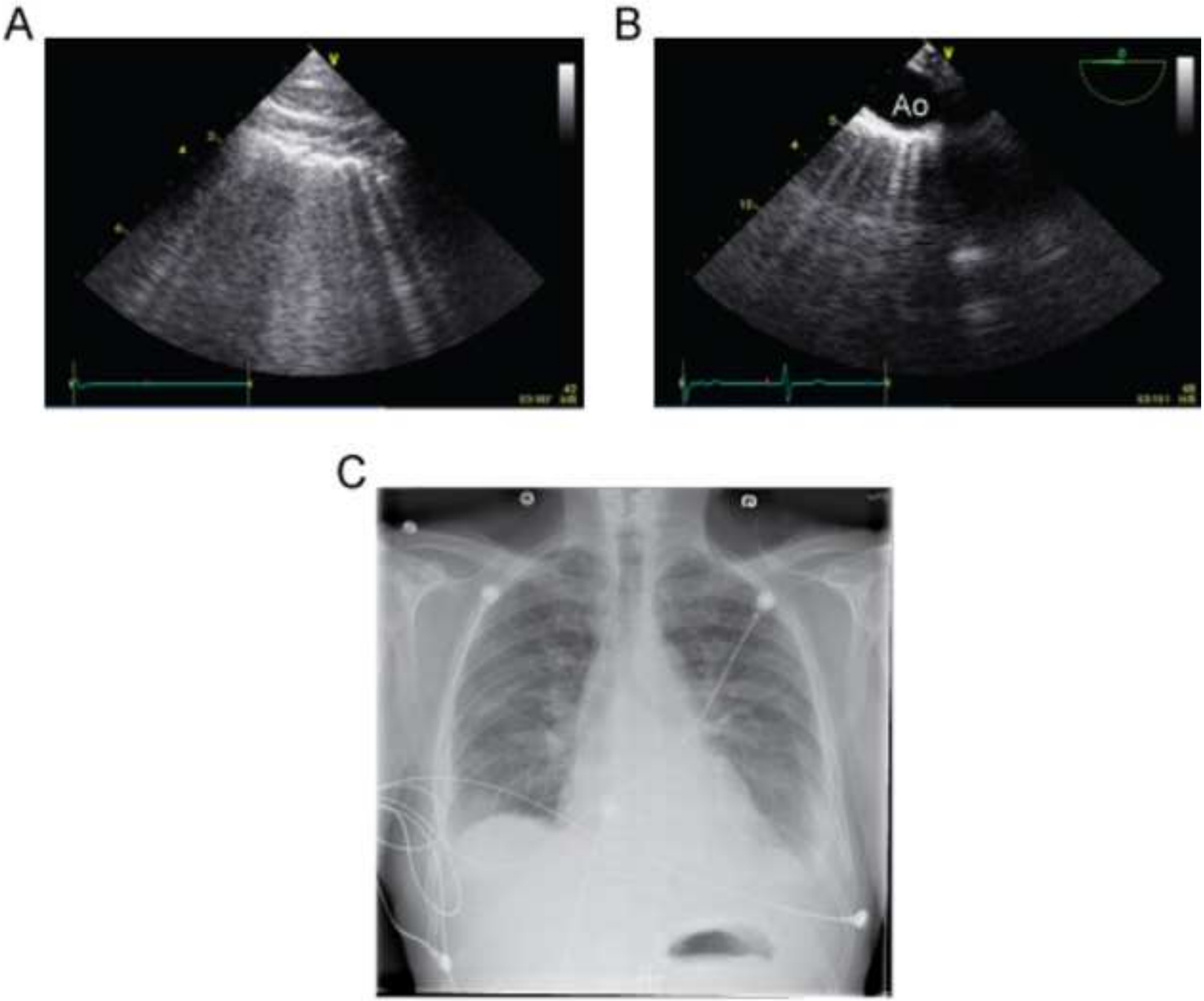


Figure 10

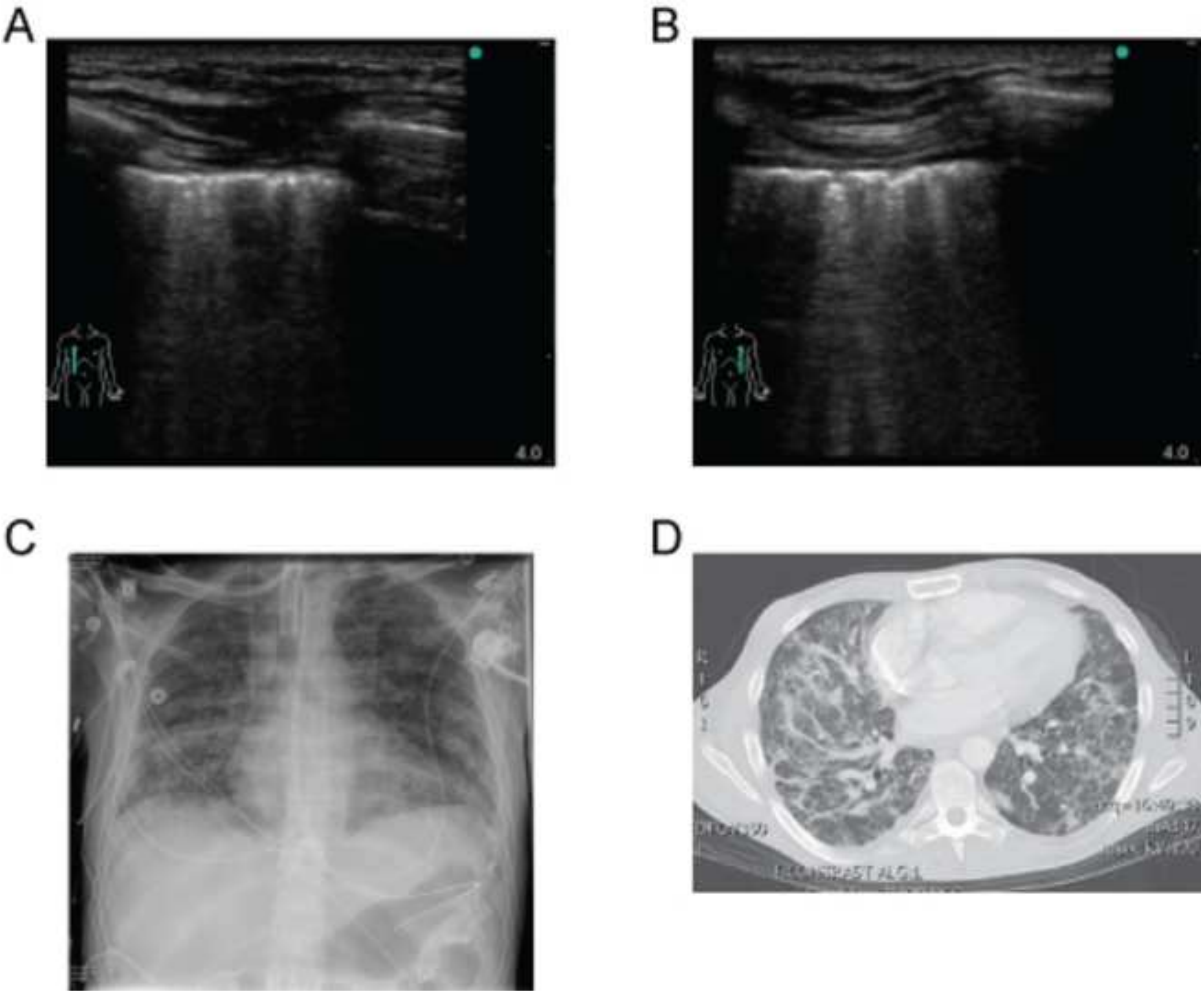


Figure 11

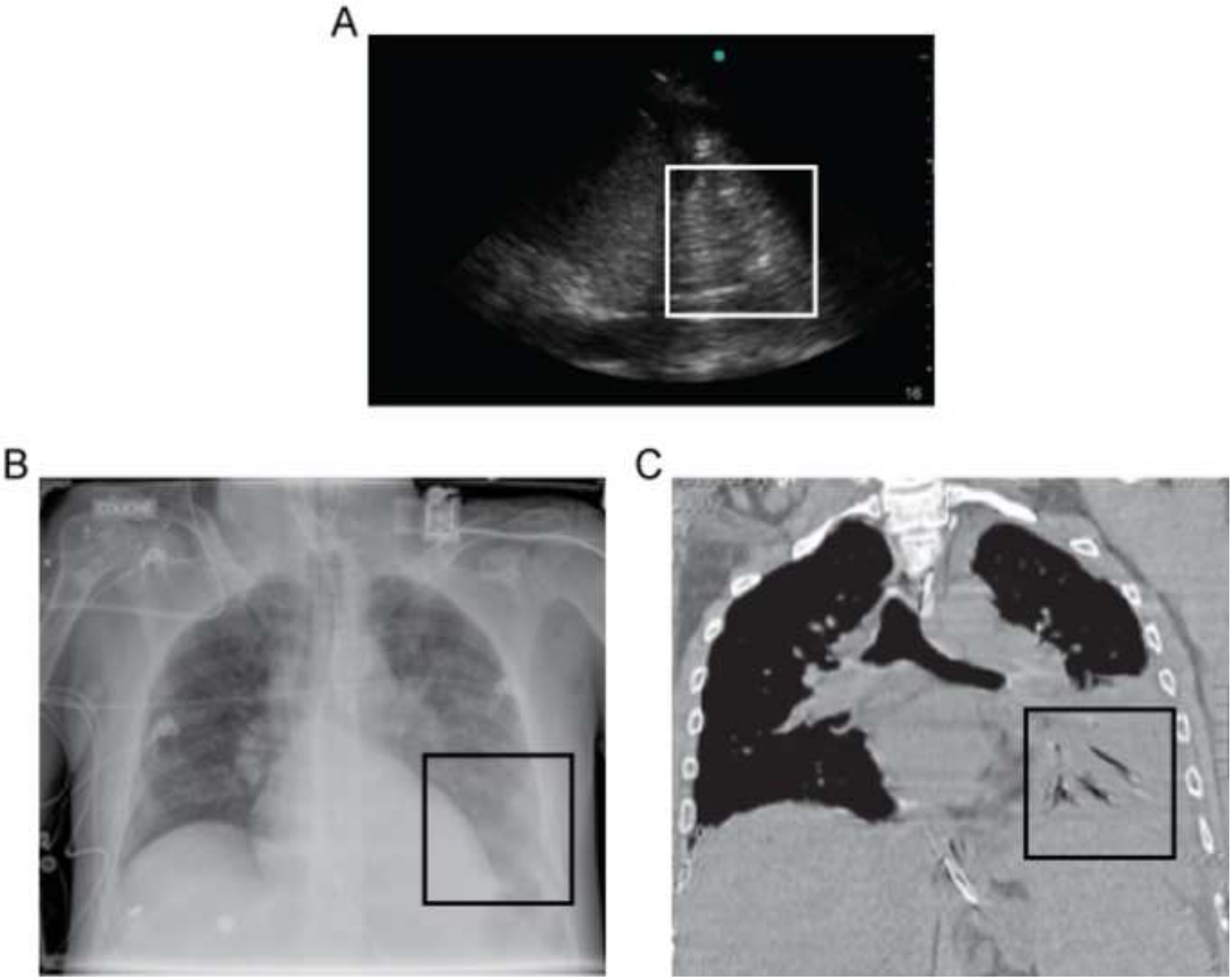


Figure 12

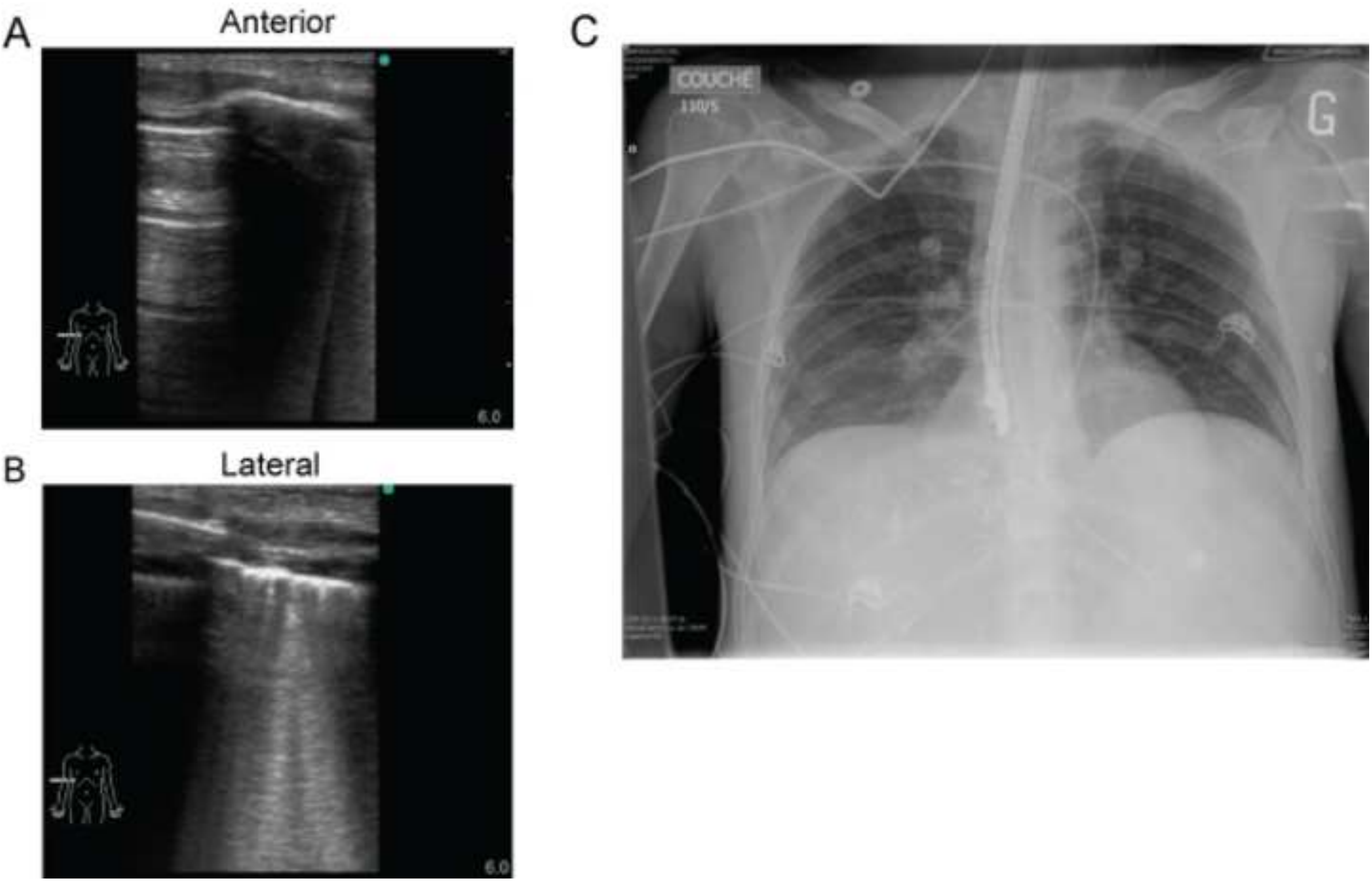


Figure 13

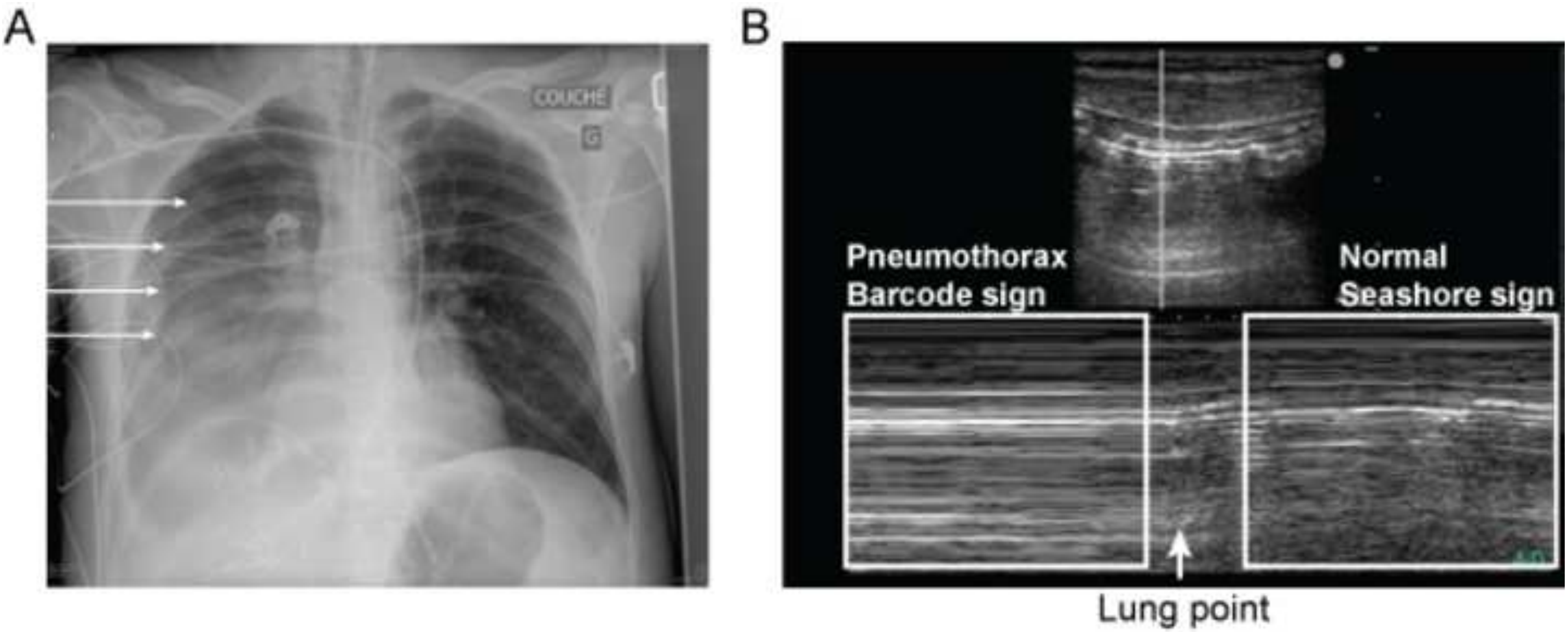

A
COUCHE
G
B
Pneumothorax
Barcode sign
Normal
Seashore sign
Lung point

Figure 14

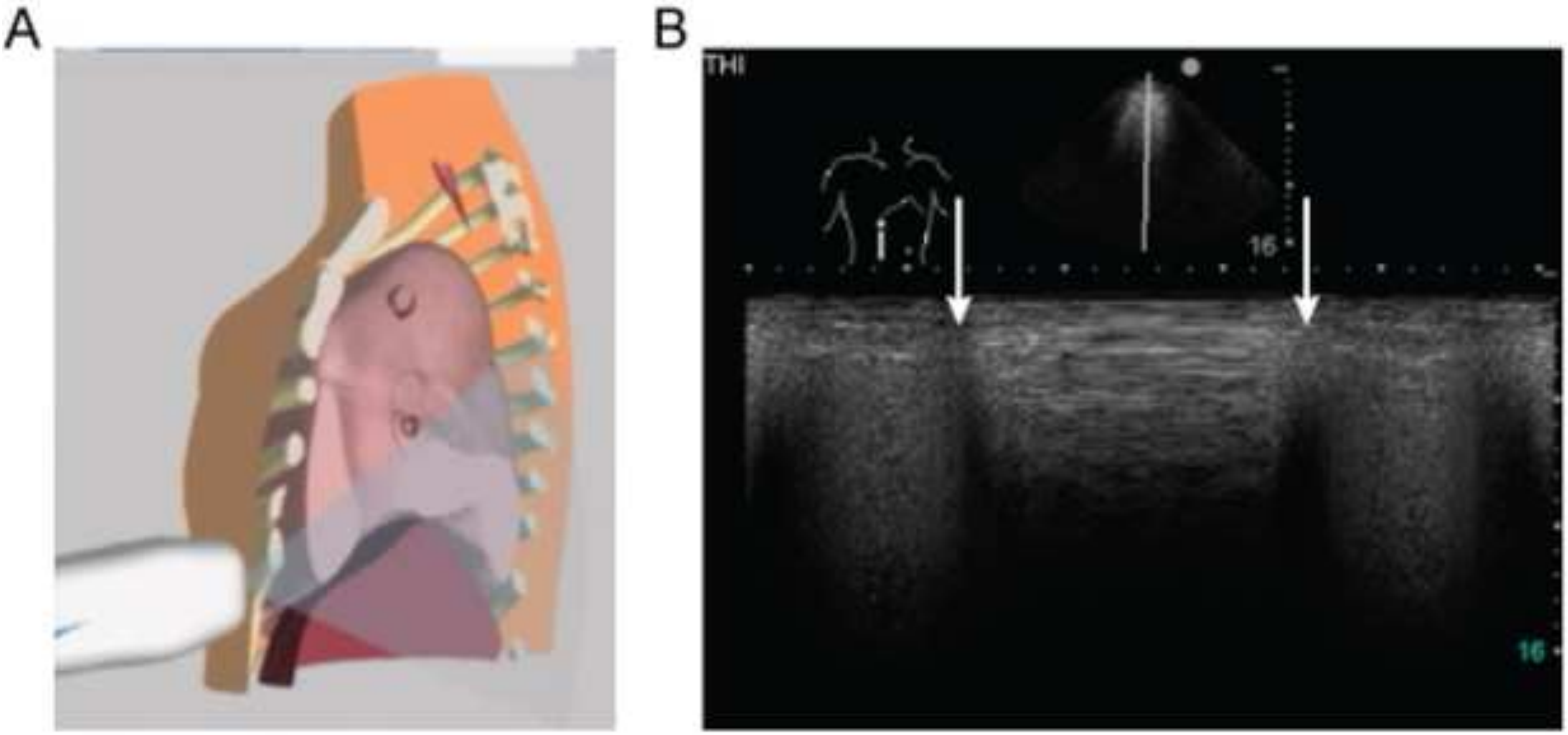


Figure 15

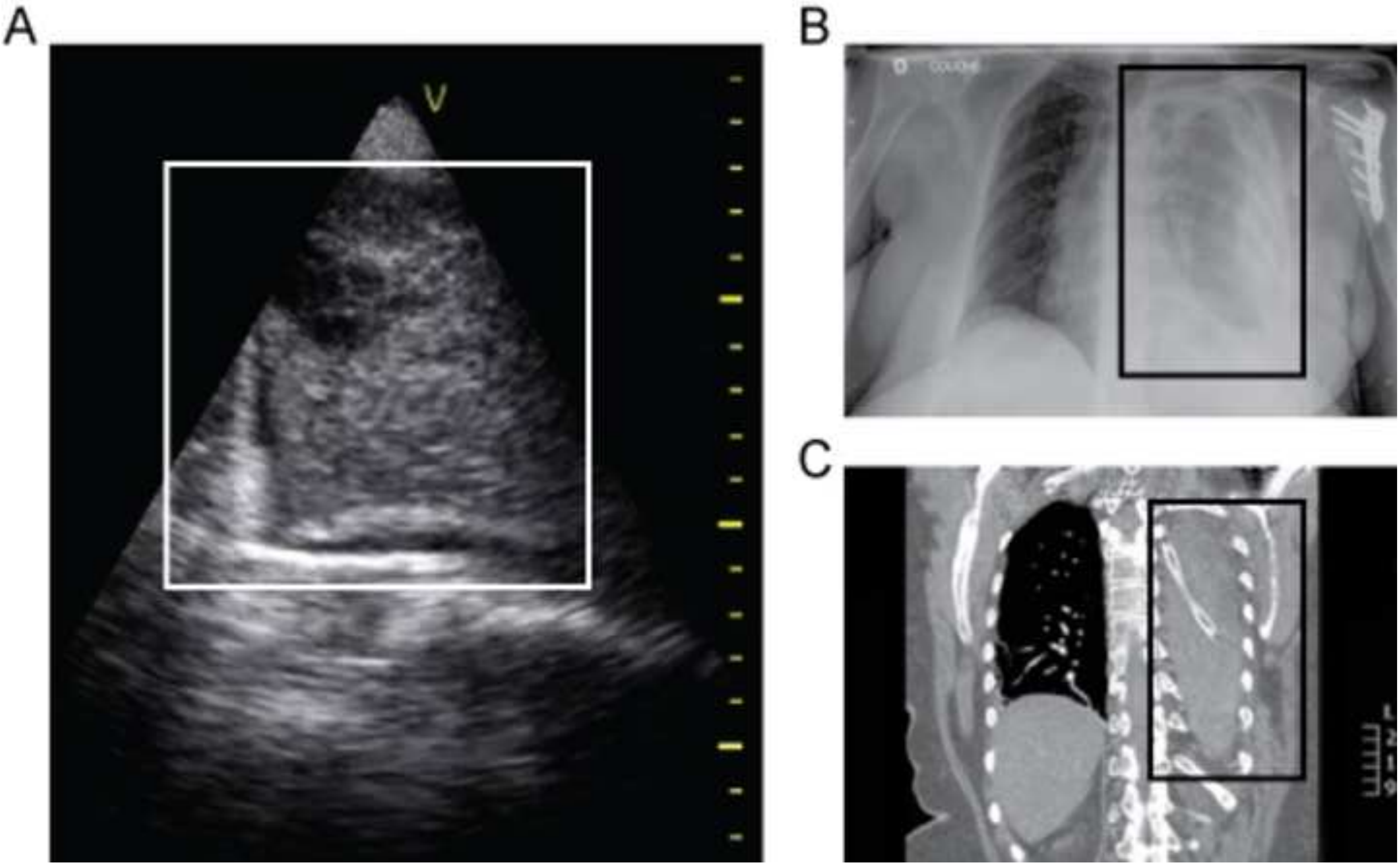
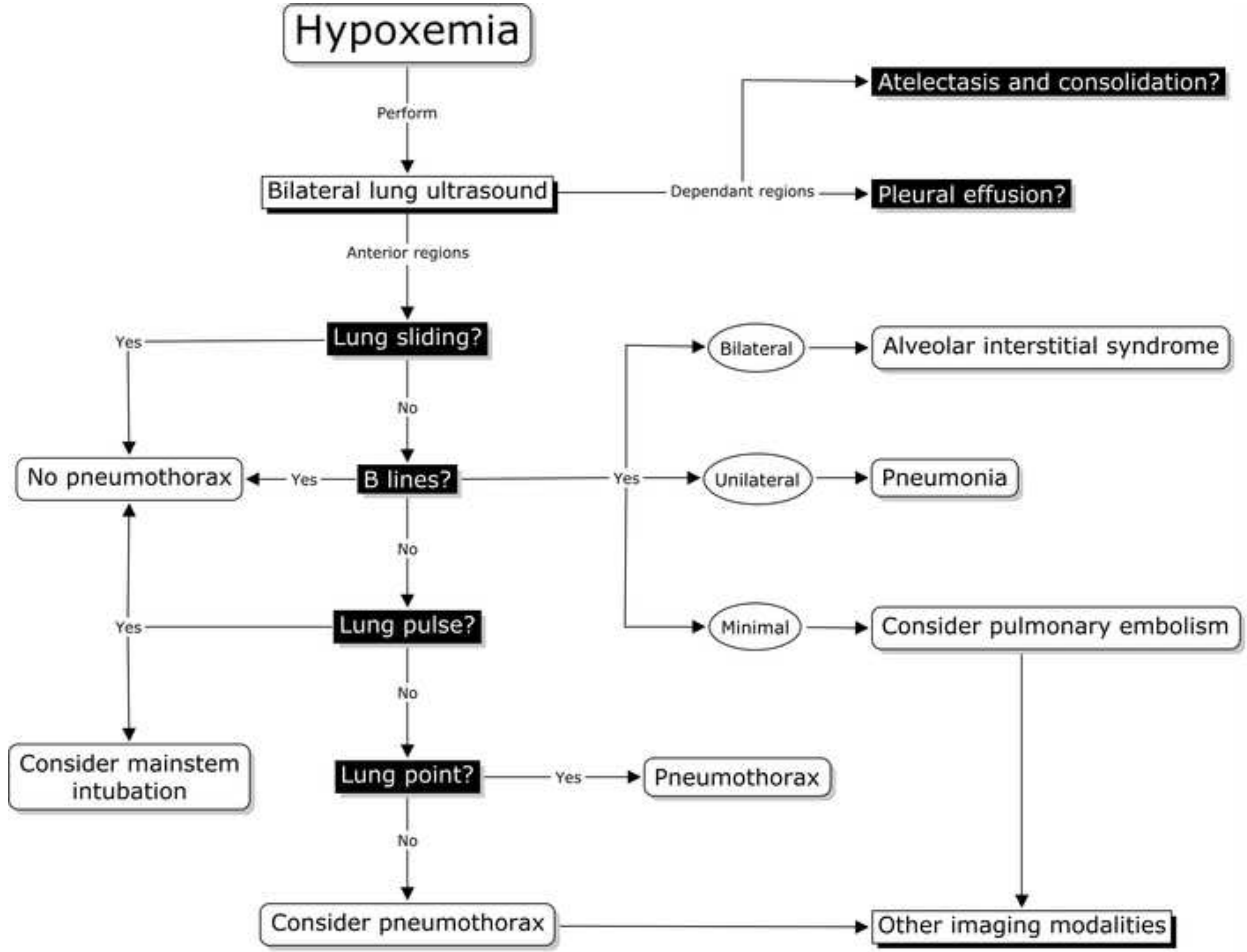


Figure 16



Hypoxemia
Perform
Bilateral lung ultrasound
Dependant regions
Atelectasis and consolidation?
Pleural effusion?
Anterior regions
Lung sliding?
Yes
No
No pneumothorax
Yes
B lines?
Yes
Bilateral
Alveolar interstitial syndrome
Unilateral
Pneumonia
Minimal
Consider pulmonary embolism
No
Lung pulse?
Yes
Consider mainstem intubation
No
Lung point?
Yes
Pneumothorax
No
Consider pneumothorax
Other imaging modalities

Supplemental Video File

Click here to download Supplemental Video File: Video Fig 1B - Phased array.wmv

Supplemental Video File

Click here to download Supplemental Video File: Video Fig 1C - Convex transducer.wmv

Supplemental Video File

Click here to download Supplemental Video File: Video Fig 1D - TEE.wmv

Supplemental Video File
Click here to download Supplemental Video File: Video Fig 6 - B lines.wmv

Supplemental Video File

Click here to download Supplemental Video File: Video Fig 10 - B lines and ARDS.wmv

Supplemental Video File

Click here to download Supplemental Video File: Video Fig 11 - Pneumonia.wmv

Supplemental Video File

Click here to download Supplemental Video File: Video Fig 14 - Abdominal point.wmv