Abstract
Ultrasound examination is a valuable method in diagnosis of various thoracic conditions including pleural or pericardial effusion, empyema, pneumothorax, pulmonary embolism, pneumonia, and primary or metastatic lung cancer. Ultrasound guidance during thoracentesis or tube thoracostomy assures minimal complications. It can also assist with staging of lung cancer by defining the extension of thoracic wall invasion or by real-time ultrasound-guided biopsy of a supraclavicular lymph node. Invasive procedures such as mediastinoscopy can be spared with effective use of endoscopic or endobronchial ultrasound in cancer diagnosis. Intensivists are able to provide better bedside care efficiently with a focused examination in critically ill patients. Thoracic ultrasound is mostly used to locate a target organ or a disease-specific condition and is often used as a complement to other imaging such as chest radiograph, computed tomogram or magnetic resonance imaging. Advantages include portability permitting bedside examination even in the intensive care units. Specific focused skills can be easily learned with formal didactic lessons and supervised training.

Air is a poor medium for sound transmission. As lung contains air, ultrasound of the lung may seem counterintuitive. The interface between chest wall and normal lung with different acoustic densities reflects most of the ultrasound waves, preventing a direct examination of an otherwise healthy lung. In pathological conditions such as tumor invasion, consolidation or atelectasis, the alveoli are replaced with more dense tissue allowing better sound conduction. When the pleural space is occupied with fluid or the consolidated lung reaches the chest wall, it opens an acoustic window permitting ultrasound examination of the lung.

Although ultrasound is now being used in most intensive care units (ICU) for vascular access, the potential of ultrasound use by pulmonologists for other thoracic applications is still underestimated. The role of ultrasound examination in lung cancer staging is not mentioned in the current guidelines. Ultrasound is practiced in the emergency rooms throughout the world for focused assessment with sonography for trauma to determine rapid intervention for cardiac tamponade, severe intrathoracic or intra-abdominal bleeding or organ injury. Ultrasound is helpful to locate the best site for chest tube placement or the insertion of a trocar prior to thoracoscopy or to drain a complicated pleural effusion. It can be used to localize parenchymal consolidation, tumor, chest wall, pleural masses or lymph nodes. Intrathoracic invasion of tumor masses in addition to cardiac function may also be detected easily. At the Oststadt-Heidehaus Hospital in Germany, ultrasound is routinely used in cancer surveillance to scan pleura, chest wall, liver, adrenal glands, lymph nodes or bones. An enlarged supraclavicular lymph node detected during examination is aspirated at the same time with minimal additional preparation allowing diagnosis and cancer staging. Fine needle aspirate or histological specimen may be obtained under real-time guidance with minimal risk of pneumothorax from the chest wall or subpleural peripheral lung masses.

Ultrasound involves no ionizing radiation or nephrotoxic contrast dye exposure. As opposed to other imaging techniques such as computed tomogram (CT), magnetic resonance imaging (MRI) or even simple radiographs, ultrasound examination may be performed anywhere and on any critically ill patient as a preliminary examination or to further investigate an existing finding noted on other radiographic imaging.

In this chapter we will briefly describe the clinical applications of ultrasound in thoracic diseases involving chest wall, mediastinum, lung parenchyma, pleural fluid, lymph nodes, and diaphragm. We hope this discussion will...
encourage nonradiologists to consider ultrasound as an attractive tool to aid with physical examination and interventional procedures.

**Principles of Thoracic Ultrasound**

Depending on the available transducers, a good examiner may be able to achieve best results even when the circumstances are not optimal. Frequently, the somormorphological image may not be decisive because of limitations or artifacts. Lung patterns during examination are mostly dynamic and the thoracic ultrasound examination is largely based on the analysis of artifacts [1]. Familiarity with various common artifacts and adequate technical skills are the basic requirements for thoracic ultrasound.

Chest CTs are mostly done in supine position. Unlike CT or MRI, there is no standardized operator interface for image acquisition in ultrasound except for the marker on the screen that corresponds to the transducer orientation. The examination is dependent on the skills of the individual operator and the orientation of the probe. So, reproducibility of images is not as precise as with other imaging such as CT. An optimal image acquisition depends on the choice and placement of the appropriate probe with an adequate preset at the right spot at an optimal angle with the patient in the best possible position. Good thoracic ultrasound examination consists of not just the acquisition of static images but analysis of the dynamic somormorphological changes associated with probe positioning or respiratory movement.

**Echogenicity**

Ultrasound images are displayed on a gray scale. The strongest echo appears white while it is black when no sound wave is reflected from the organs. Depending on the reflected wave amplitude, the following terms are used to define echogenicity. When no sound wave is reflected and the image appears black it is anechoic as in pleural effusion. It is isoechoic when the echoes are of comparable amplitude with the surrounding tissue as with kidneys or spleen. It is hyperechoic when echoes are stronger than the surrounding tissue as in diaphragm, and hypoechoic when it is weaker than that from the surrounding tissue.

**Description of Probes**

Tissue penetration of ultrasound decreases as frequency increases. Superficial organs are better visualized with higher frequency and deeper structures with lower frequency transducers. The gain and the power of the ultrasound need to be adjusted to obtain an adequate image. Most ultrasound equipments have preset modes for better imaging of specific organs of the body. For superficial imaging, a preset for the thyroid gland is useful. Otherwise most of the thoracic structures may be examined with abdominal preset.

The size of the probe is vital in real-time interventional procedures. A smaller probe will leave more room for needle insertion during real-time vascular access, thoracostesis, tube thoracostomy or percutaneous biopsy. There are primarily three types of transducers used in thoracic imaging, e.g. linear array, curvilinear array and a phased array.

Linear array transducers have piezoelectric crystals arranged in a linear sequence on the transducer head (fig. 1a). Parallel pulses are generated forming a line of sight perpendicular to the transducer face with a large footprint (part of transducer in contact with body surface). It produces a rectangular display. A linear array 7.5- to 10-MHz transducer with a thyroid preset is best to visualize superficial structures of the neck. This is also useful for vascular access or to determine pleural thickening, pleural masses or subpleural parenchymal lesions of lung. These high-frequency transducers provide an excellent high-resolution image of superficial structures but are not ideal for deeper tissue examination.

The curved array transducers consist of linear arrays shaped into convex curves that produce a large field of view with a large footprint (fig. 1b). These provide a pie-shaped image and are helpful to examine large pleural effusion, lung or abdominal structures or to view the lung from an abdominal approach.

In the phased array transducers, crystals located on the transducer head are pulsed as a group and the direction of the beam is continually changed in phases producing a pie-shaped image with a smaller footprint (fig. 1c). The benefit is a relatively smaller transducer with a large field of view at depth. A 2- to 5-MHz-phased array or a sector probe is good to visualize deeper structures such as atelectatic lung, complicated pleural effusion or heart through the intercostal space. They are also useful to visualize the pleural space from an abdominal approach through the liver.

**Position of the Patient and Relationship with Other Organs**

In the ultrasound nomenclature, a popular term used is the earth-sky axis. The thoracic organs are composed of water and air. Air rises and the water descends following the rules of gravity. Intrathoracic organs and pleural fluid shift with different patient positions. Successful examination depends on appropriate understanding of the anatomy in relation to patient position during image acquisition.
The lymph nodes or tumors of the anterior mediastinum that are not in contact with the chest wall in supine position may come against the chest wall when the patient is turned to a slightly prone left or right lateral decubitus position. A sitting position is ideal to localize very small pleural effusion, as most of the fluid is then collected in the costodiaphragmatic recess. The probe may need to be held close to the surface of the bed to locate pleural fluid in a supine patient in the ICU. Masses or lymph nodes in supraclavicular or the anterior mediastinum may be best visualized by turning the patient’s head to the extreme right or left or in flexion or extension. Pleural space can be visualized better from a posterior approach in a sitting patient with the hand placed on the opposite shoulder or above the head.

**Orientation of Transducers**

The secret of the acquisition and interpretation of thoracic ultrasound images lies in the ability of the examiner to correlate the obtained images virtually with the patient anatomy. Although ultrasound provides a 2-dimensional image, by sliding or tilting the transducer or by observing respiratory movement, a 3-dimensional dynamic image may be reconstructed in the mind. Being able to see the 3-dimensional image of the pathological changes is a key factor in image interpretation. Depending on the location of the target organ, patient position, clinical complaints, chest radiograph or CT images, the examiner tries to orient the transducer to the best possible site. However, this requires experience.

Each transducer is marked with a probe indicator, signifying the direction of examination that corresponds to a marker on the display screen. Usually this marker is placed on the left upper corner of the display screen; however, most current ultrasound units allow customization of the screen. The probe indicator of the transducer is placed in the cephalad direction during sagittal scanning of the chest. The probe indicator should be placed as much cephalad as possible when scanning through the intercostal window along the rib axis. During transverse scanning, the probe indicator is directed toward the patient’s right side. Transducer placement with operator and patient position to examine pleural cavity and mediastinal window are described in fig. 2.

Intrathoracic structures may be visualized better by holding the probe along the longitudinal or transverse axis over the rib spaces. It may take several attempts to find the best position and the correct angle to inspect a target structure. Anatomic landmarks are of assistance especially before any invasive procedure. Pleural surface on the right side is limited by the liver and the diaphragm, and on the left by the spleen with the diaphragm. The demonstration of kidneys on either side indicates structures below the diaphragm. The sonomorphological image of an empyema is very similar to a full stomach. Identification of these organs will assure a safe procedure and prevent needle puncture of liver, spleen or a full stomach.

**Technical Skills**

Good hand control is essential for successful scanning. By holding the probe comfortably, visualization can be maximized with a gentle rotating and rocking movement of the transducer. By sliding the transducer slowly over different rib spaces, a better window for visualization may be found. Using the thenar eminence to stabilize the hand against the
Examiner Position

In addition to appropriate positioning of patients and the transducers, the examiner needs to be flexible to complete an examination or ultrasound-guided procedure comfortably. A second monitor placed across the patient may be helpful in prolonged examination. An assistant available during interventional procedures to adjust the settings or to store images will assure a complete sterile technique. Some ultrasound units now have a foot paddle to allow image acquisition without compromising sterility.

Doppler Use in Thoracic Ultrasound

Doppler function has limited utility in the pleural examination but can be useful to detect vascularity of a chest wall, pleural or subpleural parenchymal mass. It can be useful
during vascular access, especially in hypotensive critically ill patients. Color flow Doppler needs to be used cautiously as it produces artifacts with respiratory movement and experience is needed to interpret it.

**Normal Ultrasound Anatomy of the Chest**

Normal chest wall consists of echogenic soft tissue layers representing layers of muscle and fascia. Ribs appear as smooth echogenic line below the soft tissue. Visceral and parietal pleura can be identified as two echogenic lines below the ribs with a 7.5- to 10-MHz high-resolution linear array probe. With real-time imaging, the sliding of the two pleural surfaces known as the ‘gliding sign’ can be seen. At the pleura-lung interface, air-filled lung prevents parenchymal examination.

**Clinical Applications of Ultrasound**

Ultrasound technology ranging from bulky machines to ultraportable pocket size equipments are now available (fig. 3–6). For critical care echocardiography or transthoracic ultrasound examination, we prefer a laptop-size instrument mounted on a cart with different probes (linear, curvilinear, phased array) available. A brief description of the clinical application in thoracic ultrasound follows. It is described in detail in other chapters of this book.

**Pleural Pathology**

Pleural effusion appears as an anechoic layer between the parietal and the visceral pleura. Movement of the atelectatic lung with respiratory cycle may be noticed through the pleural fluid. In supine position, pleural effusion is best witnessed from the lateral chest wall posterior to the midaxillary line with the probe pointed upwards. In the upright or sitting patient, it can be located easily from the posterior or lateral chest wall.
Transudates as a rule are anechoic, whereas exudates may appear anechoic or hyperechoic. Diffusely echogenic pleural effusion appearing as a ‘snowstorm’ usually represents empyema containing protein or tissue debris. Echogenic septations or loculations confirm a complex empyema and are much better identified with ultrasound than with the CT. The differentiation between lung abscess and empyema is sometimes difficult because a hypoechoic center may be found in both [2]. Hydropneumothorax can also be identified. A hemothorax may have hypoechoic or echogenic regions, occasionally with dependent layering of blood. Pleural thickening seen in fibrosis or empyema appears as a hypoechoic broadening of the pleura. Malignant effusions are usually anechoic but may become septated with repeated thoracentesis. Malignant pleural masses such as metastatic lesions or mesothelioma present as nodular pleural thickening and may accompany a pleural effusion.

**Pneumothorax**
Air localized within the pleural cavity collects in the nondependent part and is best identified in the supine position with the probe held perpendicularly on the anterior chest wall. The depth of the pneumothorax cannot be determined. A pneumothorax is usually diagnosed by the absence of normal pleural gliding sign (movement of parietal pleura on the visceral pleura) and comet tail appearance, and the presence of exaggerated reverberation artifact (an artifact produced by reflection of sound at the chest wall-air interface). M-mode is of additional help. Operator experience is crucial to analyze these artifacts.

**Pneumonia**
Consolidated lung in contact with chest wall or contained in pleural effusion may appear as echogenic. Similar findings may be seen with pulmonary hemorrhage, bronchoalveolar carcinoma or a lung infarct. Branching hyperechoic structures representing air bronchogram may be seen. Atelectatic lung is usually echogenic without any air bronchogram.

**Primary or Metastatic Lung Cancer**
Peripheral lung masses close to the pleura appear hypoechoic; however, it may become echogenic with bleeding. Diaphragmatic involvement can be detected through liver with an abdominal approach or with a transthoracic approach when pleural effusion is present.

**Chest Wall**
Soft tissue invasion of the chest wall by a primary lung cancer or chest wall tumor is easily detected. Ultrasound provides a better image of the Pancoast tumor than CT [2]. Only MRI offers a good image of this complex anatomical location. Comparison of findings with the healthy normal side may be a clue to diagnosis. Bony invasion of tumors like plasmocytoma appear as hypoechoic lesions. The fracture of ribs or clavicle can be identified.

**Lymph Nodes**
Supraclavicular, cervical and axillary lymph nodes can be examined better with ultrasound. Reactive or malignant lymph nodes can be differentiated based on the consistency or vascularity.
**Intrathoracic Tumor Extension**
Malignant invasion of the aorta or pericardium from lung can be detected better with transesophageal echocardiogram compared to CT or MRI with up to 90% accuracy [3, 4].

**Pulmonary Embolism**
Pulmonary embolism can be diagnosed with ultrasound. It is described in detail in chapter 5, see pp. 43–50.

**Cardiac Function**
A focused cardiac examination can be done effectively by intensivists with the phased array probe to document pericardial tamponade, ventricular function, ejection fraction or contractility in critically ill patients. This is discussed in chapter 7, see pp. 60–68.

**Functional Tests**

**Diaphragm Function (Sniff Test)**
Diaphragm paralysis or paresis can be diagnosed effectively with ultrasound. Pleural fluid-diaphragm interface makes the diaphragm hyperechoic. Without pleural effusion the diaphragm can be visualized only partially. However, by placing the probe in the subcostal location, the movement of both domes of the diaphragm may be compared to determine unilateral weakness. Bilateral weakness may be difficult to interpret. Ascites, when present, will push the diaphragm into the thoracic cage whereas in COPD, the diaphragm is flattened. With rupture of the diaphragm intrathoracic abdominal organs may be seen within the thoracic cage.

**Thoracic Tumor Localization**
The gliding sign identifies structures at the interface of the parietal and visceral pleurae. A subpleural mass or lung mass will move with respiration against the parietal pleura; while pleural sliding seen deeper to a tumor or mass will confirm its location within the chest wall. Absence of any movement at a particular location will provide evidence that both lung and chest wall are involved.

**Ultrasound-Guided Interventional Procedures**

**Vascular Access**
Ultrasound-guided bedside central venous catheter placement is safer [5]. It is now a standard of care in most ICUs. A quick survey prior to placement may reveal a thrombus of the central vein and help guide with the appropriate location. Use of ultrasound reduces failure rate and complications [6]. This is crucial in coagulopathic patients where successful cannulation can be obtained in a single attempt. Peripherally inserted central catheters (PICC) are nowadays placed in most hospitals in the US with ultrasound guidance.

**Pleural Access**
Ultrasound is an invaluable tool during thoracentesis to localize the deepest collection of pleural fluid. Although not completely eliminated, the incidence of pneumothorax is minimal with ultrasound-guided thoracentesis [7]. In very small pleural effusions sometimes the effusion is only visible when the patient is in sitting position. It can be used to guide chest tube in the pleural effusion and thereby prevent any subcutaneous placement, especially in obese patients. A chest tube cannot be guided in pneumothorax, as it will not be visible in the air within the pleural cavity.

We routinely use ultrasound prior to medical thoracoscopy or indwelling pleural catheter placement to locate the ideal site and to determine septations or loculations. The catheter is usually placed in the area of the largest collection.

Details on ultrasound use during thoracentesis and thoracoscopy are described in chapters 21 and 24, see pp. 182–188, 208–214.
Endoscopic and Endobronchial Ultrasound
Endobronchial ultrasound has proved to be a very effective tool to sample mediastinal lymph nodes. Combined endoscopic ultrasound and endobronchial ultrasound makes it possible to avoid mediastinoscopy completely. Details are described later.

Pericardiocentesis
Malignant pericardial effusion or traumatic effusion causing a tamponade can be drained safely with ultrasound guidance. An easier access under real-time ultrasound guidance is the parasternal approach rather than the traditional xiphosternal approach.

Paracentesis
A therapeutic or diagnostic paracentesis can be done safely in the ICU. A sector or curvilinear 3.5- or 5-MHz probe can be used to localize maximum fluid collection. A 7.5-MHz probe can then be used to localize vascular (inferior epigastric vein about 4–6 cm lateral to the midline) structures in the abdominal wall. The best area for paracentesis is about 2 cm below the umbilicus in the white line or 5 cm superomedial to the anterior superior iliac spine [8].

Percutaneous Tracheotomy
Because trachea contains air, only the anterior tracheal wall can be visualized with the transcervical approach. In obese patients or patients with difficult anatomy, laryngeal, cricoid and other tracheal cartilages can be identified with additional information on the depth of the trachea from the skin and the thickness of pretracheal fascia or tracheal deviation. An ultrasound examination is helpful to determine the size of the thyroid gland and the location of the isthmus. With Doppler flow imaging, nearby vascular structures can also be identified [9].

Ultrasound-Guided Biopsy
Subpleural peripheral lung, pleural-based or chest wall masses can be safely biopsied with ultrasound guidance. In Germany and some centers in the United States [10], pulmonologists perform needle aspiration or core biopsies. This technique largely depends on obtaining an image through an adequate acoustic window. A lung abscess reaching the chest wall may be percutaneously drained with ultrasound guidance. Mediastinal masses and lymph nodes in the anterior and superior mediastinum can also be accessed [2]. The best way to access these nodes is with the patient in the lateral decubitus position with a suprasternal or parasternal approach. Color flow Doppler may identify nearby vascular structures.

Supraclavicular and Cervical Lymph Node Biopsy
Supraclavicular lymph nodes that are not palpable can be detected easily by ultrasound and biopsied in real time. In malignant conditions, cytological diagnosis can assist with cancer staging [11]. Nonmalignant conditions such as sarcoidosis can also be diagnosed. It is superior to CT [12] and the sensitivity of detecting metastases is increased 3-fold [12, 13]. Even bronchoscopy or other invasive procedures may be avoided in about 15% of lung cancer patients if cervical ultrasound and biopsy are included early in the diagnostic workup [12].

Training
Radiologists, cardiologists and sonographers go through an intense training before they are credentialed to obtain or interpret ultrasound images. The use of ultrasound by non-radiologists is very focused and is usually limited to common examinations and procedures within their specialty. Therefore, limited training in focused areas may be adequate. Surgical residents are able to learn basic focused assessment with sonography for trauma examination after 8 h of formal training [14]. In emergency medicine, a 1- to 3-day training course is offered with follow-up mentoring [15]. Videotaped cases are also valuable in developing interpretation skills [16]. As with any other procedure, there is a learning curve for acquiring the technical skills.

At present, there are no guidelines on thoracic ultrasound examination. In Germany, a documentation of 100 cases of ultrasound examination is required to become an internist. Skills in focused thoracic ultrasound examination may be easily learned but being able to differentiate normal from abnormal structures and then to identify specific abnormal findings requires additional experience. When in question, available resources for comparison or referral for formal radiology evaluation may be necessary.

A successful thoracic ultrasound training program for nonsurgeons such as pulmonologists or medical and surgical intensivists should include a 1- to 2-day didactic session on basic ultrasound, practice on phantom and live models followed by supervised examinations where the images are recorded and reviewed with the mentors. Proficiency can be determined by a formal evaluation after about 5–15 cases depending on the scope of the examination. Although a required number of procedures is suggested by most authorities before an individual can practice independently, we are all aware that not everyone has the aptitude to learn or practice accurately even after completion of the required
numbers. A competency evaluation before credentialing is useful rather than the acquisition of a preset number. One must remember that it is a cumulative education and strict numerical requirements for each procedure may limit its use. The availability of dedicated and competent mentors for follow-up and ongoing supervision and posttraining evaluation is necessary as each examination is unique.

Most thoracic physicians or surgeons may use ultrasound as an adjunct to other imaging studies such as CT, chest radiograph or MRI. Localization of pleural fluid and ultrasound-guided thoracentesis is the easiest to learn second to vascular access. As most pulmonologists are proficient in thoracentesis, it may be considered as an ultrasound-assisted rather than an ultrasound-guided procedure. Pulmonary fellows at one institution in the US are credentialed to perform thoracentesis independently after watching a DVD on the technique [17]. Once basic skills in acquisition and interpretation of images of pleural effusion are achieved, ultrasound-guided thoracentesis, chest tube placement, peripheral lung mass or supraclavicular lymph node examination and biopsies can be done safely with some additional training.

Limitations
The examination may be limited in subcutaneous emphysema, massive peripheral edema, morbid obesity or when patients cannot be placed in an optimal position. Insufficient operator skills can be avoided with adequate training and proctored examinations. Familiarity with one or two transducers and appropriate placement and selection of the probe can minimize these limitations. A typical thoracic examination is possible with any simple ultrasound unit. Color flow Doppler interpretation needs experience.

Frequently, diagnosis cannot be made by a single imaging technique. Concomitant imaging of different organs of the body may lead to a diagnosis. For example, compression ultrasound of lower extremity, echocardiogram and transthoracic ultrasound examination may indicate pulmonary embolism when V-Q scan or CT angiogram cannot be done. Detection of a new pathological condition, for example, finding a tumor of the kidney during a routine ultrasound examination, is uncommon in thoracic ultrasound.

Conclusion
Ultrasound is no longer limited to the realm of the radiologists. Availability of newer, user-friendly, inexpensive, portable units has made them an excellent tool for nonradiologists such as emergency physicians, surgeons, intensivists or pulmonologists to provide superior care. In addition to a diagnosis, they provide a safe guidance for various bedside procedures, especially in critically ill patients where a detailed ultrasound examination may avoid transportation to the radiology suite. Cancer staging can be done by aspiration of an easily accessible lymph node or chest wall mass. Even though ultrasound has no significant physical risks, false-negative or false-positive diagnoses may have dire consequences. With adequate focused training, the same clinician can confirm a finding, provide necessary diagnostic or therapeutic intervention and deal with complications, if any, while the patient is still on the table, in a cost- and time-efficient manner.

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