Exploring the Pleura

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Learning objectives

Review the anatomy of the pleura using schematic illustrations and correlate it with imaging findings.

Provide an overview of the principal diseases that may affect the pleura, focusing their main clinical and radiologic features.
Background

Anatomy of the pleura

The Pleura is a serous membrane that involves the lungs and lines the inside of the chest wall by folding back onto itself to form a two-layered membrane structure. The inner pleura (visceral) cover the lungs and forms the interlobar fissures, which separate or partially separate the lobes of the lung. Recognizing the fissures (major/oblique, minor/horizontal and accessory fissures) is essential for localization and diagnosis of both pleural and parenchymal abnormalities. The outer pleura (parietal) lines the inner surface of the thoracic wall (costal pleura), the lateral aspect of the mediastinum (mediastinal pleura), the thoracic inlet (cervical pleura) and the thoracic surface if the diaphragm (diaphragmatic pleura) (Fig. 1 on page 6). External to the parietal pleura is a layer of loose areolar tissue (extrapleural fat), and a layer of fibroelastic endothoracic fascia that covers the surface of intercostal muscles and intervening ribs (Fig. 2 on page 6).

The two pleural layers continue one by another on the inner face of the lung, at the level of the hilum and beneath it, constituting the reflection lines of the pleura. Between the two pleural layers there is a potential space known as the pleural cavity which contains a small amount of liquid (5-20 mL), that lubricates the pleural surfaces and contributes to the movement of the two layers during lungs expansion on inspiration. The surface projection of pleura is larger than the surface of the lung itself creating a series of recesses (costo-mediastinal, phrenico-mediastinal and costo-diaphragmatic) that allow lung to expand into them when inhaling and accumulate fluid when standing (Fig. 1 on page 6). The vascular supply of the parietal pleura is from the systemic circulation, whereas the visceral pleura is supplied by branches of the pulmonary arteries. Lymphatic drainage of the visceral pleura is by way of a lymphatic plexus that covers the surface of the lung and connects to bronchial lymphatics that drain centrally along the bronchovascular bundles to the pulmonary hilum. The parietal pleura is the primary drainage route for the pleural space and is lymphatically connected to the intercostal, internal mammary and mediastinal lymph nodes chain.

Radiology in pleural disease

Radiologists are often involved in the recognition and characterization of pleural diseases, several times detected incidentally or as a secondary effect of another disease process. Chest radiograph (CXR) remains the initial examination of choice in investigation of pleural disease and in assessing disease progress. Other imaging techniques such as ultrasound (US), computed tomography (CT), magnetic resonance imaging (MRI) and
positron emission tomography (PET) can be performed in the evaluation of abnormalities detected by CXR or to guide interventional procedures.

Chest radiograph

- Normal pleura is not usually visible on CXR, except when it forms part of a lung fissure or where the two lungs abut each other in the midline, constituting the anterior (below the level of the manubrium) and posterior junction lines (from above the clavicles to the level of the arch of the aorta). Fig. 3 on page 7

- An erect posterior-anterior (PA) and lateral CXR are usually performed.

- Additional views such as the lateral decubitus film and expiratory CXR can be obtained to detect small pneumothoraces and small pleural effusions, as little as 5 mL (lateral decubitus film). (Fig. 4 on page 8)

Chest ultrasound

- The pleura is a relatively superficial structure and therefore is accessible to US.

- Pathologic processes involving the pleura and the pleural space may be characterized with US according to their acoustic properties. Furthermore, US of pleural space became in last decades a leading real-time method for demonstrating and characterize small pleural effusions.

- US is extremely useful on guiding interventional procedures (e.g., needle biopsy of visible pleural lesion, placing pigtail catheters / drainage tubes, particularly in complicated cases of small or loculated effusions and pneumothoraces). (Fig. 5 on page 9)

Computed tomography

- CT is the best means of further assessing pleural abnormalities seen on CXR or US and is very sensitive to determine the extent of pleural lesions and to detect small lesions not visible on CXR.

- The pleura and chest wall are well evaluated using routine CT techniques. (High-resolution CT (HRCT) can demonstrate the anatomy of the lung/pleura/chest wall interface better than conventional CT. Soft-tissue window settings are most suitable for evaluation of pleural abnormalities.

- In normal subjects, a 1- to 2-mm-thick soft tissue stripe is usually visible in intercostal spaces between adjacent rib segments (the intercostal stripe). This line primarily
represents the innermost intercostal muscle but also reflects the combined thicknesses of visceral and parietal pleura, the fluid-filled pleural space, the endotheoracic fascia and fat layers (Fig. 6 on page 10). In the paravertebral regions, the innermost intercostal muscle is absent, and a much thinner line (or no line at all) is visible at the pleural surface.

- Major fissures can be difficult to see on CT obtained with 5-mm collimation. However, the position of each major fissure can be inferred from the location of the relatively avascular region of lung 1 to 2 cm in thickness, which contains no large vessels. Sometimes, an ill-defined band of density is seen in the middle of the avascular band. The minor fissure is usually hard to see because it parallels the plan of the scan, and usually is approximate position is determined by a lucent, avascular region in the anterior right lung (Fig. 7 on page 11). Acessory fissures as azygos fissure can also be well recognize on CT (Fig. 8 on page 11).

- CT scan should be acquired before and following the administration of intravenous contrast to provide soft tissue enhancement, which allows differentiation of pleural thickening from fluid; differentiation of pleural effusion from lung atelectasis and consolidation, identification of pleural lesions, and demonstration of peripheral enhancement of empyemas.

- As US, CT is extremely helpful on guiding interventional procedures.

Magnetic Resonance Imaging

- MRI is an excellent imaging modality for assessment of primary chest wall tumors, chest wall infections, and chest wall or diaphragmatic extension of intrathoracic masses. MRI can potentially characterize pleural effusions, and differentiate between exudates and transudates.

- On T1-weighted images, particularly with contrast enhancement, the extent of invasion of normal tissues can usually be established. T2-weighted sequences are extremely sensitive in demonstrating areas of cystic degeneration, inflammation, and edema.

- The ability of MRI to image in arbitrary planes of section used to be an advantage over CT in assessment of the lung apices, diaphragm, and spinal column. Imaging in sagittal and coronal planes is especially helpful in assessing the extent of malignant tumors, such as mesothelioma. (Figs. 34-36)
**Fig. 1:** Coronal (a) and sagittal (b) illustration of pleural sac and recesses.

Fig. 2: Illustration of normal anatomy at the pleural surface.

Fig. 3: Erect PA (a) and lateral (b) chest radiographs showing the horizontal (small arrows) and oblique fissures (large arrow). c) erect PA chest radiograph showing the posterior junction line (small arrow), where the two lungs abut each other in the midline. d) lateral chest radiograph where is possible to evaluate the inferior extent of the posterior pleural space (large arrow).

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**Fig. 4:** Lateral decubitus radiograph showing a small pleural effusion (small arrow).

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**Fig. 5:** Lateral decubitus radiograph showing a small pleural effusion (small arrow).

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**Fig. 6:** Normal anatomy at the pleural surface. CT scan following the administration of intravenous contrast. In a normal patient, a thin white stripe between adjacent ribs (small arrows) represents the intercostal stripe, primarily representing the innermost intercostal muscle (separated from the more external layers of the intercostal muscles because of a layer of intercostal fat). In the paravertebral region only a very thin line (or noun) is visible - the paravertebral line - because in this region, the innermost intercostal muscle is anatomically absent (large arrow).

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**Fig. 7:** a) Sagittal CT scan shows normal appearance of the right horizontal (small arrow) and oblique (large arrow) fissures. The fissures delineate the upper (UL), middle (ML) and inferior (IL) lobes. b) On axial CT scan the region of the horizontal fissure usually appears as an avascular area (black arrow) and oblique fissure is well defined (large arrow).

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**Fig. 8:** Azygos fissure and azygos lobe. a) Chest radiograph shows the characteristic curvilinear appearance of the azygos fissure (small arrow). Sagittal CT (b) and axial CT (c) reveal a better delineation of the azygos fissure (small arrows) and the azygos lobe (AL).

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Findings and procedure details

I. PLEURAL EFFUSION

Pleural effusion is the most common pleural abnormality. It develops when the rate of formation of fluid and its reabsorption are mismatched. Pleural fluid may be classified as *transudate* or *exudate* based on their compositions, but a variety of liquids can accumulate in the pleural space (e.g., blood, chyle, and occasionally bile, urine, cerebrospinal fluid and intravenous infusions). Traditionally, the distinction between a transudate and an exudate requires thoracocentesis.

**Transudates** are usually related with a systemic disease and are typically bilateral. They result from an increase in the capillary hydrostatic pressure or a decrease in colloid osmotic pressure. Their main causes are congestive heart failure, states associated with hypoalbuminemia / overhydration, renal failure and cirrhosis.

**Exudates** usually result from an increase in the permeability of the microvascular circulation due to inflammatory or neoplastic processes involving the pleura. An exudative effusion meets at least one of the following criteria:

1. Pleural fluid total protein / serum total protein ratio greater than 0.5
2. Pleural fluid LDH / serum total LDH ratio greater than 0.6
3. Pleural fluid LDH level more than two thirds of the upper limit of normal for serum.

Less specific criteria used to diagnose an exudate include a pleural specific gravity exceeding 1.016 and a pleural fluid protein level exceeding 3 g/dL (high protein content). The principal causes of pleural effusion are listed in Table 1 on page 25.

CXR, CT and US are the most frequently used tests for demonstrating pleural fluid. The appearance of an effusion depends on the patient's position at the time of examination, the quantity of fluid and the mobility of effusion, which may be free or loculated.

**Radiographic features**

In *Upright view*, pleural free fluid first accumulates in the most inferior portions of the pleural space, including the costophrenic angles and subpulmonic regions. Usually, costophrenic angle blunting is the first recognizable plain film finding of pleural fluid. Lateral costophrenic angle blunting on frontal radiographs requires at least 175 ml of pleural fluid, while posterior costophrenic angle blunting on lateral radiographs requires
at least 75 ml of pleural fluid. As the effusion increases, fluid can be observed lateral to the lower lobes, separating them from adjacent chest wall.

In moderate free pleural effusion it’s possibly to see homogeneous opacity in the lower zone with an upper curvilinear border with a meniscus-like shape. The opacity is denser laterally, while medially the effusion produces only a general haziness with a upper wedge-shaped geometry. The "meniscus" is often higher laterally than medially because lung attachments (hilum and pulmonary ligament) alter the distribution of forces (Fig. 9 on page 25).

Free pleural effusion within the fissures shows different findings depending on the shape and orientation of the fissure. Effusions in the major fissure appear on frontal view as an arcuate opacity, sharply defined medially and inferiorly, whereas fluid extending into the lateral aspect of the minor fissure often results in a opacity resembling a rose thorn (the "thorn sign").

Massive pleural effusion usually results in significant or complete lung atelectasis, producing complete opacification of the hemithorax with displacement of the mediastinum and airways (Fig. 10 on page 26).

Pleural fluid accumulated in the subpulmonic region leads to apparent elevation of the ipsilateral hemidiaphragm with flattening of its medial aspect (Fig. 11 on page 26), and therefore subpulmonic fluid collections are usually difficult to recognize on frontal radiographs. However, some signs may be present: lateral displacement of what appears to the diaphragmatic dome or peak, with the lung lateral to the peak angling down sharply, lack of pulmonary vessels behind the hemidiaphragm, some blunting of lateral or posterior costophrenic sulcus and on the left side, increased distance from lung to gastric bubble (distance >2 cm).

In Supine view, frequently performed in ill patients, large amounts of fluid can be easily missed, particularly if they are bilateral, because the pleural fluid layers posteriorly. A pleural effusion may be suspected when there is increased opacity of the hemithorax without obscuration of the superior vascular markings, apparent elevation of the hemidiaphragm with reduced visibility of lower lobe vessels, blunting of the costophrenic angles, obscuration of the hemidiaphragm, thickening of the minor fissure and paravertebral stripe, or when there is an apical cap (large effusions). When in doubt, it’s possible to performe a lateral decubitus radiograph, which is much more sensitive, demonstrating as little as 5mL of pleural fluid (Fig. 4 on page 46).

Loculated effusions are defined as effusions that do not shift freely in the pleural space, usually limited in extend by pleural adhesions. Loculation of pleural fluid may be seen in exudative pleural effusions, as those that occur with empyema, and in hemothorax. It can assume different configurations depending on its location and radiographic projection (Fig. 12 on page 27). When pleural effusion loculates within the fissures, frequently
in the minor fissure, it mimics the presence of a focal lung lesion and has been referred to as "phantom tumor" or "pseudotumor".

**Chest ultrasound**

The majority of pleural fluid collections are readily identified at US as anechoic or hypoechoic collections delineated by the echogenic line of visceral pleura and lung.

US criteria determining pleural effusion are at least 3 mm thick anechogenic zone between the parietal and the visceral pleura and/or changing of fluid layer thickness between expiration and inspiration, as well as changing with different positions of the patient.

While transudates and exudates have similar radiologic appearances, they can often be differentiated at US. Pleural effusions with complex septated, complex non-septated, or homogeneously echogenic patterns are always exudate. The association with a thickened pleura and/or pulmonary parenchymal lesions also indicates the presence of an exudative effusion. Hypoechoic effusions may be either transudates or exudates. (Fig. 13 on page 28) Chest US is also very useful in determining appropriate access sites for thoracocentesis.

**Computed tomography**

Pleural effusion can be seen as free or loculated hypodense fluid, with an attenuation lower than pleural thickening or consolidated / collapsed lung on unenhanced scans. On contrast-enhanced scans, both airless lung and thickened pleura enhance, and this difference is accentuated. Free-flowing pleural fluid first accumulates in the most dependent part of the pleura space, posterior to the lower lobe. When free pleural fluid accumulates, the lung decreases in volume but tends to maintain its normal shape. Thus, a free pleural effusion generally appears crescent-shaped on CT. Some other findings can be associated with pleural effusion: passive lobar collapse (frequently), parenchymal masses, rounded atelectasis, pleural thickening, pulmonary edema and pneumonia. (Fig. 9 on page 25 and Fig. 10 on page 26)

The presence of pleural thickening on contrast-enhanced CT indicates that the effusion is an exudate rather than a transudate. Pleural fluid deep in the posterior and lateral costophrenic recesses may be confused with ascites, but different signs have been described to differentiate them (Fig. 14 on page 28):

- "Displaced crus sign": pleural fluid displaces the diaphragmatic crus anterolaterally because it collects between the spine and the diaphragm;

- "Interface sign": the interface between pleural fluid and spleen or liver is hazy);
- "Diaphragm sign": if the diaphragm can be identified, fluid inside the dome must be ascites and fluid outside the dome must be pleural;

- "Bare area sign": pleural fluid is free to collect along the full width of the costophrenic recess behind the liver, whereas the peritoneal coronary ligament prevents ascitic fluid from extending over the entire surface of the liver.

CT is particularly helpful in the assessment and management of *loculated pleural effusions*, showing a localized collection with an elliptical or lenticular shape (rather than crescentic), usually in a nondependent location and often associated with pleural thickening (best seen in enhanced CT scans) (Fig. 15 on page 29).

**Complicated parapneumonic effusion and empyema**

Pleural fluid can accumulate in patients with pneumonia, even when the pleural space is uninfected large number of patients with acute bacterial pneumonias or lung abscesses present an exudative pleural effusion, named parapneumonic effusion, which is usually classified in three stages, although these often merge with each other:

1) Exudative stage (simple parapneumonia effusion): rapid accumulation of sterile pleural fluid into the pleural cavity in response to inflammation of the pleura;

2) Fibrinopurulent stage (empyema): accumulation of large amount of pleural fluid with polymorphonuclear leukocytes, bacteria and cellular debris. Fibrin covers both visceral and parietal pleura and there is a tendency to loculation;

3) Organization stage: fibroblasts grow both in the visceral and parietal pleura surfaces, producing an inelastic membrane called the "pleural peel". Most empyemas are associated with pneumonia, surgery, trauma, or infra-diaphragmatic infection. For a conclusive proof of an empyema, positive pleural fluid cultures are needed. Bacteria usually responsible of parapneumonic effusions are anaerobic bacteria, *S. aureus*, *S. pneumoniae*, other streptococcal species and various gram-negative bacteria.

**Radiographic features**

The appearance varies with the evolution of the fluid collection. At exudative stage it has the same radiological findings of pleural fluid collection (Fig. 16 on page 30 a), while at fibrinopurulent and organized stages it appears as loculated fluid, with pleura-based oval or lens-shaped morphology (Fig. 17 on page 31a), with possible presence of air-fluid levels within.

On radiographs, an empyema may be difficult to differentiate from a peripheral lung abscess, and this distinction can be important because empyemas are often treated by
tube thoracostomy in addiction to systemic antibiotics, whereas most lung abscesses require antibiotics only.

**Chest ultrasound**

Empyema is an exudate and may show complex septated, complex nonseptated, or homogeneously echogenic patterns (Fig. 13 on page 28b).

**Computed tomography**

Parapneumonic effusions usually appear crescent-shaped on CT and about 50% are associated with pleural thickening. Pneumonia signs are usually present (Fig. 16 on page 30b). CT is currently the best method to characterize empyemas and to differentiate them from pulmonary abscesses. CT findings after intravenous administration are highly suggestive of empyema: enhancement of the parietal and visceral pleura, thickening of the extrapleural subcostal tissues and increased attenuation of the extrapleural fat (Fig. 17 on page 31b).

The enhancement of the pleura in empyema is thought to be due to the increased vascular supply of the inflamed pleura. The combination of fluid between the pleural layers and the thickening of the visceral and parietal pleura is referred to as the "split pleura sign" and is seen during the organizing phase of the empyema. In contrast to empyema, lung abscess tend to be round, ill defined, have shaggy walls of irregular thickness and destroy lung without displacing vessels.

**HEMOTHORAX**

A hemothorax is a pleural effusion that has a hematocrit over 50% of blood hematocrit. Causes of hemothorax include trauma (closed or penetrating), surgery, interventional procedures (thoracocentesis, pleural biopsy, and catheter placement), bleeding diathesis (anticoagulant therapy, thrombocytopenia), pulmonary infarct, pleural infiltration by malignancy (mesothelioma, lung cancer, and metastasis), vascular causes (arteriovenous malformation, aortic dissection), and infection.

Hemothorax often manifests as a rapidly enlarging pleural effusion, but when it becomes organized, behaves more like an empyema than a simple pleural effusion with undulating contours on CXR due to loculation and accumulation in non-dependent areas.

CT can demonstrate bloody pleural effusions as areas of high attenuation (higher than 50 HU). In a hemothorax, CT findings usually include heterogeneous attenuation of pleural fluid, hyperattenuating areas of debris within pleural fluid (Fig. 18 on page 31) and a "fluid hematocrit" level.
The course of a hemothorax depends on the source of the bleeding. Low pressure venous bleeding is usually tamponated by the pressure of the pleural effusion and compressed lung. High pressure systemic bleeding can lead to a tension hemothorax.

Long-term complications of hemothorax are chronic pleural thickening and heavy pleural calcification.

II. PNEUMOTHORAX

Pneumothorax describes the presence of air within the pleural space and is classified as *spontaneous* (without prior cause in an healthy subject - *primary* - or occurring in patient with underlying lung disease that predispose to pneumothorax, as emphysema - *secondary*) or *traumatic* (caused by *chest trauma* - penetrating or nonpenetrating, accidental or iatrogenic - or *mechanical ventilation*).

**Radiographic features**

A standard PA CR is the only examination performed routinely, although expiratory CXR and e lateral decubitus film can provide added information. Pneumothorax is demonstrated on CXR by the absence of pulmonary vessels beyond the visceral pleural line, which is not normally seen. Free air moves to the non-dependent part of the chest and, in the erect patient, accumulates in apico-lateral position (Fig. 19 on page 32a) and, in the supine patient, in anterior position.

**Computed tomography**

CT is very sensitive to diagnose pneumothorax, detecting a minimum free amount of air in the pleural space. CT is also important to differentiate pneumothorax from large bulla, to differentiate medial pneumothorax from pneumomediastinum, and to identify subpleural bullae, paraseptal lung emphysema, or other conditions that predispose to pneumothorax (Fig. 19 on page 32 and Fig. 20 on page 33). A pneumothorax may loculate in the presence of scars or may collect in the oblique fissure showing a radiolucency area (Fig. 20 on page 33).

*Tension pneumothorax* is a life-threatening condition occurring when intrapleural pressure becomes positive for a significant part of the respiratory cycle, compressing the lung and causing a restrictive ventilatory defect and an increase in the work of breathing. This condition must be treated immediately with decompression of pleural space. Mediastinal shift and hemidiaphragmatic flattening (or even inversion) are the most evident radiological findings (Fig. 21 on page 34).
III. PLEURAL THICKENING

Pleural thickening may be focal or diffuse and is frequently the result of chronic inflammation or infection of pleura. Apical lung fibrosis with adjacent thickened pleura is a common observation on chest radiographs and CT, mostly in older patients (Fig. 22 on page 34a). Most cases of pleural thickening visible on chest radiographs or CT scans are due to parietal pleural thickening. Thickening of visceral pleura is usually associated with parietal pleural thickening and pleural effusion, especially with empyema. Isolated visceral pleural thickening is rare.

In chest radiographs, pleural thickening can be seen as blunting of the lateral or posterior costophrenic angle (may also be observed with pleural effusion); a stripe of soft tissue density, several millimeters-thick, between lung and chest wall, focal or diffuse; pleural calcification; or asymmetrical increase in extrapleural fat, appearing with low density.

In CT, pleural thickening is seen as a stripe of soft tissue density with 1mm or more in thickness, internal to the ribs, internal to the intercostal stripe (Fig. 22 on page 34b) or in the paravertebral region; as pleural calcification; or as thickening of the extrapleural fat layer.

Pleural calcification

Is a frequent chest finding, associated with pleural fibrosis of any cause. The main causes of pleural calcification are fibrothorax resulting of healed tuberculosis or bacterial empyema, hemothorax and asbestos exposure. Pleural calcifications can be visualized on standard chest radiographs, but CT is more sensitive to detect them, and better to demonstrate the extension of pleural calcifications and the presence of pleural and/or pulmonary associated diseases. Bilateral symmetric disease, especially with calcified plaques on diaphragm, is more typically associated with asbestos exposure, while unilateral thickened pleura with calcification is more commonly associated with prior hemothorax or empyema.

Fibrothorax or pleural peel

Fibrothorax refers to extensive, circumferential fibrous pleural thickening, that is usually the result of organized chronic empyema, but it may also result from chronic pleural effusion and inflammation without infection, especially in patients with collagen-vascular diseases, asbestos exposure, uremia and hemothorax. Fibrothorax usually causes lung restriction and decreased lung volume (“trapped lung”).

Chest radiographs and CT findings of fibrothorax are smooth thickening of pleura; thickening of extrapleural fat, between pleura and the intercostal muscle or rib (visible on
CT scans; pleural calcification (that may be quite extensive, especially in patients with prior tuberculosis infection); and reduction in volume of the affected hemithorax. (Fig. 23 on page 35)

Asbestos related benign pleural processes

Asbestos exposure is associated with pleural plaques, pleural thickening, pleural effusions, pulmonary fibrosis (asbestosis) and malignant neoplasms of pleura and lung. Exposure to asbestos induces inflammation of pleura, especially of the parietal pleura. Later, pleural fibrosis may manifest as diffuse parietal pleural thickening or, more commonly, as focal pleural plaques. Pleural plaques related to asbestos exposure usually range between 2 and 15 mm in thickness, are typically bilateral, and localized predominantly in paravertebral and posterolateral regions of the lower half of hemithoraces and in diaphragm, and rarely in an anterior location (Fig. 24 on page 35). They can be of soft tissue attenuation or may be partial or completely calcified. They usually are observed in approximately 20 years after exposure to asbestos and do not undergo malignant transformation. However, their presence means asbestos exposure and, therefore, higher risk for development of lung and pleural malignancy. Asbestos exposure can also result in benign exudative pleural effusion, a condition likely inflammatory in nature and related to the presence of asbestos fibers at the pleural surface. Effusions are usually unilateral, small to moderate and self-limited, but may be recurrent. However, pleural effusion can be the first sign of malignancy and, therefore, pleural or lung malignancy should first be excluded. Diffuse pleural thickening results in about 20% and can involve both parietal and visceral pleura and be associated with lung function restriction. Rounded atelectasis may also be identified.

IV. PLEURAL NEOPLASMS

Lesions located in the peripheral thorax, in contact with the chest wall, can be classified as extrapleural, pleural, or parenchymal. Commonly, they are differentiated by the angle (either acute or obtuse) formed by the interface between the lesion and the adjacent pleura (Fig. 25 on page 36):

- **Pleural masses**: arising from the visceral or parietal pleura, often remain confined to the pleural space and have an appearance similar to that of extrapleural lesions, except usually have different diameters. The presence of an obtuse angle is common unless the lesion is large and may have acute angles where they meet the chest wall. Pleural lesions usually are sharply marginated and displace pulmonary vessels away from them (Fig. 26 on page 36).

- **Extrapleural masses**: usually have similar diameters and displace the overlying parietal and visceral pleura, resulting in an obtuse angle between the lesion and the chest wall.
Typically, extrapleural masses are sharply marginated at the point they contact the lung and displace pulmonary vessels form them. Associated abnormalities may include chest wall soft tissue mass or rib destruction (Fig. 27 on page 37).

- **Pulmonary parenchymal masses**: typically results in an acute angle with the pleural surface, although may result in obtuse angles with the chest wall in the presence of pleural invasion. Pulmonary lesions are often ill defined along their inner aspect and may engulf rather than displace vessels (Fig. 28 on page 37).

**Benign tumors**

The most common benign tumors affecting the pleura are lipomas and localized fibrous tumors.

**Pleural and extrapleural lipomas**

Pleural and extrapleural lipomas are benign tumors that are usually asymptomatic and incidentally discovered. CXR shows a well marginated oval or lens-shaped mass based on the pleura. CT makes the diagnosis once it demonstrates a homogeneous and well-defined mass with characteristic fat attenuation (Fig. 26 on page 36). MRI shows a pleural mass with high signal intensity on T1-weighted images and intermediate signal in T2-weighted images, similar to subcutaneous fat signal that suppress with fat-suppression sequences.

**Pleural fibrous tumor**

Pleural fibrous tumors are rare, accounting for less than 5% of all pleural tumors. They are often incidentally discovered and, although they are usually benign, 15-20% of these tumors are malignant, even though with good prognosis. They arise from visceral pleura and are not associated with prior asbestos exposure.

On **CXR** they present as a focal, smooth, sharply defined, and often large pleural mass.

On **CT**, tumor mass commonly appears well circumscribed and homogeneous, but may present areas of necrosis, calcification and large vessels supplying the tumor; tumor can be sessile, lobulated or attached to the pleural surface by a pedicle. This last finding is pathognomonic and highly suggestive of benign variety of fibrous tumors, with good prognosis; tumor contrast enhancement may be homogeneous or heterogeneous, especially in large lesions (Fig. 29 on page 38).

On **MRI**, pleural fibrous tumors have low to intermediate but heterogeneous signal intensity on both T1 and T2-weighted images, and show heterogeneous and intense enhancement with intravenous contrast administration.
Malignant tumors

Pleural malignant neoplasms may manifest as a pleural mass, pleural effusion and/or pleural thickening. Malignant pleural effusions are exudates associated either with primary or metastatic disease. However, pleural thickening on CT of a patient with malignancy and pleural effusion only suggests the presence of an exudate, and not necessarily malignant effusion, because it can be observed either with benign and malignant effusions.

The radiographic and CT findings suggestive of malignant pleural disease are nodular pleural thickening, parietal pleural thickening greater than 1 cm, circumferential pleural thickening (surrounding the lung), and mediastinal pleural thickening.

Ultrasound has limited value in characterization of malignant pleural lesions but may be very helpful to guide biopsy of visible pleural masses (Fig. 5 on page 47b).

MRI findings can help to differentiate benign from malignant pleural disease. In addition to those CT findings described above, on MRI, pleural malignancy usually reveals high signal intensity of pleural thickening or mass relative to intercostal muscles on T2-weighted images and on T1-weighted images after intravenous contrast administration. On the other hand, signal hipointensity relative to skeletal muscle on T2-weighted images favors a benign pleural disease.

Metastases

Metastases are the most common malignant tumor affecting the pleura and can be derived from almost any organ, although the lung is the most frequent primary site followed by the breast, pancreas, stomach and ovary. Metastases usually involve the visceral and parietal pleura and are frequently associated with pleural effusion, which is frequently their first manifestation (Fig. 30 on page 39).

On CXR, usually only pleural effusion is observed, sometimes loculated and unilateral, hiding the presence of metastases. In some cases, pleural metastases may be unassociated with effusion and visible as rounded or lenticular pleural masses (Fig. 31 on page 40).

CT is much more sensitive to detect pleural metastases, even in the presence of pleural effusion. On CT, metastasis usually appears as localized pleural masses, with nodular or lenticular shape and contrast enhancement. As the disease progresses, metastasis can manifest as a nodular pleural thickening. CT also allows identifying lung and mediastinal disease findings, such as pulmonary nodules or mediastinal lymphadenopathy that corroborate the diagnosis of pleural metastasis.
Malignant mesothelioma

Mesothelioma is a primary pleural malignant tumor arising from the mesothelial cells of the pleura (usually parietal pleura). It has an extremely poor prognosis (median survival < 12 months) and is usually related to asbestos exposure, with a latency period of 20 to 40 years after exposure. Other factors associated with mesothelioma are chronic pleural inflammation, radiation therapy, genetic predisposition, organic fibers and mineral fibers other than asbestos. Mesothelioma spreads most commonly by local infiltration of the pleura. Hemorrhagic pleural effusions, chest wall invasion and distant hematogenous metastases may occur.

The most common mesothelioma finding on chest radiographs is unilateral, concentric, plaque-like, or nodular pleural thickening. The tumor frequently extends into the fissures, which become thickened and irregular. Mesothelioma can rigidly encase the lung, causing compression of lung parenchyma, diaphragm elevation, intercostal space narrowing, and mediastinal shift toward the tumor. Calcified pleural plaques are present in 20% of patients with mesothelioma and are usually related to previous asbestos exposure. Pleural effusions are common and may obscure the presence of the underlying pleural thickening.

CT scan findings are similar to those of plain films but better visualized and in more detail (Fig. 32). Pleural thickening and effusion can be distinguished with CT scanning, especially after contrast administration (Fig. 33 on page 42). Pleural thickening is usually nodular or irregular, although a new pleural effusion may be the only recognizable finding. Mesothelioma is visible most frequently along the lateral chest wall; mediastinal pleural thickening or concentric pleural thickening is seen with extensive disease. Pleural plaques and calcification are well identified with CT scan.

On MRI, mesothelioma presents with minimally increased T1 signal relative to the chest wall musculature and moderately increased signals on T2-weighted images or T1-weighted images obtained after injection of gadolinium. MRI can be superior to CT in revealing two types of tumor invasion (invasion of the diaphragm and invasion of the endothoracic fascia) or a single chest wall tumoral focus (Fig. 34 on page 43 and Fig. 35 on page 44). This can be useful in selected patients candidates for surgical resection. MRI may also be important to assess patients with contra-indications to the use of iodinated intravenous contrast administration. Fibrous pleural plaques are usually isointense or less intense relative to muscle, and inflammatory pleural disease may mimic the increased MRI signal intensity of mesothelioma.

Pleural lymphoma

Lymphomas rarely affect the pleura and they are generally associated with other sites of diseases, especially mediastinal adenopathy and/or parenchymal infiltrates. Pleural lymphoma, particularly Hodgkin's disease, may present with pleural effusions due to
mediastinal lymphatic obstruction and direct pleural infiltration. Pleural and extrapleural soft tissues thickening may or may not be present. (Fig. 36 on page 45)
Table 1: Principal causes of pleural effusions.

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Fig. 9: a) Chest radiograph shows a homogeneous opacity that occupies the inferior part of the left chest, with costophrenic angle blunting (small arrow) and meniscus sign (large arrow). b) non-enhanced CT scan reveals a moderate dependent pleural effusion posterior to the lower left lobe (black arrow) with passive lobar collapse (white arrow). It's possible to see ascites in the left side (*).
Fig. 10: 51-year-old woman with bilateral ovarian tumor and dyspnea. a) Chest radiograph shows a complete opacification of the right hemithorax. b) CT scan revealed a large pleural effusion with right lung collapse and leftward displacement of the mediastinum and airways (arrow).
**Fig. 11:** Subpulmonic effusion. a) Chest radiograph in erect position showing an apparent elevation of the right hemidiaphragm with a peak more lateral than usually. The lung vessels are not visible through the hemidiaphragm. This is a typical aspect of a subpulmonic effusion and a scheme is also reported (b).

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**Fig. 12:** Loculated effusion. a) Chest radiograph shows a peripheral opacity with well-defined borders and obtuse angles with the chest wall (arrow). b) Non-enhanced CT scan revealed a right posterolateral heterogeneous pleural thickening, with low attenuation...
(arrow). Finally, US (c) confirmed the presence of an hypoechoic pleural fluid (*) with thin septations (arrow).

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**Fig. 13:** Chest US. a) Pure hypoechoic pleural effusion (small arrow). b) Complex echogenic pleural effusion (*) with thickened pleura (small arrow), representing an empyema.

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**Fig. 14:** Bilateral pleural effusion and ascites. On axial CT (a and b) some findings can help to differentiate the pleural fluid from ascites, particularly in the right side: pleural fluid displaces the diaphragmatic crus antero-medially, the displaced crus sign; the interface between the pleural fluid and spleen and liver is hazy, the interface sign (small arrows); pleural fluid is present along the entire posterior costophrenic recess behind the liver, the bare area sign (black arrow); where the diaphragm is identified (head of arrow), fluid inside the dome (white x) is ascites and fluid outside the dome (black x) is pleural. Note the presence of atelectasic lung (ª) within the fluid as a curvilinear hyperdense tongue which can sometimes be difficult to distinguish from the diaphragm. c) Coronal and d) Sagittal reformatations contribute to differentiate ascites (white x), diaphragm (black arrow), pleural fluid (white arrow) and atelectasic lung (*).

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**Fig. 15:** Loculated pleural fluid collection. a) PA chest radiograph shows blunting of the right costophrenic angle (small arrow) and an ill defined superior opacity (large arrow), associated with homolateral displacement of the mediastinum and airways (black arrow). b) Contrast-enhanced CT performed two days later shows multiple lenticular fluid collections (small white arrows), with some in nondependent position, a finding of loculation. It is possible to observe collapse of right lung (large white arrow), right pleural thickening (small black arrows) and left pleural effusion in a dependent position (*). © Radiology, Portuguese Institute of Oncology - Lisbon/PT

**Fig. 16:** Simple parapneumonic effusion. a) Chest radiograph shows costophrenic angle blunting (arrow) due to right pleural effusion. b) CT scan reveals a dependent and crescent-shaped right pleural effusion (arrow). Bilateral pneumonia is present (*).
Fig. 17: 85-year-old man with lung adenocarcinoma submitted to right superior lobectomy. Chest radiograph (a) shows a lenticular opacity (small arrow) in the right lower lobe. Contrast-enhanced CT (b) reveals a loculated, lenticular fluid collection (*) at the right base, associated with thickness of both the parietal (large arrow) and visceral (small arrow) pleural layers, the so called split-pleura sign. The thickened pleura enhances following contrast infusion.
Fig. 18: 59-year-old woman with history of right breast carcinoma and bone, liver and pulmonary metastases. a) Chest radiograph shows a large right pleural effusion. b) Non-enhanced CT scan reveals a heterogeneous attenuation of pleural fluid, with hyperattenuation areas of debris within pleural fluid (small arrows) suggesting blood clots. The effusion is associated with a circumferential pleural thickening (large arrows), suggesting malignancy. c) enhanced-CT from a 22-year-old man with a right hemothorax after penetrating trauma with a knife. Pleural effusion has high attenuation values and its possible to see some subcutaneous emphysema in right anterior chest wall (arrows).

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Fig. 19: 53-year old man with multiple myeloma and cetrilobular emphysema. a) Chest radiograph shows a bilateral heterogeneous lung, with a left pneumothorax (small arrow). b) Coronal and c) axial CT scan reveal a bilateral pneumothorax in contiguity by the retrosternal space, with greater expression on the left side (small arrows). There is communication of pneumothorax with mild pneumediastinum (large arrow) and subcutaneous emphysema (black arrow). Centrilobular and paraseptal emphysema are present as well as a diffuse ground-glass opacity.

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Fig. 20: 59-years-old woman with history of uterine sarcoma and thoracic metastases, submitted to left upper lobectomy and posterior excision of the 2nd, 3rd and 4th left costal arches with prosthetic reconstruction of the chest wall. a) erect PA chest radiograph shows a radiolucent nodular area in the left hemithorax (arrow). b) CT scan reveals an communicating air collection in the chest wall, localized in front and behind (arrows) of the prosthetic material, and also a small loculated pneumothorax (*).
**Fig. 21:** Pneumothorax after CT-guided biopsy which evolved to tension pneumothorax. 
a) CT scan performed after a CT-guided biopsy of a pulmonary lesion, shows an anterior left pneumothorax (small arrow). b) Chest radiograph performed one day after, reveals a larger pneumothorax (large arrow) with shift of the mediastinum to the opposite side (black arrow) and downward displacement of the ipsilateral hemidiaphragm (small arrow), suggesting a tension pneumothorax.
**Fig. 22:** a) Pleural apical thickening (arrows) in a 80-year-old men. b) CT scan from a different patient shows left pleural thickening located on antero-lateral region (arrow), stable for at least four years.

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**Fig. 23:** Fibrothorax. a) Chest radiograph and b) CT scan shows reduction in volume of the left hemithorax with ipsilateral displacement of the mediastinum and airways. The left pleura is diffusely thickened and calcified (small arrow). CT scan also allows to see that the extrapleural fat is also thickened (large arrow).

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**Fig. 24:** Pleural plaques related to asbestos exposure. a) CT scan shows bilateral pleural plaques, localized on paravertebral (small arrows) and posterolateral regions (large arrow) of the lower half of hemithoraces. b) Chest radiograph and c) CT scan from a different patient showing bilateral calcified pleural plaques, especially over the diaphragm (arrows).
Fig. 25: a) Pleural masses arise between visceral and parietal pleura, showing different diameters and obtuse angles with the chest wall; the interface between the mass and the lung parenchyma is usually smooth and regular. b) When the pleural mass increases greatly, the inferior angle with the chest wall generally becomes more acute. c) Extrapleural lesions usually have similar diameters and the interface with the lung parenchyma is smooth and regular. d) Peripheral pulmonary lesions involving the pleura tend to form acute angles with the chest wall, but if they have a «plaque» morphology may mimic a pleural lesion; pulmonary lesions tend to show irregular margins.

**Fig. 26:** a) Peripheral left opacification with different diameters, obtuse angles with the chest wall and a smooth and regular interface with the lung parenchyma (arrow). b) CT scan confirmed that was pleural masse with low attenuation values, suggesting a pleural lipoma (arrow).

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**Fig. 27:** a) Right peripheral opacification with similar diameters and slightly irregular interface with the lung parenchyma (arrow). a) CT scan confirmed an extrapleural mass (arrows) and CT-guided biopsy revealed extramedullary plasmacytoma.

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Fig. 28: a) Nodular opacification in the upper right lobe with acute angles with the chest wall and irregular margins (arrow). f) CT scan confirmed a pulmonary lesion involving the pleura (arrow) and CT-guided biopsy revealed lung adenocarcinoma.

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Fig. 29: 51-years-old man with history of pleural fibrous tumor excised. a) chest radiograph shows one right lenticular opacity, with slightly irregular margins and obtuse angles with the right cardiac shadow (arrow). b) chest lateral radiograph shows at least two lenticular opacities, one anterior to the cardiac shadow (large arrow) and another superiorly, in paravertebral region (small arrow). It is possible to see an elevation of the right hemidiaphragma and blunting of the costophrenic angle. c) and d) enhanced CT scan confirmed a right precardiac pleural lesion (large arrow), slightly heterogeneous and well vascularized; and a similar lesion in the right paravertebral region (small arrow). CT also revealed two more lesions, one in the right para-hilar region (partially visualized in c) - small arrow) and another in the right costophrenic recess (not visualized).

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Fig. 30: 59-year-old woman with pulmonary adenocarcinoma in the left upper lobe. a) Chest radiograph shows complete opacification of the left hemithorax (small arrow) with opposite displacement of the mediastinum and airways (large arrow) b) CT scan revealed a left pleural effusion, with collapse of the left lung and nodular thickening of the pleura (small arrow), that enhances with contrast, suggesting pleural metastases. In right lung is possibly to see a small dependent pleural effusion with irregular thickening of the pleura (large arrow), also suspicious.

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**Fig. 31:** 56-years-old woman with history of breast carcinoma with pulmonary and bone metastases, submitted to left mastectomy and left upper lobectomy. 

a) Chest radiograph shows an peripheral irregular thickening of both lungs (arrows). 
b) non-enhanced CT scan confirmed the presence of irregular thickening of the pleura (arrows). 

Sagittal c) and axial d) CT scan in pulmonary-window show the presence of small nodules along the oblique (small arrows) and horizontal (large arrow) fissures. The nodules were confirmed to be metastases and were not associated with pleural effusion.

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**Fig. 32:** 72-years-old woman with left-sided chest pain. Antero-posterior (a) and lateral (b) chest radiographs show lobulated and thickened left lateral pleura (small arrows) and a mass posterior to the left cardiac shadow (large arrow). CT scans (c and d) reveal circumferential nodular thickening of the left pleura (small arrows) and a soft-tissue mass in the left paravertebral region. CT-guided biopsy confirmed malignant mesothelioma (large arrow).

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Fig. 33: a) Chest AP radiograph shows lobulated and thickened right lateral and mediastinal pleura (small arrows), and blunting of the right lateral costophrenic angle (large arrow). b) Lateral radiograph shows the horizontal and oblique fissures thickened (black arrows). Axial non-enhanced CT scan (c and d) confirms a circumferential nodular thickening of the right pleura (small arrows) and a small malignant pleural effusion in the right costodiaphragmatic recess (*). Pleural biopsy proved that was a mesothelioma.

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**Fig. 34:** MRI from the same patient as Fig. 35. a) Axial T1-weighted MR image shows circumferential pleural thickness with slightly hypointense signal, evolving the lateral portions of pleura, mediastinal pleura and extension to the oblique fissure (arrows). b) Axial T2-weighted MR image shows few amount of pleural effusion with hyperintense signal (small arrow) between the moderate hyperintense signal of pleural thickness (large arrow). c) Coronal T2-weighted MR image shows pleural effusion in the horizontal and oblique fissures (small arrows), and diaphragmatic pleural space. The diaphragmatic dome is well defined (large arrow) and no invasion is documented.

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Fig. 35: Malignant pleural mesothelioma. a) CT scan shows a right pleural effusion (*) and irregular pleural thickness (black arrows) predicting a malignant effusion. c) In a inferior plan, CT image reveals a pleural mass (small arrows) in the right posterior costodiaphragmatic recess. On MRI, the mass (arrows) is isointense/slightly hyperintense relative to the chest wall musculature in T1-weighted images (c), and moderately hyperintense in T2-weighted images (d). MR images showed extension to the chest wall and invasion of the diaphragm. e) Sagittal T2-weighted and coronal T1-weighted images contributed to characterize the lesion (arrows) and access the relationship with adjacent structures.

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Fig. 36: 78-years-old man with left fibrothorax. Axial (a) and (b) Sagittal non-enhanced CT scans show a left paravertebral soft-tissue mass (large arrow) posterior to a pleural plaque (small arrow) and without cleavage plane with the intercostals muscles. The lesion has a central iso / hypointense area (white arrow) and a peripheral moderate hyperintense signal on T1-weighted MR image (black arrow) (c) and a central hyperintense area (edema/necrosis?) with a peripheral moderate hyperintense signal on T2-weighted MR image (black arrow). There is a fascia (head of arrow) separating the mass from the longissimus thoracic muscle (*). Calcified pleural plaques appears hypointense on both T1 and T2-weighted MR images (large arrows). e) Sagittal T1-weighted allows a better characterization of the relationship with adjacent structures. f) Whole body PET-CT study confirmed the intense 18F-FDG uptake by the mass (arrow). CT-guided biopsy revealed a pleural lymphoma.

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Fig. 4: Lateral decubitus radiograph showing a small pleural effusion (small arrow).

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**Fig. 5:** Lateral decubitus radiograph showing a small pleural effusion (small arrow).

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Conclusion

Imaging plays a key role in the identification and characterization of pleural diseases.

CXR remains the initial examination performed in the assessment of pleural diseases and the commonest in following patients over time. However it is nonspecific and further imaging techniques are often required. CT is extremely sensitive in the assessment of pleural thickening or nodularity, whereas US usually provides better evaluation of pleural fluid. CT and US are also important for intervention procedures. MRI has specific roles in the management of problematic cases, mostly involving malignant disease.

The correct interpretation of pleural anatomy and the imaging findings associated with pleural diseases contributes to a more prompt diagnosis, which potentially allows a better treatment.
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