The diaphragm: Imaging of the anatomy and pathology

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Learning objectives

Reviewing the anatomic characteristics of the diaphragm and analyzing the different diseases that affect it.

Showing the different image techniques which are useful for the correct assessment of the diaphragmatic pathology and the instructions of each of them.

Background

The diaphragm is the main muscle involved in breathing.

For a long time the diaphragm has been a difficult structure to visualize and underdiagnosed condition in many occasions. Today, thanks to new imaging techniques, especially Multislice CT, with its ability to make fine cuts and the possibility of multiplanar reconstructions and MRI, we can recognize and properly evaluate. Plain radiography remains the imaging modality of onset and ultrasound has many uses.

Findings and procedure details

I.-Anatomical Recall: Fig. 1 on page 6

The diaphragm is the main muscle involved in ventilation. This muscle is formed by the aponeurotic or sinewy middle part which is called "phrenic center", shaped like a three-leaf clover; a front part, rear-right one where the hiatus for the cava vein can be found, and a smaller back-left part. Around the phrenic center there's the "muscular or peripheral portion" which is inserted in multiple points in the ribcage: it inserts in the front part in the xiphosternum, the lateral edges are inserted in the last six ribs and at the back it weaves together with the quadratus lumborum and iliopsoas muscles forming the "Pillars" or "Crura" of the diaphragm which go on the right side to the L3 vertebra and on the left to the L2. They intertwine forming an "8-shape" creating the esophageal hiatus and aortic hiatus. The thickening of the anterior fascia of the quadratus lumborum and iliopsoas muscles make up the lateral and medial "arcuate ligaments". Fig. 2 on page 7
The hypertrophy or low set of the arcuate ligament may produce a compression of the celiac trunk that can cause epigastric pain and weight loss (median arcuate ligament syndrome). Fig. 3 on page 8

The diaphragm is innervated by the phrenic nerves, which provide it with mobility and sensitivity. They originate in the 3rd-6th cervical root and descend through the mediastinum to reach the diaphragm where they branch at the top and bottom faces. Fig. 4 on page 9

II.-Imaging techniques:

For a long time the diaphragm has been a difficult structure to visualize and thus its pathology has often been under-diagnosed.

Simple radiography: this technique is still the first image technique used. It is displayed as two upwardly convex curved lines separated by the cardiac silhouette. When inspiring, the top part of the right diaphragmatic cupola meets the front end of the 6th rib. The left hemidiaphragm is 1.5 or 2.5 cm lower than the right one in the 90% of the normal subjects, due to the weight of the heart. Fig. 5 on page 10

Ultrasound scan: it has the advantage of portability as well as the lack of radiation, reasons why it is often considered the preferred technique for children and young adults. It is identified as a hyperechogenic line. The mobility of both diaphragms can be assessed in real time and quantified by ultrasound in the "M mode". Fig. 6 on page 11

Nowadays thanks to new imaging techniques, especially to multi-slice CT (MSCT) with its ability to make fine cuts and the possibility of multiplanar reconstructions, it is easy to recognize and assess. The lateral arcuate ligament may be visible with this technique and must not be confused with lymphadenopathies or pleural mass. Fig. 7 on page 12

Magnetic Resonance (MR), as well as the MDCT, is a multiplanar technique and provides an excellent resolution of soft tissues. It does not use ionizing radiation. It has the disadvantage of respiratory movements and elevated cost. With the MRI, the diaphragm is displayed as a thin sheet of muscle that separates the thoracic and abdominal cavities. It has low signal intensity relative to that of other skeletal muscles in all MRI sequences. Fig. 8 on page 13

III.-Diaphragm Function:

The main function of the diaphragm is respiration. When the diaphragm contracts, the chest cavity expands and the air enters the lungs. When the diaphragm is relaxed, lungs contract and the air is expelled. Fig. 9 on page 14
IV.- Diaphragm Pathology:

Pathologic entities that can affect the diaphragm, both congenital and acquired, are classified into: **Fig. 10 on page 15**

1- Function disorders:

It is an underdiagnosed cause of dyspnea and should always be considered in the differential diagnosis of unexplained dyspnea **Fig. 11 on page 16**

Diaphragmatic dysfunction ranges from a partial loss of the ability to generate pressure, "Weakness" until reaching the complete loss of the diaphragm function, "Paralysis". The diaphragmatic weakness or paralysis may affect one or both hemidiaphragms. **Fig. 12 on page 17** - **Fig. 13 on page 18**

The diaphragm pathology normally appears in relation to metabolic or inflammatory disorders, after trauma or surgery, during mechanical ventilation, with mediastinal tumors, myopathies, neuropathies or diseases that cause lung hyperinflation.

The "eventration" is a congenital diaphragmatic muscle thinning causing a focal bulge. This process usually involves only one segment, being the anterior medial part of the right hemidiaphragm the most frequently affected. On the radiography we will see an elevated portion of the diaphragm, while the rest is in normal position. Occasionally a CT will be needed, and will allow us to demonstrate that the viscera is fully covered by diaphragm, thus differentiating from a diaphragmatic hernia. **Fig. 14 on page 19**

The diaphragmatic elevation can also be caused by other conditions, including normal expiration. Any process that increases intra-abdominal pressure (abdominal obesity, ascites…) can cause an elevation of the diaphragm. Conversely, the conditions that cause loss of lung volume can retract the diaphragm causing the elevation (atelectasis, pulmonary fibrosis, pulmonary resection…) **Fig. 15 on page 20**

2- Anatomical disorders. Principally hernias:

Hernias are due to the migration of abdominal viscera into the thorax through a defect in the diaphragm. They may be congenital (Morgagni and Bochdalek) or acquired (traumatic or hiatus). **Fig. 16 on page 21**

Morgagni hernias or retrosternal hernias are due to the passing of abdominal contents through an anterior-inferior congenital defect of the diaphragm (Larrey space). The hernia is covered by pleura and peritoneum. They are usually in the right hemidiafragm and
are displayed as a paracardiac mass. They most frequently affect women over 50, overweight, ascites, pregnancy... **Fig. 17 on page 22**

**Bochdalek hernias** and posterior diaphragmatic defects: They constitute the 90% of congenital hernias. They are due to a defect in the fusion of the pleuro-peritoneal membranes of the posterolateral region of the diaphragm. The 80% are located on the left side since the right side is protected by the liver. They are usually diagnosed in newborns. The presence of a large defect is associated with a high mortality rate, secondary to respiratory failure and pulmonary hypoplasia. When they are small, most are asymptomatic displayed as an incidental finding **Fig. 18 on page 23 - Fig. 19 on page 24**

**Congenital diaphragmatic defect:** Anatomical defect that causes partial or complete absence of the diaphragm. **Fig. 20 on page 25**

**Hiatal hernias:** They are due to prolapse of the proximal stomach into the thorax through the esophageal hiatus. **Fig. 21 on page 26**

On Chest’s radiographs it appears as a retro cardiac mass sometimes with hydro- air level inside. **Fig. 22 on page 27**

They are classified as: **Fig. 23 on page 28** (a-b-c)

- Type I or sliding hernia: Superior displacement of the esophago-gastric junction into the mediastinum.

- Type II or paraesophageal hernia: Superior displacement of the fundus of the stomach, anterior and lateral to the esophagus, with the esophagogastric junction located in its normal intra-abdominal position.

- Type III or mixed: it combines the two above mentioned and presents a large hernia sac and a large hiatus dilatation, usually involves one third more of stomach.

**Traumatic hernias:** Though this may be due to a penetrating injury, the most common cause is a closed thoracoabdominal trauma, especially as a result of a car accident. The left hemidiaphragm is compromised more frequently. These lesions are usually associated with other thoracic, abdominal and pelvic injuries. The diagnosis of diaphragmatic rupture can be delayed for months or even years.

The chest radiograph findings may be nonspecific (14-40%) and include: abnormal tract, elevated diaphragm and / or irregular, presence of abdominal viscera in the chest, persistent basal opacity, associated injuries (rib fractures, stroke...) **Fig. 24 on page 29**
By MSCT we can demonstrate a direct sign of failure visualizing a discontinuity in it, besides the presence of visceral or abdominal fat in the chest, constriction of the stomach or intestine at the herniation "ring sign", also the sign of the "decline viscera" when the herniated viscera is in contact with the lower ribs. **Fig. 25 on page 30**

3- Infectious Pathology:

The diaphragm may be affected by a lung, pleural or abdominal infection. **Fig. 26 on page 31**

4-Tumor Pathology:

"Primary" tumors in the diaphragm are rare. The lipoma **Fig. 27 on page 32**, fibroma **Fig. 28 on page 33**, neurofibroma and cysts are rare, particularly the fibrosarcoma, which is malignant.

It is almost always a "secondary" affection, usually due to direct extension of thoracic tumors (bronchogenic or mesothelioma) or tumors of the upper abdomen (stomach, pancreas, liver, etc.). **Fig. 29 on page 34**

Images for this section:
The diaphragm is the muscle-tendinous physical barrier that separates the thorax from the abdomen.

- It is dome-shaped with the convexity towards the thorax.
- Its upper face is covered by the lower pleura and the inner face by peritoneum.
- The diaphragm is the main muscle involved in ventilation.
- It is divided into right and left portions with different innervations each part.
Fig. 2: Scheme (Anatomy and Function. RadioGraphics 2012) showing the diaphragm’s anatomy and the different locations of the normal diaphragmatic hiatuses and inserts.
Median Arcuate Ligament Syndrome

Abdominal pain due to compression of the proximal celiac artery by a low-lying and hypertrophied median arcuate ligament.

Fig. 3: Median Arcuate Ligament Syndrome: a) sagittal CT and b) Three-dimensional VR images show significant stenosis of the proximal celiac artery (arrow) caused by the median arcuate ligament since don’t exist atherosclerotic changes in the proximal celiac artery. c) coronal MIP image shows collateral vessel
Fig. 4: Course of the phrenic nerves: a) Drawing shows both phrenic nerves, which travel through the mediastinum to reach the diaphragm, where are ramified on the superior and inferior surfaces. Axial CT images showing the course of phrenic nerve. b) The right phrenic descends immediately lateral to the superior vena cava. c) The left phrenic passes in front of the aortic arch and main pulmonary artery (d-e) show the phrenic nerves dividing on the surface of the diaphragm (yellow arrows)
Fig. 5: Chest x-ray with normal appearance of the diaphragm in inspiration

- It is displayed as two upper convexity curved lines separated by the cardiac silhouette.
- In inspiration the top of the right diaphragmatic dome coincides with the anterior end of the 6th rib.
- The left hemidiaphragm is usually 1.5 or 2.5 cm lower than the right due to heart’s weight.
Fig. 6: a) MDCT axial images showing multiple attachments to anterior ribs (red arrow) and the medial and lateral arcuates ligaments (yellow arrow). This normal structure may be mistaken with lymphadenopathy or metastatic implants. b) Coronal reconstruction showing how diaphragm descends towards the periphery forming a dome. Note the diaphragmatic pillars (blue arrows). c) Sagittal midplane reconstruction adopting a curved shape, from the xiphoid to its insertion into the middle ligament Arcuato.
Fig. 7: Evaluation of diaphragmatic movement with M-mode US: US image of the right and left hemidiaphragm and M-mode showing normal diaphragmatic movement. During inspiration, the diaphragm moves toward the transducer; during expiration, it moves away from the transducer. The excursion is measured as the distance between inspiration and the end of expiration and is 2.5 cm in normal situations.
Fig. 8: MR coronal images show the normal appearance of the diaphragm. It has low signal intensity relative to that of other skeletal muscles with all MR imaging sequences.
Fig. 9: Same patient. Normal diaphragm movement during breathing seen in frontal chest-ray. a) inspiration. b) expiration.
Fig. 10

Diaphragmatic pathology.

- **Diaphragmatic disfunction:** Paralysis, relaxation and eventration.
- **Anatomical disorders:** Fundamentally hernias: congenital (Morgagni and Bochdalek) or acquired (traumatic or hiatus).
- **Infection:** pulmonary, pleural or abdominal pathology affecting the diaphragm.
- **Neoplastic disease:** primary and metastatic
Dysfunction of diaphragm

- **Uni or bilateral**
- **Temporary or permanent**

**Symptoms**
- Dyspnea, Orthopnea (Variable)

**Causes**
- Metabolic/inflammatory disorders.
- Myopathy / neuropathy.
- Post surgery or trauma.
- Mediastinal tumors.

**Paralysis:** (complete loss of mobility)
**Weakness:** (decreased ability to produce pressure)
**Eventration:** (only a portion of a hemidiaphragm.)
**Fig. 12:** Unilateral paralysis of diaphragm: a): P-A radiograph shows elevation of the left hemidiaphragm caused by invasion of the phrenic nerve by mediastinal mass. b): P-A radiographs showing elevation of the left hemidiaphragm due to cardiac surgery c): Cervical axial CT, Posteroanterior radiograph and Coronal CT images showing elevation of the right hemidiaphragm, a finding that reflects phrenic nerve dysfunction after laryngeal surgery.
Fig. 13: Bilateral paralysis of diaphragm: a): Patient with total thyroidectomy: Coronal CT images reconstruction showed elevation of both diaphragms and combined US image (including gray-scale images and M-mode Ultrasound diaphragm) demonstrating bilateral diaphragmatic paralysis b): Bilateral atrophy in patient with amyotrophic lateral sclerosis (ALS). Coronal and axial CT whit decreased thickness (arrows) is displayed. Findings more easily demonstrated on the left side.
Fig. 14: a) Posteroanterior and lateral radiographs show focal anterior elevation of the right hemidiaphragm (arrows) while the remaining portion has normal height (b) Coronal and sagittal CT images show focal elevation with continuous diaphragm.
Fig. 15: Diaphragmatic elevation can also be caused by other conditions
Fig. 16: Scheme of diaphragm (Anatomy and Function. RadioGraphics 2012) showing the locations of diaphragmatic hernias.
Fig. 17: Morgagni hernia: a): Frontal radiograph of the chest shows an apparent paracardiac mass. b): coronal, sagittal and axial demonstrating anterior herniation of omental fat in a patient with several ascites.
Fig. 18: a): Lateral chest’s radiographs shows the right posterior diaphragmatic defect that simulates a mass. b) : Sagittal and coronal CT reconstruction marked by arrows, clearly showing that it is a small step Bochdalek hernia with abdominal fat into the chest cavi
**Fig. 19:** Bochdalek hernia. Newborn with severe respiratory distress. a) Frontal radiograph of the chest shows elevation of the left hemidiaphragm with displacement of the heart to the right. b) coronal, c) sagittal and d) axial CT images, show herniation of colon, bowel loops and spleen into the left hemithorax. e) volumetric reconstruction showing displacement of the left lung secondary to the passage of abdominal organs.
**Fig. 20:** Congenital defect of diaphragm: Large diaphragmatic hernia caused by congenital defect of the lateral part of the left hemidiaphragm persisting in the medial part. 

a) Frontal and sagittal radiograph of the chest, show an appearance that was initially interpreted as elevation of the left diaphragm. b): axial CT image revealed the edge of the left hemidiaphragm (red arrows). c): coronal and sagittal CT images, show herniation of stomach, bowel loops, colon, spleen and left kidney into the left hemithorax.
Hiatal hernia

Prolapse of the upper part of the stomach into the thorax through the esophageal hiatus of the diaphragm.

- **Type I or sliding hernia**: characterized by an upward herniation of the cardia and GE junction in the posterior mediastinum. The most common one.

- **Type II or paraesophageal hernia**: characterized by an upward herniation of the gastric fundus alongside a normally positioned cardia. GE is in normal place.

- **Type III or mixed hernia**: characterized by an upward herniation of both the cardia and the gastric fundus. It has a large hernia sac and a significant hiatal dilatation. Usually ascends one third or more of the stomach.
Fig. 22: Frontal and lateral chest’s X-ray show a retro-cardiac mass with hydro-air level inside, suggestive of hiatal hernia.
**Fig. 23:** a) A displacement of the gastroesophageal junction with a small sliding hernia. b) Axial and coronal images displaying a small paraesophagic hernia. c) Coronal and sagittal CT images show an important anterior sliding of the stomach towards thoracic cavity through an esophageal hiatus. The most serious complication is gastric volvulus.
Fig. 24: Posteroanterior and lateral radiographs showing elevation and irregularities of the left diaphragm in patient with abdominal pain and dyspnea. Background traffic accident a few months earlier.
Fig. 25: Traumatic hernia: CT scans demonstrating discontinuity of left diaphragm and the passage of omental fat and abdominal visceras.

- Discontinuity of diaphragm.
- Presence of visceral or abdominal fat in the chest.
- Constriction of the stomach or intestine at the herniation “collar sign”.
- Sign of the “decline viscera”.

**Fig. 25**

**Traumatic Hernias**

**TC findings**

- Discontinuity of diaphragm.
- Presence of visceral or abdominal fat in the chest.
- Constriction of the stomach or intestine at the herniation “collar sign”.
- Sign of the “decline viscera”.
Fig. 26: a) coronal and pleural empyema with involvement of the diaphragmatic crura (arrow) b): axial TC images showing the migration of hydatidic cyst through the diaphragm towards the lung
Fig. 27: Axial and coronal CT. Little lipoma in right diaphragmatic crura seen on TC.

**Diaphragmatic tumors**

**Primary tumors** of the diaphragm are rare

**Secondary tumors** involvement is more frequent, usually by direct extension of thoracic tumors (lung or mesothelioma) or tumors of the upper abdomen (stomach, pancreas, liver, etc.)
Fig. 28: Diaphragmatic fibroma in patient with Lymphangioleiomyomatosis (LAM). a): Thorax x-Rays: left pneumothorax (red arrow) and mass located in right pulmonary base (blue arrow). b): coronal TCMC, pulmonary window, showing lung cysts. c): Abdominal CT coronal reconstruction showing several uterine masses. d-e): MSCT mediastinal window sagittal and coronal showing a diaphragmatic mass. f): Dual coronal MRI at the lesion level.
Fig. 29: Diaphragmatic affection for neoplastic disease a) PET-TAC image shows malignant mesothelioma invading the left hemidiaphragm. b) Coronal and axial TC images of ovarian carcinoma extending above diaphragm. c) Axial and coronal TC images of suprarrenal carcinoma infiltrating the right hemidiaphragm d) Axial TC image of adenocarcinoma pulmonary with diaphragmatic extension
Conclusion

A correct and a systematic assessment of the diaphragm is necessary by the radiologist, as well as the knowledge of their different pathology and appropriate imaging techniques indications in each case. **Fig. 30 on page 36**

Images for this section:
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