Chest radiographs in the critically ill: A radiologic pictorial review.

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Learning objectives

-To outline normal chest radiographic appearances in the intensive care unit (ICU) patient.
-To describe the normal position of monitoring devices and other line placements, and prompt recognition when they are misplaced or when other complications occur.
-To review the radiographic findings of common cardiopulmonary disorders of ICU patients.

Background

1. Normal chest radiographic appearances in the ICU patient, correct and incorrect placement of various intrathoracic tubes and lines, and complications from instrumentation.

2. Radiography of lung pathologies common in the ICU patient: Pulmonary Edema, Adult Respiratory Distress Syndrome, Pneumonia in the ICU, Aspiration and Pulmonary Embolism.

Imaging findings OR Procedure details

X-ray in ICU patients

Portable chest radiography is routinely performed in the intensive care unit as a complement to the physical examination. It is available and inexpensive but has technical and diagnostic limitations. The quality of the portable radiograph can be highly variable owing to differences in film exposure and scattered radiation.

The indications for the chest radiograph can be divided into 2 groups, the routine evaluations and nonroutine study, for assessment following a change in clinical status or following a change in support devices.

- The anteroposterior (AP) radiograph replaces the standard posteroanterior (PA) in the ICU patient.

- Instrumentation, mechanical ventilation, cardiac, and other vital sign monitoring and feeding tubes, detract from other findings on the ICU chest radiograph.
X-ray's ICU patient characteristics: fig.1 on page 12

- Chest radiograph ideally obtained in the AP projection with a patient-to-x-ray plate distance of 182 cm with the patient in the upright position at maximum inspiration. More often a distance of 100 cm is used in the supine or sitting position due to the impaired mobility of ICU patients.

- Mediastinum and heart magnified due to gravitational and geometrical effects.

- Alteration of the physiology of the pulmonary vasculature due to supine position, diverting the blood to lung apices.

- Problems of supine radiographs: in differentiating pleural effusions from air space shadowing, in detecting pneumothorax.

- Incomplete inspiration produces artifacts making the diagnosis of basilar atelectasis and pulmonary edema difficult. The films should always be taken at full inspiration or at the peak of the inspiratory cycle in patients receiving mechanical ventilation.

- 65% of ICU chest radiographs reveal significant pathology that results in a change in patient management.

- Current recommendations from the American College of Radiology:

  - Suggest that daily chest radiographs be obtained on patients with acute cardiopulmonary problems and those receiving mechanical ventilation.

  - Only an initial chest radiograph is needed for the placement or change of indwelling devices.

Critically ill patients admitted to the intensive care unit are at risk for developing different disorders at the chest level. They require continuous monitoring of life functions and their support through external mechanical and pharmacological devices.

LINES AND TUBES AND OTHER DEVICES fig.2 on page 13

Tubes, lines and drainage catheters play an important role in monitoring and treating critically ill patients. Accurate placement of these devices and monitoring malfunction are crucial.

The initial portable chest radiograph plays an essential role in recognizing correct placement and complications.
Endotracheal tube fig.3 on page 14

Endotracheal tube (Ets) maintain airway access and allow mechanical ventilation of patients with respiratory failure. After the insertion, a low-pressure balloon situated close to the distal end is inflated so as to keep the tube in its final position; the balloon should not be inflated beyond the diameter of the trachea (not be greater than 2.5 cm).

- **Correct position:** Safe level 5 cm from carina (T4-T5 interspace), minimum distance 2 cm. The tube can move as much as 4 cm in association with flexion-extension movements of the patient’s neck.

- **Misplaced ETs** has been reported in 10% of the patients.

- Distal position: the tube enters the right main stem bronchus (even the intermediate), due to its more vertical orientation.

- Proximal placement: Damage to the laryngeal structures, more risk of accidental extubation. Esophageal placement: gastric air distension with potential danger of aspiration. The tube projecting laterally to the trachea with deviation of the trachea. Better recognized on a 25° left anterior oblique projection.

- Upper airway injury: lateral radiograph. Increase of soft tissue between the trachea and cervical spine.

- Sever injury such tracheal rupture: pneumothorax, pneumomediastinum, subcutaneous emphysema…

Thoracostomy tube fig.4 on page 15, fig.5 on page 16

Correct placement: thoracostomy tube fenestrations within the thoracic cavity.

- Incorrectly placed tubes for empyemas may delay drainage and result in loculation of the purulent fluid.

Nasogastric tube fig.6 on page 17

Correct placement: lower tip is generally placed in the upper small bowel (distal duodenum), which may be confirmed with an abdominal radiograph.

**Malpositioning occurs in 1%;** inadvertent tracheobronchial misplacement: presence of pleural effusion rapidly appearing, pneumomediastinum, extraesophageal tube portions, mediastinal widening or fluid level.

Catheters fig.7 on page 18, fig. 8 on page 19
Swan-Ganz (SGC)

Central venous catheter (CVC)

Swan-Ganz (SGC)

- Inserted through a subclavian or a jugular approach to right or left pulmonary artery.

- Used to measure pressures in the left atrium, pulmonary capillary wedge pressure that expresses the pressure of the left atrium.

- Catheter’s tip should project within the main pulmonary artery or the right or left pulmonary branches.

- Misplacements: more than 2 cm lateral to the Hilum. Risk of lung infarction or an arterial perforation with subsequent hemorrhage.

Central venous catheter (CVC)

- Used to monitor the patient hemodynamically, to administrate fluids and drugs and total parenteral nutrition.

- CVC have to run towards the right atrium but not to enter the atrium.

- Misplacements: when the catheter enters the right internal mammary vein: in the anteroposterior (AP) projection, the catheter could seem correctly positioned, because this vein runs almost parallel to the SVC, the ring of increased radio density indicates the end-on portion of the catheter while bending anteriorly from the innominate vein to the mammary vein. Lateral view: shows the catheter bending anteriorly towards the sternum.

- Left-sided catheter with the tip impinging perpendicularly against the right lateral wall of SVC and can damage and determine perforation.

- Inadvertent arterial puncture during the maneuvers of the insertion may be followed by neck and mediastinal hematoma. Enlarged paratracheal stripe can be seen.

- The onset days or weeks later widened mediastinum after the insertion may mean vascular thrombosis. CT is useful for diagnosis injecting contrast medium from both arms.

Cardiac pacemakers fig.9 on page 20
- **Correct placement:** the tip should appear 3 to 4 mm beneath the epicardial fat pad, lateral radiograph should show the tip imbedded within the cardiac trabeculae, a tip that appears to be placed beyond the epicardial fat stripe may have perforated the myocardium.

- The tip of the cardiac pacemaker: at the **apex of the heart**.

- Should be no sharp angulations along the length of the pacemaker wires.

- Cardiac pacers placed within the coronary sinus appear to be directed posteriorly on the lateral chest radiographs.

**Pleural drainages**

- Inserted anteriorly when they have to drain air, or posteriorly to drain fluid.

- In the presence of a pneumothorax, both inner and outer edges of the tube should be recognizable because of the presence of air either internally and externally to it, this does not happen when the tube drains an effusion, or is in contact with consolidated lung.

**PLEURAL AND PULMONARY DISORDERS**

Pleural and pulmonary disorders of the critically ill are a complex matter because many pathological conditions can superimpose and differently mix together with the effects of the mechanical ventilation and of the administration of fluids.

These conditions are: pulmonary collapse, pleural effusion, pneumonia, edema, and fluid overload pattern.

**Clinical landmark: dyspnea Radiological landmark: opacities.**

Additional TC is sometimes performed to help diagnose pathologies such as ARDS, pneumonia, pneumothorax ... and frequently reveals unsuspected pathology.

Ultrasound is used to confirm pleural and pericardial effusions.

**Pulmonary edema** fig. 10 on page 21, fig. 11 on page 22, fig. 12 on page 23

- Secondary to accumulation of fluid in the lung interstitium or alveolar space.

- Several mechanisms: increased hydrostatic gradient, increased oncotic pressure, increased capillary permeability.
- Divided into cardiac and noncardiac (oxygen therapy, transfusion reactions, fat embolism, ARDS, central nervous system disorder, aspiration).

1. **Interstitial edema**: fluid collection in the lung interstitial space and develops when the pulmonary venous pressure rises to 25-30 mmHg.

   - **Radiographic signs**: loss of definition of large pulmonary vessels, septal lines, interlobar septal thickening, diffuse reticular pattern and peribronchial cuffing interstitium.

   Septal lines represent fluid in the deep septae and lymphatics, and appear as Kerley's A lines, which range from 5-10 cm in length and extend from the hilum of the lung toward the periphery in a straight or slightly curved course. Kerley's B lines: 2 cm long, seen in the periphery of the lower lung, extending to the pleura.

2. **Alveolar pulmonary edema**: pulmonary venous pressure exceeds 30 mmHg and is usually preceded by interstitial pulmonary edema.

   **Findings**: bilateral opacities that extend in a fan shape outward from the hilum in a "batwing" pattern, increase of lung opacification, "air bronchogram" is seen and associated with congestive heart failure are usually visible in the right upper lobe. The heart is enlarged.

   **Atypical radiographic patterns**: unilateral, lobar, miliary or lower zones edema, and asymmetric distribution. Like lower zones and lobar pulmonary edema that occur in patients with chronic obstructive pulmonary disease and emphysema.

   Congestive cardiac failure causing cardiogenic pulmonary edema is usually the result of left ventricular failure, the chest radiograph is an important diagnostic tool in distinguishing fluid overload or congestive failure. In 25-40% of patients before the onset of symptoms. Ideally the best technique in this setting is a standard PA chest radiograph: detecting cardiomegaly and redistribution of pulmonary blood flow on supine AP films is difficult.

   Cardiac edema: cardiomegaly, pleural effusions, upper lobe blood diversion, septal lines, peribronchial cuffing and basal edema.

**Adult Respiratory Distress Syndrome (ARDS)**

*fig.13 on page 24, fig.14 on page 25, fig.15 on page 26, fig.16 on page 27*

Pulmonary edema occur in the absence of elevated pulmonary venous pressures.
- High mortality 50%

- **Causes**: sepsis or pulmonary infection, severe trauma, aspiration of gastric contents.

- Pathophysiology: damage to the alveolar capillary endothelium, increased vascular permeability and subsequent development of interstitial and alveolar edema.

- Presents with marked hypoxia that responds poorly even to administration of high concentrations of oxygen.

- **Pulmonary capillary wedge pressure is generally normal, but there is decreased surfactant production**, that produces noneffective ventilation. Positive end-expiratory pressure can help to decrease atelectasis.

- Prognosis: recover fully or progress to pulmonary fibrosis. Depending on age, duration.

- Stages:


  2. **Days**: late exudative. Progressive endothelial injury, necrosis of alveolar lining cells. X-ray: patchy consolidation, peripheral, progressive confluence.


  4. **Months**: fibrosis. Resolution or fibrosis. Persistence of reticular opacities and honeycombing, often anterior.

This distribution reflects the fact that patient with ARDS typically develop posterior lung atelectasis and consolidation during the exudative stage of disease. This consolidation protects the posterior lung regions from the adverse effects of mechanical ventilation, including high ventilator pressures and high oxygen tension.

- Differentation between pulmonary edema of ARDS and congestive heart failure (these conditions may coexist): ARDS is not usually associated with cardiomegaly or upper lobe blood diversion.

- Differentation between ARDS and lung contusion: lung contusion is localized to the area affected by injury and improves 48-72h. ARDS tends to be more generalized, is later in onset and slower to resolve.
Pneumonia  fig.17 on page 28

Pneumonia is a major problem in the ICU because it is a source of sepsis, particularly in mechanically ventilated patients and they are particularly susceptible.

Nosocomial pneumonias occur 3 days after hospital admission, differ from community-acquired pneumonias in both causation and prognosis.

They may be immune-compromised and several iatrogenic factors are at play: endotracheal tubes; risk of aspiration; medications used to reduce gastric acid…

- Nosocomial pneumonias are often polymicrobial: gram-negative enteric pathogens.
- Radiographic findings: difficult to differentiate from other causes of air space shadowing, including atelectasis and early ARDS. Pneumonia initially appears as patchy consolidation or ill-defined nodules. A symmetric pattern simulating pulmonary edema can occur with E-coli and pseudomonas pneumonias. Patchy air space shadowing, ill-defined segmental consolidation or air bronchograms, associated pleural effusions supports the diagnosis of pneumonia

- Complications include empyema abscess formation and bronchopleural fistulas.

Atelectasis  fig.18 on page 29

Failure of the lung to expand (inflate) completely. Caused by any process which reduces alveolar ventilation.

- Most frequently in the left lower lobe. (Due to compression of the lower lobe bronchus by the heart)

- Radiographic features of atelectasis:
  - Displacement of a fissure
  - Elevation of a hemidiaphragm
  - Crowding of the vasculature
  - Splaying of the vasculature seen in the non-affected lobe due to compensatory emphysema
  - Mediastinal shift
  - Silhouetting

-Atelectasis may also mimic pulmonary consolidation.

-Right-middle-lobe atelectasis: minimal changes on an AP supine chest radiograph. Loss of definition of the right heart border. More clearly on lateral radiograph.
- **Right-lower-lobe atelectasis**: *inferiorly triangular opacity*. Silhouetting of the right hemidiaphragm and air bronchogram. Inferior displacement of the minor fissure and the greater fissure may become visible on the AP radiograph.

- **Left upper lobe atelectasis**: the lobe moves anteriorly, with loss of the left upper cardiac border, opacification and elevation of the left hilum, near-horizontal course of the left main bronchus, posterior leftward rotation of the heart, compensatory emphysema of the left lower lobe, *(the *Luftsichel* or air crescent sign; the appearance of aerated lung abutting the arch of the aorta, between the mediastinum and the collapsed left upper lobe)*.

- **Left lower lobe atelectasis**: medially and posteriorly triangular opacity, giving the heart an unusually straight lateral border. Silhouetting of the left hemidiaphragm usually occurs, which may be associated with an air bronchogram. In underpenetrated film is easily missed.

**Aspiration**

ICU patient is at a particular risk of aspiration pneumonitis, often as a result of a compromised airway. Contributory factors: impaired consciousness, placement of ET and NG tubes. Aspiration of gastric contents induces a chemical pneumonitis called Mendelson's syndrome. The lung responds to pH <2.5 with severe bronchospasm and the release of inflammatory mediators.

- **Initial response**: chemical pulmonary edema. The consequence of pneumonitis may reveal pulmonary consolidation within the first two days.

- Bilateral air space shadowing, perihilar, asymmetric. Radiographically the consolidation usually begins to resolve by the third day and. In some, the consolidation may worsen with added complications of secondary infection, lung abscesses and pleural effusion.

**Pulmonary embolism fig.19 on page 30**

Pulmonary embolism in the ICU setting may be completely silent, but it is a cause of sudden death.

- Risk factors: immobilization, trauma, surgery, shock, obesity, pregnancy, polycythemia vera and antithrombin-III deficiency.

- The importance of a chest radiograph is in ruling out other pathologies that may have a clinical presentation similar to that of pulmonary embolism.

- Radiographic signs: discoid atelectasis, elevation of the hemidiaphragm, enlargement of the main pulmonary artery, pulmonary oligemia beyond the point of occlusion:
Westermark's sign. A relatively late sign of pulmonary infarction is a rounded pleural-based consolidation that is rounded centrally and is called a Hamptom’s Hump. A Hamptom’s Hump can be differentiated from a pneumonic consolidation as the former lacks an air bronchogram.

**Pneumothorax** fig. 20 on page 31, fig.21 on page 32

Represents accumulation of air in the pleural space. It may occur spontaneously or secondary to trauma.

Radiographic appearance depends upon how the radiograph has been exposed.

- Erect patient: air rises to apicolateral surface of the lung. Thin, white pleural line with no lung markings beyond.

- Supine patient: air rises anteromedially. Air can sometimes be trapped in a subpulmonic location, anterolateral extension of air into costophrenic angle. Deep sulcus sign.

- A skin fold may mimic a pneumothorax. Continues outside the chest.

- Tension pneumothorax: depression of a hemidiaphragm, a shift of the heart border, the superior vena cava and the inferior vena cava.

**Pneumomedistinum**

Represents air in the mediastinum, usually remains asymptomatic.

- Air around the great vessels, the medial border of the superior vena cava, and the azygos vein seen as surrounding lucencies.

- A posteromedial pneumomediastinum is usually the result of esophageal rupture, air dissects into the paraspinal costophrenic angle and beneath the parietal pleura of the left diaphragm.

**Pneumopericardium**

Refers to an accumulation of gas/air between the myocardium and pericardium.

- Can be an occasional complication of pneumothorax, postoperative cardiac patient.

- Air may accumulate inferior to the cardiac shadow, which crosses the midline above the diaphragm. (Continuous diaphragm sign)
**Pleural effusions** fig.22 on page 33

Accumulation of fluid within the pleural space.

- Secondary to heart failure, fluid overload, hypoproteinemia, infection, pulmonary embolism, thoracic and upper abdominal surgery, neoplastic disease, subphrenic inflammatory processes, trauma and ascites.

- Is easier to identify in the erect patient as fluid collects at the base of the lung.

- In the supine position pleural fluid accumulates in the posterior basilar space, which appears as homogeneous density that increase in intensity towards the lung base. The normal broncovascular markings are retained in this veil-like density.

- Pleural cap at the lung apex in larger pleural effusions.

- Widened mediastinum when fluid accumulate on the medial side of the lung.

- When effusions are suspected: lateral decubitus film is indicated.

- Loculated pleural effusions and when fluid is retained within the fissures becomes a challenge for diagnosis.

**Pericardial effusions** fig.23 on page 34

Accumulations of fluid between the visceral and parietal pericardium.

- Are difficult to differentiate from cardiomegaly.

- Cardiomegaly with a change in cardiac silhouette, resulting in a featureless, globular or "water bottle” shape.

**Images for this section:**
Chest radiographs on the same patient a few minutes apart showing the effect of technique. In (a) image shows mediastinal widening and left basal clouding due to poor inspiratory effort. In (b) image has been taken in good inspiration; cardiomegaly, middle lobe atelectasis are persistent, but basal clouding disappears.

Fig. 1: fig.1
Fig. 2: fig.2
A position of the tip of the endotracheal tube: In (a) is in normal position, in (b) is in the right main bronchus (arrow). Causing atelectasis of the left lung.

**Fig. 3:** fig.3
Thoracostomy tube • The last side hole: interruption in the radiopaque line, should lie within the thoracic cavity.

PA chest radiograph in a patient with bilateral pleural effusions. The tubes are correctly inside the thoracic cavity.

Fig. 4: fig.4
Thoracostomy tube

The last side hole: interruption in the radiopaque line, should lie within the thoracic cavity.

Young woman with pneumonia with pleural effusion. PA (a) and lateral (b) chest radiograph show a misplaced pleural drainage. The last side hole(*) is inside the thoracic cavity, but misplaced in a superior position.

Fig. 5: fig.5
Nasogastric tube • Ideally: the distal duodenum.

The nasogastric tube is misplaced in (a); too short (arrow) and is correctly positioned the distal duodenum in (b) (arrow).

Fig. 6: fig.6
Fig. 7: fig.7
Central venous catheter

- Between proximal venous valves of the subclavian or jugular veins and the right atrium.
- **Straightforward** along superior vena cava towards the right atrium but not to enter the atrium.
- Misplacement: enters the right internal mammary vein in the AP projection.

The catheter’s tip enters the right atrium: is misplaced (arrow).

**Fig. 8:** fig.8
Fig. 9: fig.9

**Pacemaker**

- Tip should be at the **apex of the right ventricle**.
- No sharp angulations.
- Tip: 4 mm beneath the epicardial fat pad.
- Tip beyond the epicardial fat may have perforated the myocardium.

AP and lateral chest radiograph showing a pacemaker misplacement; the position of electrode does not lie within the apex of the right ventricle (**`).
Pleural and pulmonary disorders

Pulmonary edema

Interstitial

- Fluid collection in the lung interstitial space.
- Pulmonary venous pressure > 25-30 mmHg.
- Loss of definition of large pulmonary vessels, septal lines, interlobar septal thickening, diffuse reticular pattern and peribronchial cuffing interstitium.
- Kerley A and B.

Alveolar

- Pulmonary venous pressure > 30 mmHg.
- Bilateral opacities: “batwing” pattern.
- Increase of lung opacification, “air bronchogram” is seen and associated with congestive heart failure are usually visible in the right upper lobe.
- The heart is enlarged.

Fig. 10: fig.10
Fig. 11: fig.11

AP chest radiograph showing features of interstitial pulmonary edema. Loss of definition of large pulmonary vessels, septal lines, Kerley B (arrow).

AP chest radiograph showing features of alveolar pulmonary edema. Opacification of both lung with increasing density towards the lung bases, cardiomegaly.
Pleural and pulmonary disorders

Pulmonary edema

Interstitial

Resolution

Fig. 12: fig.12

AP chest radiograph showing features of interstitial pulmonary edema. Loss of definition of large pulmonary vessels, septal lines, Kerley B lines (arrow).

AP chest radiograph showing resolution of interstitial edema.
Pleural and pulmonary disorders

Adult Respiratory Distress Syndrome (ARDS)

- Edema in absence of elevated pulmonary venous pressures.
- High mortality 50%
- **Causes:** sepsis or pulmonary infection, severe trauma, aspiration of gastric contents.
- Damage to the alveolar capillary endothelium, increased vascular permeability → interstitial and alveolar edema.
- Marked hypoxia that responds poorly even to administration of high concentrations of oxygen.
- Pulmonary capillary wedge pressure is generally normal, but there is decreased surfactant production: noneffective ventilation.
- **Prognosis:** recover fully or progress to pulmonary fibrosis. Depending on age, duration.
  - *Differentiation between pulmonary edema of ARDS and congestive heart failure* (these conditions may coexist): ARDS is not usually associated with cardiomegaly or upper lobe blood diversion.
  - *Differentiation between ARDS and lung contusion*: lung contusion is localized to the area affected by injury and improves 48-72h. ARDS tends to be more generalized, is later in onset and slower to resolve.

**Fig. 13:** fig.13
Fig. 14: fig.14

AP radiographs of the patient with acute pancreatitis and ARDS. Opacification of both lungs with increasing density and air space shadowing. In (b) exist pneumomediastinum (arrow) result of complication: barotrauma.
AP chest radiograph. Shows the evolution of ARDS. Some patients progress patchy consolidation to pulmonary fibrosis one month following the onset of ARDS. Note in (b) the reticular pattern due to fibrosis.

Fig. 15: fig.15
Axial CT scan of the patient with ARDS. Shows the evolution of ARDS two months after. Some patients progress to pulmonary fibrosis. Reticular opacities (b) and honeycombing in anterior location due to adverse effects of mechanical ventilation.

**Fig. 16:** fig.16
Pleural and pulmonary disorders

Pneumonia

AP chest radiograph (a) and CT scan (b) showing bilateral consolidations, and pleural effusions associated with an air bronchogram secondary to hospital-acquired pneumonia.

Fig. 17: fig.17
Fig. 18: fig.18

AP chest radiograph of left lower lobe atelectasis. The left lower lobe collapses medially and posteriorly to lie behind the heart. It classically displays a triangular opacity, which may be visible through the cardiac shadow, giving the heart an unusually straight lateral border.
Fig. 19: fig.19

AP chest radiograph of a patient presenting with shortness of breath and hypoxemia, which shows right pulmonary oligohemia, and enlargement of the main pulmonary artery due to right pulmonary embolism.
AP chest radiograph of a patient presenting with shortness of breath and hypoxemia, which shows right pulmonary oligohemia, and enlargement of the main pulmonary artery due to right pulmonary embolism.

**Fig. 20:** fig.20
Pneumothorax and pneumomediastinum. AP chest radiographs (a), (b). CT scan (c), (d).

In (a) note air around the great vessels (*). Subcutaneous emphysema is well seen.

In (b) Air is trapped in a supulmonic location between the lung-heart and diaphragm (arrow).

In (c), (d) CT scans shows pneumothorax, large pneumomediastinum and subcutanous emphysema.

**Fig. 21:** fig.21
Fig. 22: fig.22

Pleural and pulmonary disorders

Pleural effusions

AP chest radiograph showing hazy opacification of the right lung, suggestive of right pleural effusion.
Pleural and pulmonary disorders

Pericardial effusion

AP chest radiograph shows enlarged globular heart secondary to pericardial effusion.

Fig. 23: fig.23
Conclusion

The knowledge of chest roentgenology in the intensive care unit is a real challenge for the general radiologist.

This work provides a comprehensive overview of the above mentioned conditions and a guideline of interpretation based not only on the radiological aspect and distribution of the lesions, but also on the physiopathological and clinical grounds.

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References


