The role of thoracic imaging in the intensive care unit

Radiology is critical in managing patients on intensive care units. The portable chest X-ray is widely used, but ultrasound and computed tomography are of diagnostic value in selected cases. This article discusses the role of thoracic imaging in the intensive care unit.

Radiology plays a critical role in the management of patients on intensive care units. The portable chest X-ray is the most commonly used radiological investigation in the intensive care unit, and despite its limitations, remains a useful and relatively inexpensive bed-side adjunct in critically ill patients. Therefore interpretation and recognition of its limitations is essential for intensive care clinicians.

Daily chest X-rays are often requested, but this is controversial. Routine intensive care unit chest X-rays are of low diagnostic and therapeutic value (Hendrikse et al, 2007), although chest X-rays are useful in assessing device placement, pneumothorax, pneumonia and adult respiratory distress syndrome (Hendrikse et al, 2007). Abandoning daily chest X-rays in favour of clinically indicated radiographs does not adversely affect quality or patient safety outcomes (Krivopal et al, 2003; Hejblum et al, 2009), and safely achieves cost savings (Graat et al, 2006).

An alternative and increasingly accepted bedside technique for assessing the thorax is ultrasound. Ultrasound is a non-invasive, dynamic investigation increasingly used by non-radiologists. It confers multiple benefits including no radiation exposure, portability, rapid results and cost-effectiveness. Non-radiologists can perform it competently following brief focused training (Chalumeau-Lemoine et al, 2009). Its use in the intensive care unit is increasing beyond pleural disease characterization (Ioos et al, 2011; Hew and Heinze, 2012).

Table 1. Approach for evaluating intensive care unit chest X-rays

Assess the technical quality of the study
Locate all support devices and document position of catheter or device tips
Search for evidence of barotrauma
Assess for pleural effusions
Evaluate any air space opacification
If available, compare with previous studies

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Computed tomography provides more comprehensive thoracic evaluation than chest X-ray, and is better at detecting clinically occult abnormalities. It is useful in managing clinical conundrums and conditions with non-specific or few chest X-ray signs; in these circumstances interpretation in conjunction with clinical and laboratory information is essential. However, computed tomography has a number of drawbacks including higher radiation doses, use of nephrotoxic contrast and lack of portability. The latter is an important consideration as adverse effects are reported in up to 59% of intensive care unit intra-hospital transfers (Shirley, 1999), as a result of human, technical, organizational and patient factors (Fanara et al, 2010). Recommendations to improve intra-hospital transfer focus on the use of protocols, meticulous checks, and adequate training and equipment (Fanara et al, 2010).

This article discusses the role of thoracic imaging in intensive care; given the widespread use of the portable chest X-ray, the main focus is on plain film interpretation.

A systematic approach to interpreting an intensive care unit chest X-ray

Developing a systematic method to interpret any radiological examination is important. *Table 1* suggests a systematic approach to evaluate chest X-rays in the intensive care unit.

Technical quality of the intensive care unit chest X-ray

There are important technical differences between departmental and portable chest X-rays. The former are acquired in a posteroanterior direction, which minimizes cardiac magnification. In contrast, a portable chest X-ray is taken anteroposteriorly, which artificially increases cardiac size and in supine films also causes vascular redistribution.

An optimal portable chest X-ray requires an upright patient to take a maximum inspiration. However, intensive care unit patients are often unable to do this, leading to sub-optimal films with magnification of the heart and mediastinum, relatively denser lungs from reduced lung volumes, and lung bases obscured by an elevated diaphragm. Supine positioning also magnifies the cardiac silhouette, physiologically increases upper lobe pulmonary blood flow, and modifies signs of pleural effusions and pneumothoraces.

Therefore appreciation of the technical differences of bedside chest X-rays is important since these can produce images mimicking and/or modifying signs of pathology.

Evaluation of devices and their potential complications

Chest X-rays are useful to assess medical device position (Hendrikse et al, 2007); this is critical as clinical examination is not infallible in confirming correct placement. The location of each device and the level of its tip should be evaluated and documented by tracing the outline in either a craniocaudal or lateral to medial direction.

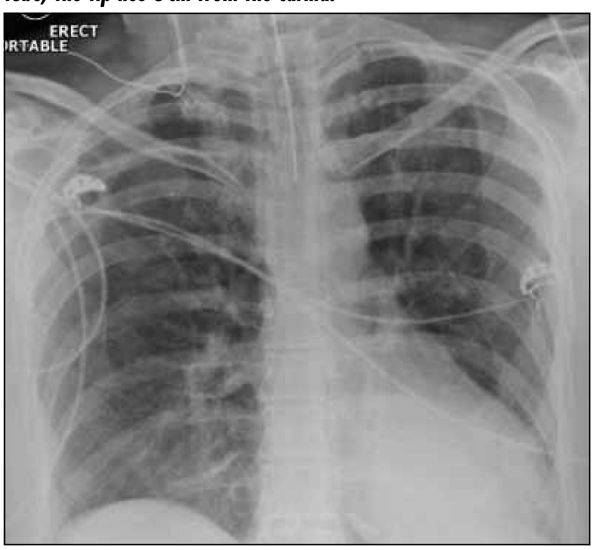
Endotracheal tubes

Assessment of endotracheal tube placement is essential as malposition occurs in approximately 15% (McCoy et al, 1997) and may cause bronchial obstruction. Endotracheal tube position should be assessed with the head in a neutral position, as neck movement displaces the tip by as much as 2 cm. An endotracheal tube is recognized on a radiograph by its longitudinal radio-opaque line. Tracheal intubation is confirmed by the endotracheal tube lying within the tracheal air column, ideally with the tip 5–7 cm from the carina (*Figure 1*). The minimum safe distance of the tip from the carina is 2 cm to allow for neck movement. If carina visibility is obscured a surrogate landmark is the T5–T7 vertebral bodies which indicate the level of the carina in 95% of patients. An important caveat is in inadvertent oesophageal intubation. This should be immediately recognized by clinical examination; waiting for a chest X-ray delays recognition with resultant mortality and morbidity. Radiological signs of oesophageal intubation can be subtle and are suggested by lung hypo-inflation and excessive oesophageal and gastric air.

Overzealous endotracheal tube intubation leads to the contralateral lung collapsing and risks ipsilateral lung over-inflation and a pneumothorax. Distal intubation is more likely to be right sided because of the steeper orientation of the right main bronchus (*Figure 2*). Intubation of bronchus intermedius causes the entire left lung and right upper lobe to collapse. Too proximal intubation can lead to laryngeal trauma or unintended extubation.

Verification of correct endotracheal tube placement by ultrasound has been described (Weaver et al, 2006). Correct placement is suggested by demonstrating both lungs are 'sliding', absence of which strongly indicates unilateral or oesophageal intubation (Weaver et al, 2006).

Figure 1. Chest X-ray showing a correctly placed endotracheal tube; the tip lies 3 cm from the carina.



Tracheostomy tube

Tracheostomy tubes should lie approximately at the level of T3 (*Figure 3*). Unlike the endotracheal tube, the position of tracheostomy tubes should not alter with neck

Figure 2. Chest X-ray showing a misplaced endotracheal tube. The tip of the endotracheal tube is in the right main bronchus (arrow) with resultant collapse of the left lung. The tube needs to be withdrawn into the correct position and the chest X-ray repeated.

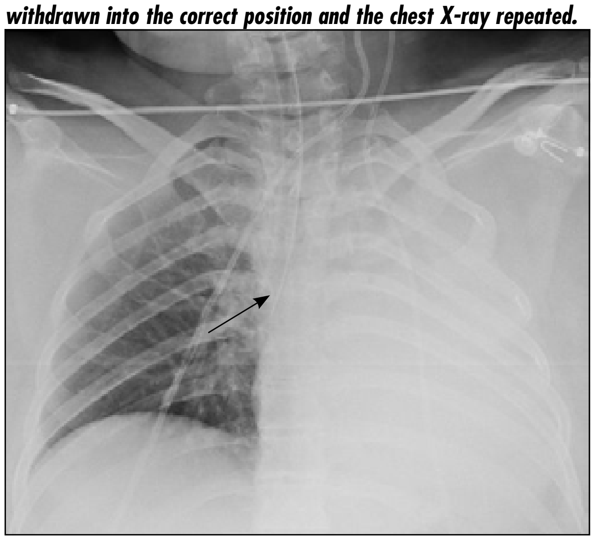
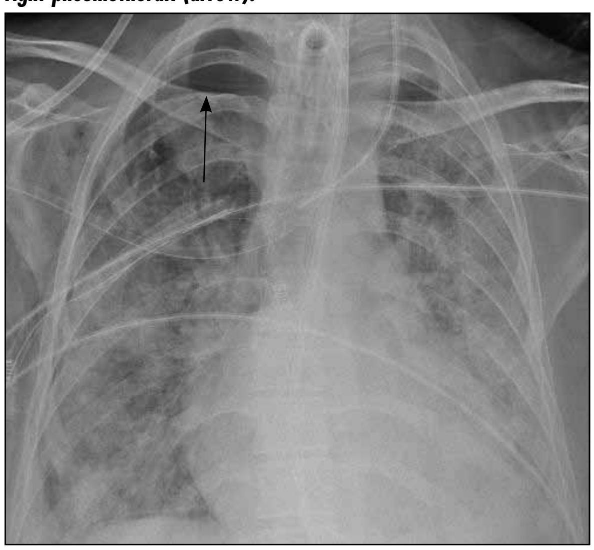


Figure 3. Chest X-ray showing correct placement of a tracheostomy tube in a young patient with prolonged ventilation for endotracheal tube. Note the extensive bilateral alveolar opacification and small right pneumothorax (arrow).



flexion or extension. If a cuff is present it should not distend the tracheal wall, as over-inflation predisposes to tracheal wall pressure necrosis.

Intercostal chest drains

Intercostal chest drains drain fluid or air from the pleural cavity. A chest X-ray should be performed post-insertion or when the pleural space stops draining. An intercostal chest drain and all its drainage holes must be seen within the pleural space it is intended to drain (*Figure 4*). Drainage holes are recognized as regularly spaced gaps along the tube's longitudinal radio-opaque line. If these lie subcutaneously air can track between the fascial planes resulting in subcutaneous emphysema (*Figure 5*). Clinically this presents as palpable subcutaneous crepitus, and when gross can appear alarming, although it is usually a self-limiting condition. Radiologically subcutaneous emphysema appears as streaky dark lines, particularly between the pectoral fascial layers (*Figure 6*).

Intercostal chest drain malposition is the commonest complication of thoracostomy (Baldt et al, 1995), with complication rates higher in critically ill patients (Remérand et al, 2007). Chest X-rays can demonstrate misplaced intercostal chest drains, but in general their position is better shown by computed tomography (*Figures 7* and *8*).

Nasogastric tubes

Nasogastric tubes are commonly used for enteral feeding or decompression. Misplaced nasogastric tubes are a registered 'never event' (National Patient Safety Agency, 2011), following incidents of death and harm from feeding via misplaced nasogastric tubes (*Figure 9*). For feed-

Figure 4. Chest X-ray showing a correctly placed intercostal chest drain in the right apex for a pneumothorax. Also note the correctly sited endotracheal tube with the tip 2.5 cm from the carina, the nasogastric tube tip well below the diaphragm, and the correctly sited left central venous pressure line.

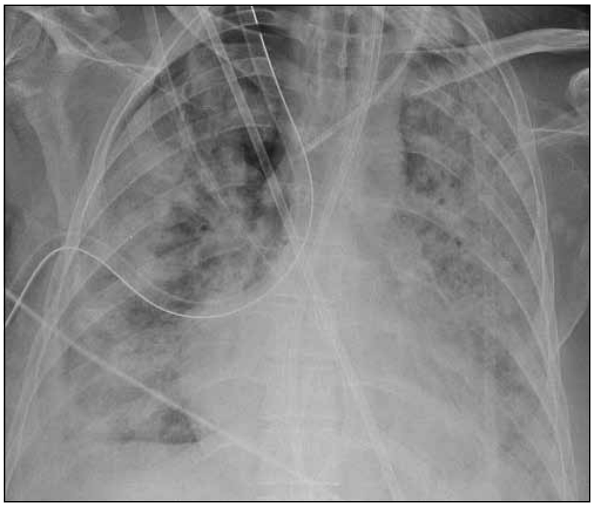


Figure 5. Chest X-ray showing a right intercostal chest drain in situ. The tip is lying within the pneumothorax, but the drainage hole lies outside of the pleural cavity within the subcutaneous tissues (arrow). The intercostal chest drain tube needs to be re-sited and the chest X-ray repeated.

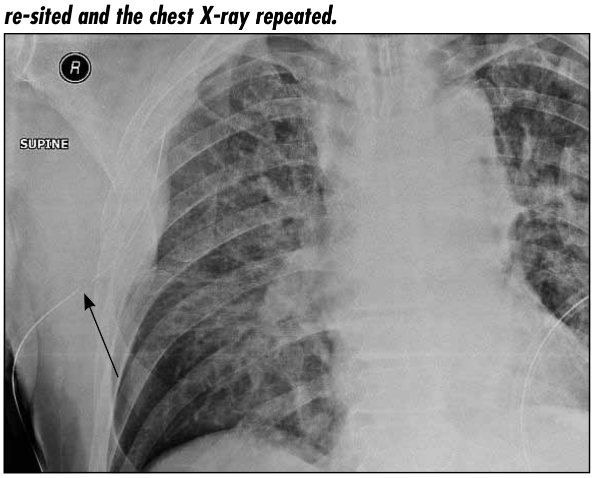


Figure 6. Chest X-ray showing a left-sided pneumothorax and florid subcutaneous emphysema seen as subcutaneous streaky dark lines extending into the neck. Note the two correctly placed left-sided intercostal chest drains, each with their drainage hole within the pleural space.

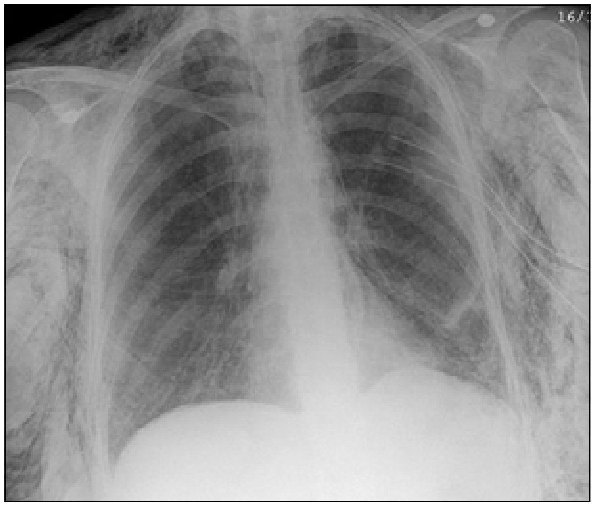


Figure 7. Chest X-ray showing an incorrectly placed right basal intercostal chest drain, which is neither draining pleural fluid or a pneumothorax.

ing, the tip of a nasogastric tube should ideally lie within the antrum of the stomach or duodenum. There are local guidelines for checking nasogastric tube position which must be done by a suitably qualified and trained person. Fundamental features to assess nasogastric tube placement on a chest X-ray include:

1. Does the path of the nasogastric tube follow the oesophagus and avoid the contours of the bronchi?
2. Does the nasogastric tube bisect the carina?
3. Does the nasogastric tube cross the diaphragm in the midline?
4. Is the tip of the nasogastric tube clearly seen below the diaphragm?

The nasogastric tube is only safe for feeding if all these criteria are met. If there is any doubt advice from a more experienced practitioner must be sought. Ultrasound has been suggested as an alternative to radiography (Vigneau et al, 2005).

Figure 8. Computed tomography of the same patient as in Figure 7 confirming inadvertent malpositioning of a right intercostal chest drain – the drain has traversed the right lower lobe and its tip abuts the right heart border. There is associated injury of the lung parenchyma with haematoma surrounding the intercostal chest drain and a small pneumothorax. The intercostal chest drain tube needs to be removed and the chest X-ray repeated.

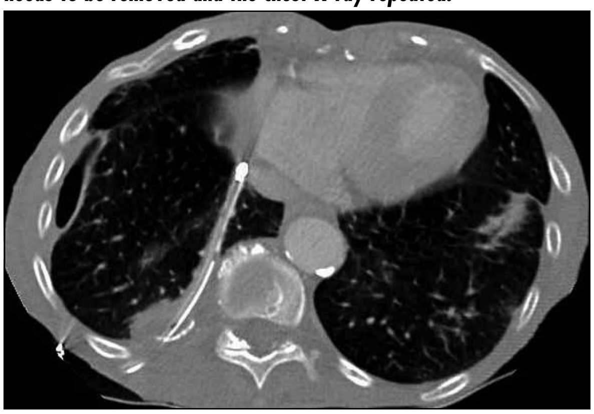


Figure 9. Chest X-ray showing an incorrectly placed nasogastric tube. The nasogastric tube tip has passed through the right main bronchus down the right lower lobe bronchus and into the right lower lobe. The nasogastric tube is in an unsafe position for feeding and needs to be completely withdrawn and re-sited.

Central venous pressure and Swan–Ganz lines

Proper placement of central venous pressure and Swan–Ganz catheters is essential to accurately measure physiological status and/or deliver therapy.

A central venous pressure catheter tip should lie within the superior vena cava between the right atrium and subclavian or jugular veins. This is recognized on a chest X-ray by the catheter tip lying medial to the anterior portion of the first rib (*Figure 4*). It is important to check the tip is not within the right atrium, as this predisposes to arrhythmias and thrombosis, and risks right atrial perforation. A Swan–Ganz catheter tip should lie within the right, left or main pulmonary artery, and not extend into the pulmonary hilum (*Figure 10*). The chest X-ray should also be examined for post-insertion complications.

Ultrasound increases the success rate of central venous pressure insertion, saves time, and decreases the complication rate (Hind et al, 2003), and as later discussed can also evaluate insertion-related pneumothoraces.

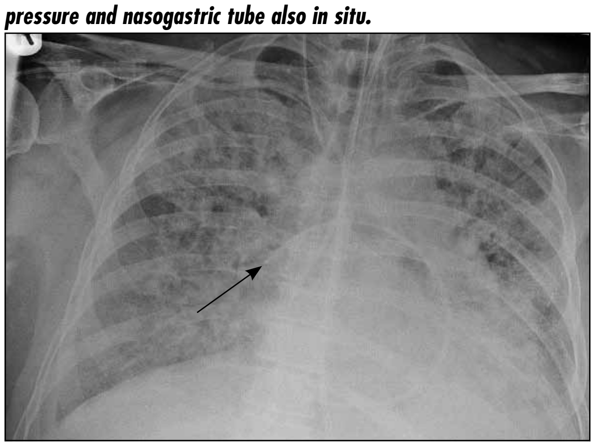
Evidence of barotrauma

Barotrauma is a well-recognized complication of mechanical and non-invasive ventilation. Increased alveolar pressures injures the lung causing extra-alveolar air to accumulate. This manifests as subcutaneous emphysema, pneumomediastinum and/or a pneumothorax.

Pneumomediastinum

A pneumomediastinum is mediastinal air secondary to a perforated airway or alimentary organ; rarely the source is an infective gas-forming organism. Radiologically a pneumomediastinum is seen as a sharp radiolucent line outlining the mediastinal great vessels, often extending into the neck (*Figures 11a–c*).

Figure 10. Chest X-ray showing incorrect placement of a Swan–Ganz catheter; the tip is projected outside the middle mediastinal border (arrow), indicating the tip lies in a segmental right pulmonary artery. Correctly sited right central venous pressure and nasogastric tube also in situ.



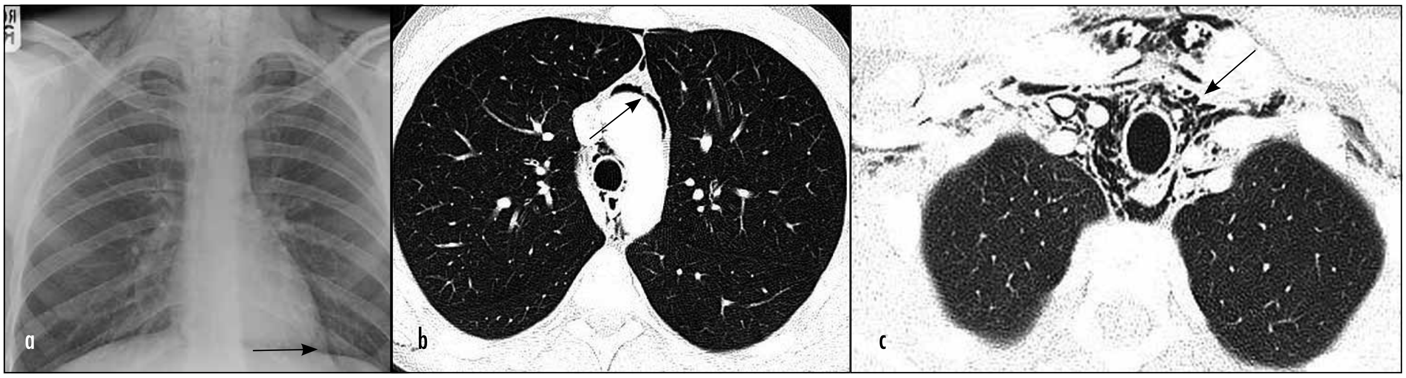


Figure 11. a. A chest X-ray in a patient presenting with excessive vomiting, dyspnoea and palpable subcutaneous emphysema in the right supraclavicular region. The limitations of a chest X-ray are demonstrated as the pneumomediastinum is subtle. However, given the clinical history, the presence of a thin rim of air around the cardiac apex (arrow) and bilateral supraclavicular subcutaneous emphysema, it raises a strong index of suspicion for an oesophageal or tracheal perforation. Thoracic computed tomography of the same patient demonstrating (b) mediastinal air (arrow) and (c) extensive supraclavicular air (arrow). The computed tomography confirmed a proximal oesophageal perforation.

Pneumothorax

A pneumothorax is the accumulation of air in the extrapleural space causing collapse of the underlying lung. Presentation can be clinically occult and initially diagnosed by a chest X-ray. Conversely catastrophic presentation, cardiac arrest or severe respiratory distress can occur secondary to a large tension pneumothorax.

Pneumothoraces are more difficult to detect on portable chest X-rays, particularly on supine films. In the supine position air preferentially collects anteromedially, resulting in subtle signs including sharp demarcation of the middle mediastinal structures, a prominent cardiophrenic sulcus and hyperlucency of the upper abdominal quadrant. The latter is not specific and can be seen with a pneumoperitoneum or air within a sub-diaphragmatic abscess. If diagnostic uncertainty exists a lateral decubitus view can be helpful, but this can be difficult on the intensive care unit as a result of X-ray beam scatter affecting neighbouring patients. Patients are imaged with the suspected pneumothorax side uppermost to allow air to accumulate in the least dependent space. Despite these manoeuvres between 30 and 72% of pneumothoraces are radio-occult (Soldati et al, 2006). Computed tomography is more sensitive at detecting pneumothoraces, particularly those that are radio-occult.

Ultrasound is reported to be more sensitive than chest X-ray (Lichtenstein, 2007; Alrajhi et al, 2012), leading some to propose it as the ‘bedside gold standard’ (Wilkerson and Stone, 2010; Ioos et al, 2011; Alrajhi et al, 2012). Ultrasound diagnosis of pneumothoraces relies on three signs: abolition of ‘lung sliding’, the ‘A-line’ sign, and the ‘lung point’ (Ioos et al, 2011). Readers are referred to Hakimisefat and Mayo’s (2010) article describing the key components of chest ultrasound.

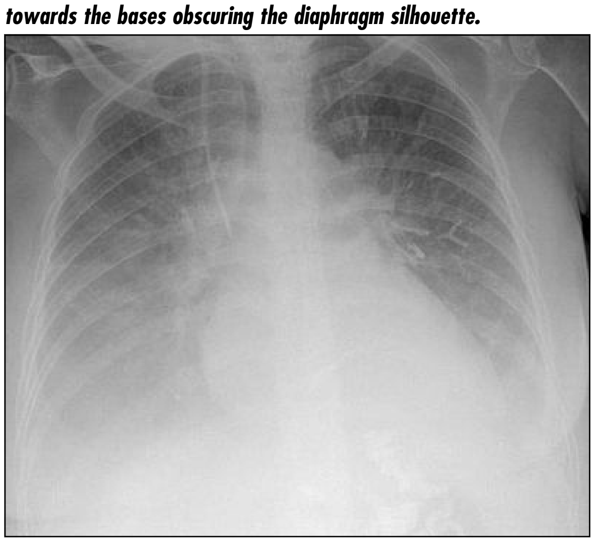
Evidence of pleural effusions

Pleural effusions are common in intensive care unit patients. Most are of limited clinical significance, but some require aggressive management. Transudate effusions in intensive care patients most often result from volume overload, decreased plasma oncotic pressure, and regions of altered pleural pressure attributable to atelectasis and mechanical ventilation. Exudates are most commonly secondary to infection or malignancy.

Pleural effusion signs are gravity dependent. Blunting of the costophrenic angle is the earliest erect chest X-ray sign of basal fluid accumulation. Detection of supine pleural effusions is more difficult, as signs are more subtle and fluid accumulates within the posterior-basal region which allows a greater volume (up to 400–500 ml) to remain occult. Signs include a generalized ‘veil-like’ opacity that becomes increasingly dense towards the base with loss of the diaphragm silhouette (*Figure 12*). Again, if diagnostic uncertainty exists a lateral decubitus film can be helpful. Here the patient is imaged with the suspected side of the effusion lowermost.

Ultrasound assessment of pleural effusions has considerably better diagnostic performance than chest X-ray

Figure 12. Supine chest X-ray showing bilateral pleural effusions. The pleural fluid has tracked posteriorly causing increasing haziness towards the bases obscuring the diaphragm silhouette.



(Xirouchaki et al, 2011) (*Figure 13*). It can help to distinguish a transudate from an exudate; the latter is suggested by visualizing septations and heterogenous echogenicity (*Figure 14*). However, definitive diagnosis requires pleural fluid sampling. To reduce complications this should be performed under ultrasound guidance (Jones et al, 2003). Ultrasound-guided intercostal chest drain insertion for pleural effusion drainage is also strongly recommended (Havelock et al, 2010).

Assess air space opacification

Air space opacification on a chest X-ray is a non-specific finding representing fluid, pus, blood or cells within the air spaces. Image interpretation is often complicated by co-existent pathology. Therefore it is essential that images are interpreted in light of the clinical context, physiological and biochemical parameters.

Adult respiratory distress syndrome

Adult respiratory distress syndrome is a rapidly developing condition associated with significant mortality. It is principally a clinical diagnosis (*Table 2*) (Bernard et al, 1994). Adult respiratory distress syndrome is initiated by direct or indirect lung injury. Injury increases capillary endothelium permeability leading to protein-rich fluid flooding the alveoli, creating a state of non-cardiogenic oedema. Pulmonary interstitium and air space exudate damages alveoli reducing surfactant production and hyaline membrane formation.

Figure 13. Ultrasound showing a simple transudate pleural effusion with associated lung atelectasis. Marker A measures the depth of the subcutaneous tissue above the pleural effusion. Marker B measures the depth of the pleural effusion. Both measurements are useful to facilitate safe thoracic intervention.

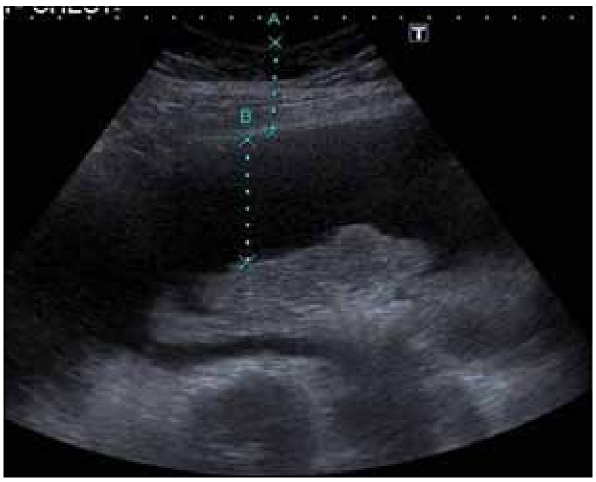


Figure 14. Ultrasound showing a complex loculated effusion in the right hemithorax with multiple discrete locules. A represents the minimum depth and B represents the maximum depth of the effusion. Sonographic findings suggest an empyema.

Early appearances

Chest X-ray findings lag 12–24 hours after the initial insult. The earliest changes consist of patchy bilateral alveolar infiltrates, which typically coalesce by 48 hours to produce diffuse alveolar opacification containing air bronchograms. These changes often predominate at the bases and persist for days to weeks (*Figures 15a* and *b*). Adult respiratory distress syndrome may be complicated by superimposed pneumonia or pulmonary oedema which, although difficult to recognize, should be considered if new focal opacities or a pleural effusion develops.

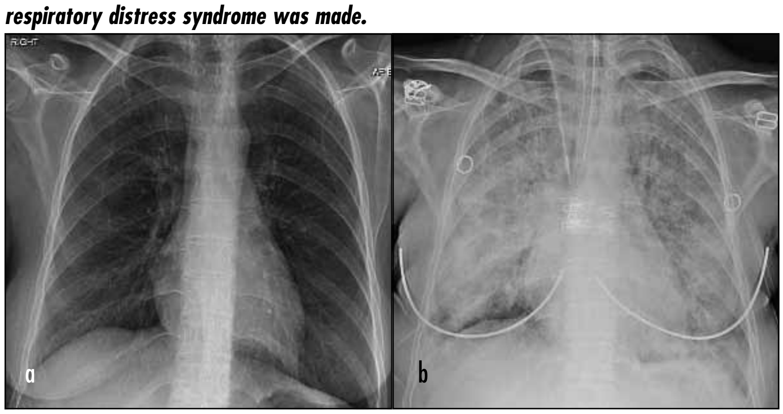
Late sequelae

Surviving patients inevitably suffer some degree of fibrotic lung disease. Follow-up computed tomography typically shows a coarse reticular pattern of multiple interlacing line shadows accompanied by architectural distortion in a striking anterior distribution (Desai et al, 1999).

Table 2. Acute respiratory distress syndrome diagnostic criteria defined by the American European Consensus Conference

All four clinical features must be present for the diagnosis:
Acute clinical onset
Bilateral pulmonary opacities
Absence of elevated left atrial pressures (pulmonary capillary wedge pressure ≤18 mmHg)
Arterial oxygen tension:inspired oxygen (partial pressure of oxygen in arterial blood/fractional inspired oxygen) 201–300 mmHg
From Bernard et al (1994)

Figure 15. a. Normal chest X-ray in a patient presenting with pancreatitis. b. Chest X-ray of this patient 48 hours later shows extensive bilateral air space opacification in a predominantly basal distribution. Note the heart is not enlarged and the absence of pleural effusions. Given the radiological signs and clinical history a diagnosis of acute respiratory distress syndrome was made.



Pneumonia

Hospital-acquired pneumonias are a leading cause of death in intensive care unit patients (Leroy et al, 2004). Consolidation in a lobar or sub-lobar distribution is a suggestive but non-specific finding. Computed tomography is useful to distinguish pneumonia from other causes of air space opacification, as well as to evaluate complications (*Figures 16a* and *b*).

Aspiration

Radiographic and clinical findings depend on the type and volume of aspirated material. Chest X-rays range from normal to area(s) of focal consolidation that rapidly deteriorate to diffuse bilateral air space opacification. The right lung is more likely to be affected, but patients nursed supine typically have changes in the posterior segments of the upper lobes and superior segments of the lower lobes.

Cardiogenic pulmonary oedema

Cardiogenic pulmonary oedema is the accumulation of fluid in the interstitium and alveoli. The earliest erect chest X-ray signs reflect the re-distribution of pulmonary blood flow to upper lobes, and consist of widening of the vascular pedicle, increased prominence of the upper pulmonary vessels, and an increase of the pulmonary artery to bronchus ratio of the middle and upper lobes. As cardiogenic pulmonary oedema progresses fluid leaks into the peripheral interlobular septa producing Kerley B lines, and into the peri-bronchovascular interstitium causing loss of definition of the perihilar vessels, referred to as perihilar haze. In advanced states fluid fills the air space. Differentiating abnormal opacification secondary to cardiogenic pulmonary oedema from adult respiratory distress syndrome can be difficult. *Table 3* lists some helpful differentiating chest X-ray signs.

Figure 16. a. Chest X-ray shows non-specific bilateral air space opacification. b. Thoracic computed tomography of this patient demonstrating a right upper lobe cavitatory lesion that was not shown on the plain film. An air crescent sign (arrow) is contained within the lesion, which is typical of angioinvasive aspergillosis infection.

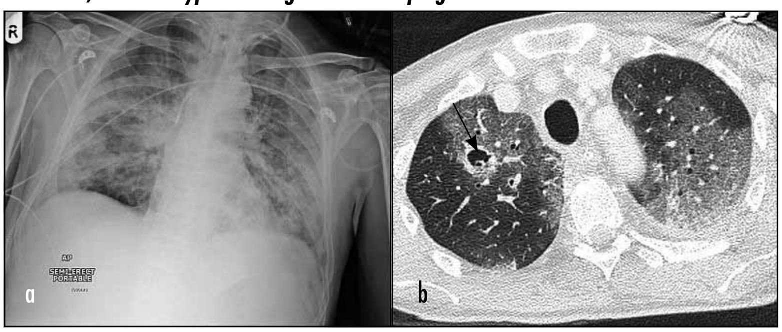


Table 3. Differentiating cardiogenic pulmonary oedema from acute respiratory distress syndrome on chest X-ray

Differentiating feature	Cardiogenic pulmonary oedema	Acute respiratory distress syndrome
Time course	Rapid onset	Lag time 12–24 hours
Progress	Dynamic, pulmonary clearing with diuretic therapy	Changes persist for days to weeks
Cardiomegaly	Present	Absent
Pleural effusions	Common, bilateral	Occasionally, secondary to complication
Vascular redistribution	Upper lobe pulmonary diversion	No vascular redistribution
Opacification pattern distribution	Predominantly hilar	Predominantly basal
Interstitial oedema or Kerley B lines	Present	Absent
Long-term radiology	Normal lung parenchyma	Coarse reticular pattern

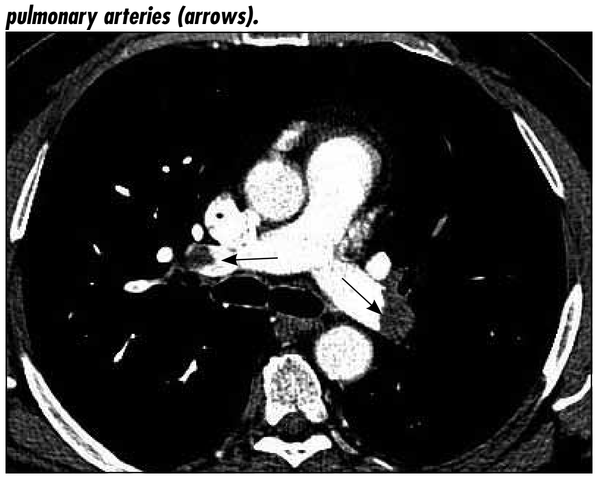
Pulmonary embolism

Morbidity and mortality from pulmonary embolism in the intensive care unit remains high (Bahloul et al, 2010). Chest X-rays are insensitive in diagnosing pulmonary embolism. A normal chest X-ray is the commonest finding (Worsley et al, 1993), but thoracic opacification may also be evident. Therefore the role of a chest X-ray is to exclude other causes of respiratory embarrassment.

Computed tomography pulmonary angiography is the main technique for diagnosing pulmonary embolism (*Figure 17*), with a negative test having a high negative predictive value (Tillie-Leblond et al, 2002). Computed tomography pulmonary angiography also images the entire thorax, allowing assessment of other pathologies.

As with chest X-rays, the technical quality of a computed tomography pulmonary angiogram must initially be assessed. A computed tomography pulmonary angiogram may be non-diagnostic in the presence of a poorly opacified pulmonary arterial tree or artefact secondary to patient motion or metal implants (Wittram et al, 2004). Pulmonary artery opacification can be optimized by good peripheral intravenous access to allow contrast injection of at least 5 ml per second. A positive computed tomography pulmonary angiogram should prompt a search for

Figure 17. Computed tomography pulmonary angiogram showing excellent opacification of the pulmonary arterial tree. Bilateral pulmonary emboli lie in the distal aspect of the right and left pulmonary arteries (arrows).



signs of right heart strain, as it is a predictor for early death (Schoepf et al, 2004). Features of right heart strain include enlarged right heart chambers, leftward bowing of the interventricular septum, and engorgement of the inferior vena cava and hepatic veins.

Compare with previous imaging

Comparing a chest X-ray with previous imaging is invaluable, particularly when evaluating air space opacities and a sub-optimal film.

Conclusions

Radiology plays an important role in managing intensive care unit patients. Portable chest X-rays are useful, but allowance for technical factors is important. There is increasing application of intensive care unit thoracic ultrasound beyond pleural assessment. Computed tomography can add diagnostic value in selected cases. **BJHM**

Conflict of interest: none.

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KEY POINTS

- Appreciation of the technical differences of bedside chest X-rays is important since these can produce images mimicking and/or modifying signs of pathology.
- The location of each device and the level of its tip should be evaluated and documented by individually tracing its outline in either a craniocaudal or lateral to medial direction.
- Ultrasound-guided intercostal chest drain insertion for pleural effusion drainage is also strongly recommended.
- It is essential that images are interpreted in light of the clinical context, physiological and biochemical parameters.
- Comparing a chest X-ray with previous imaging is invaluable, particularly when evaluating air space opacities and a sub-optimal film.