Diagnostic strategy for parenchymatous disorders of the lungs in the intensive care unit setting

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Learning objectives

- To illustrate the role and capabilities of CT in the analysis and management of parenchymatous pulmonary lesions in intensive care setting.
- To present a structured approach of analysis in this setting.
- To stress the importance of clinical data in the imaging diagnostic process in intensive care setting.

Background

The identification of the nature of pulmonary distress in the context of the intensive care unit is often complex because of the possible combination of several mechanisms, sometimes superimposed on a pre-existing disorder.

Adult Respiratory Distress Syndrome (ARDS), or to a lesser degree acute alveolar damage, may be seen in a heterogeneous group of patients. It is most commonly seen in polytrauma patients or those with extrathoracic sepsis, infectious or aspiration pneumonia. However, 20 to 30% of ARDS cases don't have a definite diagnosis. A similar clinical and radiological presentation may be observed in diffuse infiltrative pneumonia or alveolar hemorrhage.

In the case of acute diffuse infiltrative lung disease, an insidious onset, and symptoms or etiology not strictly responding to classical criteria of ARDS may be observed. A delay in the appearance of respiratory symptoms greater than 1 week combined with bilateral radiological infiltrates strongly suggests an acute diffuse infiltrative lung disease. A unilateral infiltrate almost definitively excludes such a disorder.
These conditions should not be considered as an idiopathic interstitial pneumonitis, which has a different prognosis. Moreover, some pathology such as drug induced lung disease may have a chronic, subacute or acute presentation.

**Imaging findings OR Procedure details**

**Role of Imaging**

**General considerations**

The role of imaging appears as essential as clinical and biological data, in particular when the diagnosis is unclear. In all cases, previous history such as that of malignancy, drugs and industrial exposure should be considered in the diagnostic process. As far as possible, the patient's immune status should be clarified, and the differential diagnosis tailored according to the type and length of history of immunocompromise. Current imaging should always be compared to previous examinations.

Computed tomography (CT) gives the greatest radiological detail of the lungs, but its place in the diagnostic process remains to be evaluated. CT is useful in defining the type and therefore the etiology of the abnormality present. Its contribution is undeniable in certain situations, such as in the context of immunocompromise or an underlying or associated thoracic condition. The CT findings may suggest a previously unsuspected infectious cause, for example, the first presentation of an immunocompromised patient with Pneumocystis carinii pneumonia. In the circumstance of an atypical presentation, the diagnosis may be made thanks to information provided by CT. The differential diagnosis given would be tailored according to the observed findings, sometimes resulting in a
specific therapeutic approach. CT may also point towards an infectious or medication related etiology, congestive cardiac failure, or a rarer cause such as a vasculitis. A mixture of pathologies may be observed. Several possible diagnoses are often considered, as comparable radiological findings may be seen in a variety of conditions. This is particularly the case with infection and a diffuse infiltrative pneumonitis, where the clinical presentation and radiological findings may be similar.

**Technique**

The examination technique is based on a volumetric acquisition using a contiguous millimetric slice thickness and overlapping reconstructions. The role of post-processing tools, in particular multiplanar reconstructions with the application of maximum and minimum intensity projections, is invaluable. These tools are available with current CT machines which are able to scan the entire thorax in a very short period of time, in the order of 5 seconds or less.

The acquisition may be performed in a mechanically ventilated patient due to the present temporal resolution. Excellent spatial and contrast resolution should also be highlighted.

Increasingly, substantial dose reductions may be achieved as a result of the excellent natural contrast of the lung parenchyma. This is a significant point where multiple follow up examinations may be necessary. The use of a contrast media injection is rarely required unless specific vascular detail is needed, as in cases of suspected angio-invasive aspergillosis, or pulmonary infarction to detect underlying pulmonary emboli. In the context of renal impairment, the risk-benefit ratio must be considered.

**Lesion distribution**

Additionally, CT may also guide clinicians in their investigations. It may direct bronchoalveolar lavage, or less commonly, transbronchial or percutaneous lung biopsy. The management remains minimally invasive.

**Interpretation method: identification of the predominant lesion type**
One of the essential parts of the interpretation process is to identify the main radiological pattern present, including its geographical distribution and associated signs. The principal radiological findings will be subsequently described: alveolar consolidation, ground glass opacity, septal and peribronchovascular thickening, micronodules, nodules, and cavities. Pleural, mediastinal, vascular and chest wall abnormalities should also be considered.

**Consolidation**

*Focal consolidation*

A solitary area of alveolar consolidation with ill-defined margins, often sub-pleural and limited by an adjacent fissure, which evolves into a well-defined segmental / lobar opacity that may or may not contain an air bronchogram, suggests a pneumonia as seen in community-acquired pneumonia (CAP) (figure 1).
Fig.: Fig. 1 Pneumococcus pneumonia in a hypoxemic patient. Coronal MPR image in lung parenchymatous window clearly shows a focal consolidation in the left lower lobe limited by the fissure.

References: A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE

The appearances of bacterial pneumonia are similar to those seen in infection due to atypical organisms (*Mycoplasma pneumoniae, Chlamydia* sp. *or Legionella pneumophila*). Other bacterial agents are the Gram negative bacilli, especially *Pseudomonas, Enterobacter, Klebsiella, Escherichia coli*, and Gram positive organisms; in particular community acquired methicillin-resistant Staphylococcus aureus.

Atelectasis with the absence of an air bronchogram suggests a mucoid impaction.
Alveolar consolidation may also be observed in *Pneumocystis jirovecii* infection, organizing pneumonia, radiation induced pneumonitis, bronchioloalveolar cell carcinoma, pulmonary lymphoma and acute interstitial pneumonitis (figure 2).

**Fig.**: Fig. 2 Kaposi disease in a HIV patient. Axial CT images in lung (a) and mediastinal (b) windows show a peribronchovascular consolidation (arrows) with a pleural effusion.

**References:** A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE

An inhalational pneumonitis could be suggested by right or bilateral lower zone involvement.

Bilateral lung involvement with basal predominance and abscess formation suggests infection by *Pseudomonas aeruginosa*.

Pulmonary infarction must be suspected in the case of a triangular, pleural based density with a truncated peak (figure 3).
Fig.: Fig. 3 Pulmonary infarct in patient with tricuspidian endocarditis. Axial CT scan images after intravenous contrast administration in parenchymatous (a) and mediastinal (b) windows demonstrate a triangular pleural based condensation with a truncated peak.

References: A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE

*Patchy consolidation and centrilobular micronodules*

Patchy alveolar consolidation suggests a bronchopneumonia, even more so when associated with centrilobular micronodules and tree-in-bud formation (figure 4).
**Fig.**: Fig. 4 Hemophilus influenzae bronchopneumonia. Axial native CT scan image in parenchymatous window (a) shows patchy consolidations and micronodules. Successive (left to right) maximum intensity projection (MIP) images of increasing slab thickness (b, c) more clearly depict the centrilobular and tree-in-bud formation (arrow) suggestive of an infectious bronchiolitis.

**References:** A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE

Centrilobular nodules and tree-in-bud formation with a heterogeneous, multifocal distribution and associated with bronchial wall thickening is suggestive of an infectious bronchiolitis.

There are no specific features of causative organisms. Aspergillosis and atypical mycobacterial infection should be considered according to the clinical context.

*Organising pneumonia*
Alveolar consolidation and/or ground glass opacity in a peribronchial and/or subpleural distribution implies an organising pneumonia, of unclear cause and whose evolution may be acute and mimic ARDS. A drug induced condition should be considered in particular.

**Diffuse consolidation**

Diffuse lesions are suggestive of diffuse alveolar damage. Air bronchograms and small volume pleural effusions are frequently seen. It may therefore be difficult to differentiate between classical ARDS and acute diffuse infiltrative pneumonitis. This group may be classified according to the clinical, radiological or biological presentation, according to histology or etiology. It encompasses a heterogeneous group of conditions, amongst which it is possible to distinguish pulmonary edema from diffuse alveolar damage of unknown cause, pneumonia due to unusual, odd or exotic organisms, drug-induced pneumonitis, pneumonitis associated with connective tissue disorders and vasculitis, pneumonitis linked to malignant processes, eosinophilic pneumonias, alveolar hemorrhage, and finally, when no underlying cause can be found, idiopathic infiltrative pneumonitis.

**Ground glass opacity**

Ground glass opacity (GGO) is defined as hyperdensity which does not obscure bronchial walls or vascular structures. GGO may correspond to partial or total alveolar filling, thickening of the alveolar septa with partial alveolar collapse, pulmonary fibrosis or an increase in size of the capillary vasculature.

The distribution of GGO and any associated lesions should be considered. Bilateral symmetrical lung involvement may be observed in ARDS with an extrapulmonary cause, as opposed to the pattern of lung involvement with a pulmonary cause. In an immunocompetent patient, infection due respiratory syncytial virus or varicella should be evoked. In an immunocompromised patient, Pneumocystis jirovecii (figure 5), cytomegalovirus (CMV) and mycoplasma infection should be considered. The differential diagnosis will include infectious and drug-induced causes, alveolar hemorrhage, organizing pneumonia and hypersensitivity pneumonitis. In the latter case, the rapid reversal of ARDS following withdrawal of the provoking allergen is highly suggestive.
Fig.: Fig. 5 Pneumocystis jirovecii pneumonia in a patient with auto-immune hepatitis on long-term corticotherapy. Axial CT scan in parenchymatous window shows symmetric bilateral ground glass opacities and gravity-dependent consolidations. A pneumomediastinum is also seen (arrows).

References: A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE

Concerning alveolar consolidation and GGO change, the geographical distribution of abnormalities, including cortical or medullary predominance, must be analyzed (figure 6).
Fig.: Fig. 6 Pneumocystis jirovecii pneumonia. Axial CT scan in parenchymatous lung window demonstrates bilateral ground glass opacities with medullary predominance and relative cortical sparing (arrows).

References: A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE

Lesions non declives are more suspicious than lesions declives. Peripheral lesions suggest eosinophilic pneumonia, vasculitis or resolving pulmonary edema. Hydrostatic pulmonary edema commonly has a perihilar or medullary distribution, but may also be diffuse, homogenous or heterogeneous, or predominantly decline. The size of the pulmonary vessels must always be analyzed. This can be an important indicator of hemodynamic disturbance, in a similar way to the presence of cardiomegaly or bilateral pleural effusions (figure 7). Gravitational ventral-dorsal redistribution may be seen in the prone position in non-fibrosing ARDS.
**Fig.**: Fig. 7 Hydrostatic pulmonary edema in a neutropenic patient after bone marrow allograft. Axial CT scan image in parenchymatous lung window demonstrates bilateral ground glass opacities, bronchial thickening (blue arrows), increased size of a pulmonary vein (black arrow) and bilateral pleural effusion.

**References:** A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE

**Nodules**

**Micronodules**
In the assessment of micronodules, post processing with maximum intensity projection (MIP) is required whereby the voxels with the highest attenuation values are projected throughout the 2D image. This helps to distinguish between a miliary/hematogenous and a bronchogenic pattern of spread (figure 8).
**Fig.**: Fig. 8 Coronal reformatted CT scan image (a) demonstrates ill-defined micronodules (blue arrows). Coronal maximum intensity projection (MIP) image (b) depicts more clearly the presence of centrilobular micronodules and tree-in-bud formation (black arrows) corresponding to a bronchogenic pattern.

**References:** A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE

A random distribution of nodules is in keeping with miliary/ hematogenous dissemination, suggestive of TB and metastases, but also histoplasmosis, candidiasis, blastomycosis or a viral cause (CMV, herpes, varicella), particularly in an immunocompromised patient (figure 9).

**Fig.**: Fig. 9 Axial CT scan image in a parenchymatous lung window demonstrates a diffuse and random distribution of multiple ill-defined micronodules corresponding to a miliary / hematogenous dissemination.

**References:** A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE

A bronchogenic pattern is characterized by the presence of centrilobular micronodules associated with tree-in-bud formation, with a heterogeneous distribution and typically subpleural sparing. Such a pattern may be seen in bacterial, mycobacterial, fungal, viral
and mycoplasma infection. Bronchiolitis and/or bronchopneumonia due to Aspergillus should be considered first in the immunocompromised patient.

**Nodules**

Pulmonary nodules due to an infectious cause are often encountered in nosocomial infections and in immunocompromised patients. They may be due to nocardiosis, tuberculosis, or semi-invasive aspergillosis in a neutropenic subject. The characteristic appearances in this case are of pulmonary nodules with a halo of ground glass density or triangular subpleural consolidation. Infection due to mucormycosis, candida, herpes simplex and CMV must also be considered in this situation. Nodules may equally be seen in infection due to *Cryptococcus, Coccidioides, Blastomycosis* or atypical mycobacteria. The rarer types of infection such as candidiasis, cryptococcosis, aspergillosis and nocardiosis should be considered according to the clinical context.

The possibility of septic emboli should be systematically considered in the case of cavitating nodules, particularly when peripheral or basal in situation (figure 10).

Non-infectious causes such as Wegener's granulomatosis should also be kept in mind, as should cavitating metastases and lymphoma (figure 11).
Fig.: Fig. 10 Septic emboli. Axial CT scan image in a parenchymatous lung window shows a peripheral cavitating pleural based nodule (blue arrow) corresponding to a septic embolus.

References: A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE
**Fig.**: Fig. 11 Epstein-Barr virus induced lymphoma in a bone marrow transplanted patient. Axial CT scan in parenchymatous lung window shows a solid lymphomatous nodule in the left lower lobe.

**References:** A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE

**Infiltration of the pulmonary interstitium**

Peribronchovascular thickening and / or smooth or nodular thickened septal lines may suggest hydrostatic pulmonary edema, or perilymphatic infiltration in keeping with lymphangitis carcinomatosis or lymphoma (figure 12). In the case of hydrostatic
edema, the pulmonary veins are usually enlarged, with cardiomegaly and pleural effusions. Dominant septal lines may also suggest rarer causes such as acute idiopathic eosinophilic pneumonia, also associated with pleural effusions (figure 13).

**Fig.**: Fig. 12 Lymphangitic carcinomatosis in a patient with gastric carcinoma. Axial CT scan image in parenchymatous lung window demonstrates peribronchial (blue arrows) and septal thickening.

**References:** A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE
Fig.: Fig. 13 Acute eosinophilia pneumonitis. Axial CT scan image in parenchymatous lung window shows peribronchial and septal thickening (blue arrows), a pleural based parenchymatous condensation (black arrow) and bilateral pleural effusion.

References: A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE

Cysts

Cystic lesions should be analyzed according to their geographical distribution and associated signs. Cavitation seen with areas of consolidation suggests infection due to a Gram negative bacillus or fungus. Community acquired pneumonia due to methicillin resistant staphylococcus aureus, secreting the Panton-Valentine toxin, should also be suspected (figure 14).
Fig.: Fig. 14 Community-acquired pneumonia to Staphylococcus Aureus Methicillin-resistant, secreting Panton-Valentine toxin. Axial CT scan in parenchymatous lung window shows nodules in the left upper lobe and cavitary condensation in the right upper lobe (blue arrow).

References: A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE

The immune status of the patient and the clinical context should also be taken into consideration.

Bunched groups of cysts sparing the cortex and containing air-fluid levels are suggestive of cystic bronchiectasis.

According to its distribution, honeycombing suggests idiopathic or secondary usual interstitial pneumonitis, or chronic or drug-induced hypersensitivity pneumonitis. Acute deterioration of idiopathic pulmonary fibrosis may occur with a frequency of less than 10% per year per patient, which may precipitate acute respiratory insufficiency requiring treatment in intensive care.

Likewise bronchial distortion and irregular septal lines are always looked for, as their presence suggest underlying fibrosis. Of note, the distortion is not always permanent and may correspond to an organizing pneumonia or reversible interstitial pneumonitis.
In addition, chronic obstructive bronchitis with emphysema and/or airway remodeling may be found, as well as bronchiectasis (figure 15).

![Diffuse centrilobular emphysema complicated by a bilateral pneumonia. Axial CT scan in parenchymatous lung window demonstrates bilateral declive ground glass opacities and condensation in a patient with diffuse centrilobular emphysema lesions, giving a pseudohoneycombing appearance. A typical centrilobular emphysematous lesion with a central dot corresponding to the centrilobular artery is shown (blue arrow).](image)

**Fig.** Fig. 15 Diffuse centrilobular emphysema complicated by a bilateral pneumonia. Axial CT scan in parenchymatous lung window demonstrates bilateral declive ground glass opacities and condensation in a patient with diffuse centrilobular emphysema lesions, giving a pseudohoneycombing appearance. A typical centrilobular emphysematous lesion with a central dot corresponding to the centrilobular artery is shown (blue arrow).

**References:** A.-L. Brun; radiology, Pitié-Salpêtrière Hospital, Paris, FRANCE

Multiple bilateral cystic lesions, or pneumatoceles, may be seen during the fibrosing phase of ARDS in zones declives, in addition to traction bronchiectasis.

Barotraumatic lesions due to assisted ventilation such as interstitial emphysema, pneumomediastinum, pneumothorax and/or subcutaneous emphysema should be easily identifiable.
**Fig. 1:** Pneumococcus pneumonia in a hypoxemic patient. Coronal MPR image in lung parenchymatous window clearly shows a focal consolidation in the left lower lobe limited by the fissure.
Fig. 2: Fig. 6 Pneumocystis jirovecii pneumonia. Axial CT scan in parenchymatous lung window demonstrates bilateral ground glass opacities with medullary predominance and relative cortical sparing (arrows).
**Fig. 3:** Fig. 5 Pneumocystis jirovecii pneumonia in a patient with auto-immune hepatitis on long-term corticotherapy. Axial CT scan in parenchymatous window shows symmetric bilateral ground glass opacities and gravity-dependent consolidations. A pneumomediastinum is also seen (arrows).
**Fig. 4:** Fig. 9 Axial CT scan image in a parenchymatous lung window demonstrates a diffuse and random distribution of multiple ill-defined micronodules corresponding to a miliary / hematogenous dissemination.
**Fig. 5:** Fig. 13 Acute eosinophilia pneumonitis. Axial CT scan image in parenchymatous lung window shows peribronchial and septal thickening (blue arrows), a pleural based parenchymatous condensation (black arrow) and bilateral pleural effusion.
**Fig. 6:** Fig. 14 Community-acquired pneumonia to Staphylococcus Aureus Methicillin-resistant, secreting Panton-Valentine toxin. Axial CT scan in parenchymatous lung window shows nodules in the left upper lobe and cavitary condensation in the right upper lobe (blue arrow).
Conclusion

The use of thoracic CT is becoming increasingly frequent in the investigation of patients with multiple potential medical problems in the intensive care setting. Although the use of CT appears pertinent, its role in the evaluation of hypoxic parenchymal disease is unclear and remains to be evaluated. It adds to the information obtained on bronchoscopy. It may be the decisive factor in determining the diagnosis and guiding the clinician's therapeutic approach. It could clarify the presence of an underlying problems and in particular suggest complication of a pre-existing pathology.

Therefore, a thorough diagnostic approach which includes CT may be helpful in the management of patients in intensive care, although mixed findings may be encountered. This minimally invasive technique offers the prospect of research into the role of CT in the management of hypoxic respiratory insufficiency with diffuse infiltrates.

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