Infections in the Intensive Care Setting: Role of Radiology

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Imaging plays a vital role in the diagnosis and management of a wide range of infections and their associated complications in the intensive care unit (ICU). A wide range of modalities is available nowadays, even at the bedside, increasing the armamentarium of resources available to us. The understanding of the modalities with specific knowledge of the advantages and disadvantages of each of these modalities would enable optimal utilization of resources, prompt management of various conditions with better clinical outcomes.

A radiograph is often the first investigation done in a patient suspected of having an infection on clinical grounds in the ICU setup, especially in suspected chest infections. This is not only due to the limited utility of the physical examination in the intensive care setup but also due to the widespread availability of bedside radiography machines. However, radiographs may not always be diagnostic due to the low sensitivity and specificity of the findings. Usage of sub-optimal radiographic technique in the ICU setting, and the presence of monitoring and other devices (either in or on the patient) that obscure parts of the exposed field as well hinder in the interpretation of the pathological findings (Bekemeyer et al. 1985; Henschke et al. 1983; Janower et al. 1984).

Ultrasonography (USG) is increasingly used in the ICU setup due to its immediate bedside availability and the ease of performing it without the need for technicians (as for radiographs/CT). It is a useful adjunct to radiographs and helps in diagnosing and differentiating certain non-specific findings on the radiograph. Also, USG can be used for performing image-guided procedures like draining fluid/collections or for diagnostic aspiration.

Computed Tomography (CT) is predominantly used as a problem-solving tool in the ICU setup as usually the patient needs to be shifted to the CT suite for the scan. Hence acutely ill or unstable patients need to be stabilized initially before a CT can be performed. Also, there is nearly 100 times greater radiation exposure with a CT
compared to a routine chest radiograph (Mettler et al. 2008). CT plays an important role in the CNS due to the limited utility of radiographs and USG.

Magnetic Resonance Imaging (MRI) is rarely used in the ICU mainly due to its long acquisition times and the resultant need for sedation/anesthesia. Initially, MRI was predominantly used for CNS imaging due to a lack of motion-related artifacts. However, with technological advances and the availability of faster sequences, it is increasingly used as a problem-solving tool in the chest and abdomen as well.

The utility of imaging modalities in various clinical situations is discussed as per various organ systems involved.

### 19.1 Chest

Chest radiographs were widely obtained on a daily basis in the ICU setup previously (Figs. 19.1 and 19.2). However, studies have shown that routine daily chest

![Fig. 19.1](image-url) **Fig. 19.1** Different patterns on Chest Radiograph—(a) Typical fluffy air space opacities with air bronchogram in a bilateral perihilar location in a case of pulmonary edema. There is also an incidental mal-positioned central venous catheter. (b–d) Collapse—mal-positioned ET position into the right bronchus intermedius causing a collapse of the entire left lung and the right upper lobe (b), collapse of right upper lobe (c), typical triangular retrocardiac opacity obscuring the left hemidiaphragm in a case of left lower lobe collapse (d)
radiograph is not indicated for all patients in the intensive care setup. The American College of Radiology (ACR) considered daily portable CXRs most appropriate for patients receiving mechanical ventilation (MV) until 2008. However, later work revealed that patient-centered outcomes (e.g., mortality, length of stay, and duration of MV) are not associated with routine daily CXRs. Based on this, the ACR recommendations were amended. In 2014, the entire category of patients receiving MV was removed and routine CXRs in all stable patients in the ICU were categorized as “usually not appropriate.” In patients with a central venous catheter, a Swan-Ganz catheter, a feeding tube, or a chest tube placement, only postprocedure radiographs are indicated. Stable patients with cardiac diseases and those with purely extrathoracic disease require only admission films upon entry into the ICU (Amorosa et al. 2013; Soo and Edey 2012; Savoca et al. 1978; Godoy et al. 2012a; Godoy et al. 2012b).
Chest USG enables prompt differentiation of pleural effusion vs. consolidation and also helps in bedside image-guided interventions enabling better precision, improved outcomes with lesser chances of failed attempts (Fig. 19.3).

Some of the common infective pathologies of the chest encountered in the intensive care setting are discussed below.

**Aspiration** It is common in ICU patients. It can be divided into three forms: Aspiration pneumonitis, aspiration pneumonia, and central airway obstruction. The severity of aspiration would depend on the type and volume of the aspirate. Risk factors include general anesthesia, depressed consciousness, neuromuscular disorders, esophageal disease. Focal or multifocal consolidation in the dependent parts of the lungs is the most common radiographic finding. Acinar filling results in poorly defined nodules in an airway distribution. Other findings include airway wall thickening and plugging, and associated volume loss. Aspiration pneumonitis usually shows clearing within the first few days. A lack of clearing or progression is sugges-

![Fig. 19.3 Chest ultrasonography: The high sensitivity in the detection of minimal effusion demonstrated as a thin anechoic streak (a). Moderate effusion with septae debris (b), associated pleural thickening and collapsed lung (c). Homogenous echogenicity with linear streak artifacts (air bronchogram) in consolidation (d). Stratosphere sign on M-mode in a case of pneumothorax (e).](image-url)
tive of the development of pneumonia. In the supine position (typical of ICU setup), the aspiration is typically located in the posterior aspect of the upper lobes, the superior and posterior basal segments of the lower lobes resulting in a central predominance on the AP supine radiograph (Lee and Ryu 2018; Hu et al. 2015; Newman et al. 1982; Shifrin and Choplin 1996; Prather et al. 2014; Franquet et al. 2000).

**Pneumonia** In the ICU setup, it is usually Hospital-acquired pneumonia (HAP—lower respiratory infection manifesting clinically 2 or more days after hospital admission) or Ventilator acquired pneumonia (VAP—lower respiratory infection manifesting clinically 2 or more days after intubation). Gram-negative bacteria are the most frequently implicated in HAP. Radiographic changes in pneumonia typically occur more slowly than in atelectasis, aspiration, or pulmonary edema. It is generally impossible to specifically identify the causative organism based on the radiological appearance; however, there are some general radiological patterns that enable us to narrow down on the list of differential diagnosis (Tarver et al. 2005; Katz and Leung 1999; Reynolds and Banerjee 2012; Langer and Haeusler 2009).

Various radiological patterns and the commonly associated organisms include

- **Lobar consolidation**—Streptococcus pneumoniae, Klebsiella pneumoniae, Pseudomonas aeruginosa
- **Necrotizing pneumonia/cavitation/lung abscess**—Staphylococcus aureus, gram-negative bacteria including Acinetobacter baumannii, rarely Candida albicans
- **Bronchopneumonia**—Staphylococcus aureus, gram-negative bacteria, aspergillosis, atypical organism like Mycoplasma (peribronchial nodules and bronchial wall thickening)
- **Interstitial**—infrequent pattern—viral infections
- **Nodular**—Septic emboli (Staphylococcus aureus), Angioinvasive fungal infections (immunocompromised host)

**Complications** Radiology plays an important role in the early diagnosis of various complications and prompt image-guided interventions would prevent further clinical deterioration. Various complications include (Fig. 19.4)

- **Pulmonary**—Lung abscess, gangrene, ARDS.
- **Pleural**—Synpneumonic effusions and empyema due to *Staphylococcus aureus*, gram-negative bacteria; Pneumothorax in cavitatory infections especially in ventilated patients; bronchopleural fistula.
- **Vascular**—Pulmonary hemorrhage, vascular thrombosis, pseudoaneurysms.
- **Others**—Chest wall osteomyelitis, empyema necessitans, etc.

ARDS, pulmonary embolism, pulmonary edema, and atelectasis can mimic pneumonia especially in the ICU setting and a multidisciplinary approach with a clinical-radio-pathological discussion would be needed to differentiate these from
pneumonia and its above-described complications (Vilar et al. 2004; Lampichler 2017; Klein et al. 1995; Light et al. 1980; Mueller and Berlin 2002).

19.2 Central Nervous System

Neurological infections constitute an important etiological cause requiring admission to ICU. In addition, health-care associated neurological infections, including those that develop as complications secondary to various procedures, may develop in critically ill patients admitted to an ICU for other indications. Although bacterial infections are the most common cause, mycobacterial and fungal infections are also frequently encountered. The single most important prognostic factor is the delay in institution of specific treatment and thus timely diagnosis is of utmost importance.

Fig. 19.4 Pneumonia and its complications—Patchy air space opacities in bilateral lung fields in a case of bronchopneumonia (a), lung abscess with air-fluid level (b), empyema with loculated collection (c), patchy bilateral air space opacities in ARDS (d)
Patients with CNS infections usually present with altered sensorium which may or may not be accompanied by fever. Both CT and MRI are useful in the evaluation of CNS infections; however, MRI is more sensitive than CT in the evaluation of both meningeal and parenchymal inflammation. MRI with or without IV contrast is the most appropriate imaging according to the ACR appropriateness criteria in a suspected case of meningitis/encephalitis (Douglas et al. 2014). However, this is usually not possible in the ICU setting and hence CT scan is the initial investigation most of the time.

The use of IV contrast not only enables the radiologist to identify abnormal meningeal enhancement (although low sensitivity) that can be seen in meningitis but also increases the sensitivity for identification of intra-axial complications like a cerebral abscess, etc. which are discussed in further detail in later sections. Prior to administration of iodinated contrast, most radiologists would recommend the need for a pre-procedure renal function test to ascertain that the kidney function is normal. This might delay the scan by a few hours. In patients who would need immediate scans or in those with deranged renal parameters a non-contrast CT scan can be performed to rapidly rule out hydrocephalus so that a lumbar puncture can be performed and microbiological analysis of the CSF done to ascertain the specific causative organism (Kastrup et al. 2008; Aiken 2010; Rangarajan et al. 2014).

Meningitis Imaging has a very low sensitivity in the diagnosis of meningitis. Thin continuous leptomeningeal enhancement may be seen along the convexity of the brain in cases of bacterial and viral meningitis. The presence of exudates in the basal cisterns is considered typical of tuberculosis. MRI easily differentiates basal cisternal enhancement from vessels in the region of the circle of Willis in a case of equivocal abnormal subarachnoid space enhancement on CT. Also, enhancement over the cerebral convexities is easier to appreciate on MRI as opposed to CT because the overlying inner table of the skull is seen as an adjacent signal void on MR imaging unlike in CT in which the bones show hyperdense signal resulting in decreased contrast difference between the meningeal enhancement and the bone. In a patient in whom contrast administration is not possible, a non-contrast MRI would provide more details than a non-contrast CT due to better contrast resolution at the expense of longer scan duration (Douglas et al. 2014; Mohan et al. 2012).

The main role of imaging in meningitis is to detect complications (Kastrup et al. 2008; Rangarajan et al. 2014; Mohan et al. 2012; Rath et al. 2012) (Fig. 19.5) which include

- Communicating hydrocephalus—due to impaired CSF absorption by inflammatory exudates. Leptomeningeal-ependymal fibrosis leading to irreversible communicating-obstructive hydrocephalus may follow bacterial meningitis
- Cerebritis
- Abscess
- Ventriculitis—a thin rim of ventricular enhancement
Subdural effusion—irritation of the dura by the infectious agent or by its products. Or secondary to inflammation of the subdural veins with an associated increase in protein and fluid in the subdural space.

Subdural empyema

Cortical/subcortical/basal ganglia infarcts—due to the involvement of perforating basal vessels by associated vasculitis (especially in tuberculosis)

Venous infarcts—due to venous sinus thrombosis.

Cerebritis and Abscess. Four pathological stages are described in the formation of an abscess each with distinct imaging features:

- Early cerebritis stage—normal or poorly marginated cortical or subcortical edema and mass effect
- Late cerebritis stage—more defined, but still irregular, a rim-enhancing lesion with a hypodense center
- Early capsule stage—discrete lesion with thin enhancing rim and surrounding edema

Fig. 19.5 Meningitis and its complications—Smooth leptomeningeal enhancement in bacterial meningitis (a), thick enhancing exudates in the basal cisterns in tubercular meningitis (b), smooth leptomeningeal enhancement with hydrocephalus (c), subdural fluid with smooth peripheral enhancement in subdural empyema (d), hypodensity in the left basal ganglia region with loss of gray–white matter differentiation due to development of infarct (e), smooth enhancement of the ventricular lining with periventricular hypodensity in ventriculitis secondary to rupture of bacterial abscess into the ventricle (f)
• Late capsule stage—progressive central necrosis, cavity shrinks, decreasing surrounding edema

Usually, the diagnosis is made in the late cerebritis stage or early capsule stage. MRI is superior to CT due to its greater sensitivity to subtle parenchymal changes, like white matter changes. Also advanced techniques like MR spectroscopy help in the differentiation of bacterial/fungal/tubercular abscess (Rangarajan et al. 2014; Rath et al. 2012).

**Encephalitis** Infiltration of the parenchymal by inflammatory cells and is commonly due to a viral etiology. The brain damage is due to a combination of intracellular viral growth and the host inflammatory response. A few common viral encephalitides are described in detail below (Fig. 19.6).

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**Fig. 19.6** Encephalitis—bilateral hippocampal hyperintensity in herpes encephalitis (a, b), bilateral asymmetric thalamic hyperintensity in Japanese encephalitis (c), smooth ependymal enhancement with debris in the ventricle in ventriculitis in CMV (d)
Herpes simplex encephalitis—HSV 1 is the cause in nearly 95% of the cases and is considered to be caused due to latent herpes simplex virus in the Gasserian ganglion, with retrograde spread along the trigeminal nerve to involve the temporal and inferior frontal lobes. This explains the predilection for the involvement of the limbic system (inferomedial temporal lobes, the orbital surface of the frontal lobes, and the insular cortex). Posterior occipital cortex, cerebral convexity, and the external capsule may also be involved with typical sparing of the basal ganglia. Involvement may initially be unilateral but is typically followed by less severe contralateral disease. This “sequential bilaterality” is highly suggestive of herpes encephalitis. Small petechial hemorrhages are often present. In immunocompromised patients, there may be multifocal involvement and may not conform to the typical imaging appearance (Rangarajan et al. 2014; Granerod et al. 2016; Bonnici-Mallia et al. 2016).

Varicella-zoster virus encephalitis usually presents as brainstem encephalitis due to spread along the V and VII cranial nerves to the brainstem. This may be accompanied by vasculitis.

Cytomegalovirus encephalitis is usually seen in immunocompromised patients and is characteristically accompanied by ependymitis. Post-contrast MRI reveals considerable enhancement along the ependyma (Rangarajan et al. 2014; Mohan et al. 2012; Rath et al. 2012).

Japanese encephalitis (JE) presents with characteristic neurologic findings during the acute stage like extrapyramidal signs such as tremor, dystonia, and rigidity. JE should be distinguished from other types of encephalitis, particularly HSE, because antiviral therapy for HSE is very effective in the acute stage while specific antiviral therapy is not available for JE, its treatment being supportive. JE shows diffuse meningoencephalitis affecting both gray and white matter of the cerebral hemispheres, basal ganglia, brainstem, cerebellum, and thalamus (Rangarajan et al. 2014; Basumatary et al. 2013; Misra et al. 2003).

Other infections include cryptococcosis, toxoplasmosis, neurocysticercosis, and various other viral infections which are beyond the scope of discussion in the chapter.

Demyelination (including both Acute Demyelinating Encephalomyelitis (ADEM) and Multiple sclerosis) is a great mimicker with a wide range of imaging appearances. Typical white matter involvement with sparing of gray matter are subtle signs to help in the differentiation from infective pathology, although a definitive distinction may not be possible always based on imaging and would need correlation with clinical features and microbiological and pathological analysis of the CSF (Rangarajan et al. 2014; Ketelslegers et al. 2010).

### 19.3 Abdomen

Infections in the abdomen in the ICU setting can be grouped into hepatobiliary, gastrointestinal, genitourinary, and peritoneal causes as enlisted below.

1. Hepatobiliary
   - Liver abscess
   - Cholangitis
• Emphysematous cholecystitis
• Infected pancreatic collections
• Splenic abscess
2. Gastrointestinal
• Infective enterocolitis and related complications
• Intestinal perforations
• Post-op leaks
3. Genitourinary
• Pyelonephritis
• Cystitis
• Prostatitis, Prostatic abscess
• Endometritis, Salpingo-oophoritis
• Tubo-ovarian abscess
4. Peritoneal
• Spontaneous bacterial peritonitis
• Secondary peritonitis

Septic shock and acute kidney injury are more common in abdominal infections than with infections in other sites. And there is a greater degree of diversity in the causative organism than other organ systems. Hence an accurate and timely diagnosis is imperative to improve clinical outcomes (Shirah and O’Neill 2014).

Although radiology does not help in identifying the exact etiology of intra-abdominal infection, it can be helpful to narrow down on the organ system and to decide upon further treatment strategies (Fig. 19.7).

Gastrointestinal —In a suspected case of bowel obstruction or perforation, plain x-rays can demonstrate free air in the setting of perforation, pneumatosis in the setting of ischemic bowel, or abnormally dilated loops of bowel in the setting of toxic megacolon or bowel obstruction. In a relatively stable patient in the subacute or post-op setting, contrast studies may be used to reveal fistulas or leakage from a perforated hollow viscus or anastomotic leaks. However, CT scan with IV contrast helps in diagnosing luminal and extraluminal pathology as well as to look in hidden areas that may not be seen with ultrasound especially in the post-op setting due to a limited acoustic window (Paulson and Thompson 2015; Jaffe and Thompson 2015; Suri et al. 1999).

Hepatobiliary Ultrasonography can be a highly useful tool to localize the infections in case of hepatobiliary or genitourinary causes. It helps in assessing the solid organs for abscesses or granulomas, assessing the biliary tract in patients with obstructive jaundice or for assessing intra-abdominal collections or free fluid (in cases of peritonitis) with good diagnostic accuracy in experienced hands. Also, it can be used for guided aspiration to improve the diagnostic yield. When cross-sectional imaging is to be used, CT with IV contrast is used to look for complications and other associated findings, while MRI with MRCP (magnetic resonance cholangiopancreatography) is better to assess the biliary tree. CT also has higher sensitivity in detecting complicated pancreatic collections and also helps in CT guided drainage procedures in infected pancreatic collections (Dhaka et al. 2015; Morgan et al. 1997).
Genitourinary Uncomplicated UTI does not warrant further imaging and is usually confirmed by urinalysis. However, in complicated cases, cross-sectional imaging is used to look for complications like perinephric collections/emphysematous pyelonephritis.

Endocavitary probes for Trans-vaginal ultrasound or Trans-rectal ultrasound examination in cases of suspected genital infection improve the diagnostic accuracy although a transabdominal ultrasound of the pelvis using bladder as acoustic window also gives reasonably good results in detecting the genitourinary pathologies.

Fig. 19.7 Abdominal Pathologies—Small bowel obstruction with dilated small bowel loops and multiple air-fluid levels (a), large bowel obstruction with dilated large bowel loops and absence of rectal air (b), pneumoperitoneum on chest radiograph (c), coronal CT showing air in the left renal fossa in emphysematous pyelonephritis (d)
and pelvic collections. CT may be required in certain cases when the extent of the disease cannot be ascertained on USG (Laing 1992).

**Peritoneal** Usually present with free fluid or collections in the peritoneal cavity, ultrasound-guided aspiration of which would help in diagnosing the cause and the specific organism.

### 19.4 Miscellaneous Infections

Other sources of infections can be the extremities in the form of cellulitis and their complications. USG is used in such cases to rule out complications like abscess formation. Bone involvement by infections is rare in the ICU setting, although rarely acute osteomyelitis and septic arthritis may be seen in the pediatric population. Infections of the extracranial head and neck usually require ENT examination along with ultrasound and CT with IV contrast for identifying various complications like a retropharyngeal abscess.

### 19.5 Role of Interventional Radiology

As discussed above image-guided interventions play a crucial role in the management of various infections. Ultrasound-guided procedures can be done at the bedside while fluoroscopy and CT guided procedures need shifting of the patient to the radiology department. Various procedures that can be done include -

- **Diagnostic aspiration**—using 18G or 20G needles for pleural, peritoneal, abdominal, and pelvic collections.
- **Diagnostic sampling (biopsy)**—CT guided biopsy is done for certain lung infections that do not respond to empirical therapy.
- **Therapeutic aspiration**—usually USG guided Pigtail insertion (8-12F) using either a single puncture or Seldinger technique with graded dilators. CT guidance used for pancreatic collections and some pelvic collections.
- **Biliary drainage** (Percutaneous Transhepatic Biliary Drainage—PTBD)—in cholangitis when an endoscopic procedure cannot be done or has failed.
- **Urinary drainage** (Percutaneous Nephrostomy—PCN)—in complicated UTI like pyonephrosis.
- **Vascular interventions**—complications of infections like pseudoaneurysms can be managed with endovascular embolization.

Thus radiology plays an important role in the management of infections in the ICU setting and its optimal usage would enable us to localize, diagnose, and treat some of the complications in a timely and minimally invasive manner improving the overall clinical outcomes.
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