Emergency Radionuclide Imaging of the Thorax and Abdomen

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Introduction

Nuclear medicine (NM) utilizes a variety of unsealed radioactive compounds, known as radiopharmaceuticals or radiotracers. Given in small (tracer) quantities, radiopharmaceuticals typically consist of two components: a radionuclide (also known as a radioisotope) and a molecular or cellular carrier; the latter determines the biologic distribution upon administration to a patient. The most common routes of administration in clinical practice are intravenous (IV) and oral.

Based on its respective radionuclide, a radiopharmaceutical emits specific gamma rays, which can be detected and processed into medical images by gamma cameras, which is termed scintigraphy. The resulting scintigraphic images depict the biodistribution of the administered radioactivity within the patient's body, thereby reflecting normal or abnormal physiological function combined with a low-resolution anatomical representation of the organs/organ systems under investigation. The physiological data are complementary to the anatomical data and, in certain conditions, prove more beneficial than the anatomical data alone.

In the emergency setting, appropriate triage and timely diagnosis are of utmost importance. Emergency physicians have come to rely more and more heavily on medical imaging for diagnosis and management; decisions to admit or discharge often hinge on the radiological diagnosis. NM examinations are generally underutilized in the emergency setting for a number of fundamental reasons. Emergency physicians tend to be less familiar with the NM options and are less experienced with their respective appropriateness and advantages. Common logistical challenges include limited availability and longer duration compared to other types of imaging examinations. Specifically, there may be difficulty obtaining radiopharmaceuticals during evenings, nights, and weekends. In many institutions, NM personnel are typically only on-site during regular working hours; at some institutions, the NM technologists are "on call" while in others, there is no availability during the off-hours. This lack of ready access is likely one of the major determinants that leads emergency physicians to request fewer NM examinations. Even when available, however, scintigraphic examinations generally require more time than radiography (X-ray) or computed tomography (CT).

Nevertheless, NM can play important primary and secondary roles in diagnosis and management in the emergency setting. Within the radiological armamentarium, selected scintigraphic examinations offer significant value because those negative examinations exclude diagnoses with high certainty, while positive examinations direct appropriate management. Currently, the most common radionuclide imaging examinations of the thorax and abdomen in the emergency setting are ventilation/perfusion (V/Q) lung scintigraphy, myocardial perfusion imaging (MPI), hepatobiliary scintigraphy (HBS), and gastrointestinal (GI) bleeding scintigraphy (Table 14.1). This chapter will review their appropriate utilization, highlight their advantages and disadvantages, and illustrate each by way of representative case examples.

Acute Pulmonary Embolism: Ventilation/Perfusion (V/Q) Lung Scintigraphy

Pulmonary embolism (PE) is a potentially fatal complication of deep venous thrombosis. In acute PE, thrombus dislodges from the vein, migrates to the pulmonary vasculature, and lodges in a main pulmonary artery or segmental branch. Thromboemboli reduce the cross-sectional area of the pulmonary arterial vascular bed, thus potentially resulting in hypoxia and hemodynamic compromise. Diagnosing acute PE can be very difficult clinically due to nonspecific symptoms and confounding clinical presentations mimicking other acute thoracic and abdominal conditions.

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Table 14.1 Common clinical indications for emergency radionuclide imaging of the thorax and abdomen

Clinical indication	Examination	Radiopharmaceuticals	Typical time to completion	Sensitivity	Specificity	Positive predictive value	Negative predictive value	References
Acute pulmonary embolism	V/Q lung scintigraphy	*Ventilation*: ^{133}Xe gas, inhaled, or ^{99m}Tc DTPA aerosol, inhaled *Perfusion*: ^{99m}Tc MAA, IV	30–60 min	70–85 % for high-probability interpretation	96–98 % for normal/very low-probability interpretation	96–99 % for high-probability interpretation with high clinical suspicion	97–98 % for normal/very low-probability interpretation	[1–3]
Acute coronary syndrome	Myocardial perfusion imaging	^{99m}Tc sestamibi IV or ^{99m}Tc tetrofosmin IV	1–2 h	90–100 %	63–71 %	15–22 %	97–99 %	[3–8]
Acute biliary conditions: cystic duct obstruction (acute cholecystitis) and common bile duct obstruction	Hepatobiliary scintigraphy	^{99m}Tc IDA analog, IV	1–4 h	88–100 %	93–100 %	85–90 %	95–99 %	[9–11]
Acute biliary conditions: bile duct injury			1–2 h	100 %	90–100 %	91–100 %	100 %	[12]
Gastrointestinal bleeding	GI bleeding scintigraphy	^{99m}Tc RBCs, IV	1–2 h	78–97 %	70–100 % for diagnosis, 88–97 % for localization	75–77 %	76–93 %	[13–16]

Table 14.2 Typical ventilation/perfusion (V/Q) lung scintigraphy technical protocol

1. Obtain contemporaneous chest radiography in posterior-anterior (PA) and lateral projections
2. Patient inhales 20 mCi (740 MBq) of ^{133}Xe gas or 3 mCi (111 MBq) of aerosolized ^{99m}Tc diethylenetriaminepentaacetic acid (DTPA)
3. Acquire ventilation images in posterior (^{133}Xe gas) or anterior, posterior, bilateral anterior oblique, and bilateral posterior oblique (^{99m}Tc DTPA aerosol) projections
4. Administer 4 mCi (148 MBq) of ^{99m}Tc macroaggregated albumin (MAA) IV
5. Acquire perfusion images in anterior, posterior, bilateral anterior oblique, and bilateral posterior oblique projections

Both CT angiography (CTA) and ventilation/perfusion (V/Q) lung scintigraphy are well-accepted modalities for the imaging evaluation of suspected acute PE. Nowadays, CTA is performed in the vast majority of patients. However, V/Q scintigraphy remains relevant because radionuclide imaging of the lungs provides physiological information regarding not only regional pulmonary arterial perfusion but also bronchoalveolar ventilation. V/Q scintigraphy also spares the patient exposure to potentially nephrotoxic iodinated contrast and results in lower radiation dosimetry [3].

Although V/Q lung scintigraphy protocols vary by institution, ventilation images, using one of two commercially available radiopharmaceuticals, are typically acquired first. The perfusion phase using a standard radiopharmaceutical follows (Table 14.2). Perfusion imaging is based on the principle of capillary blockade. The radioactive MAA particles are larger than the capillaries and lodge in the precapillary arterioles; thus, their biodistribution reflects pulmonary arterial blood flow to both lungs. On these scintigraphic images, pulmonary segments with normal perfusion demonstrate uniform perfusion throughout (Fig. 14.1), while those with decreased perfusion demonstrate lower radioactivity than normal segments (Figs. 14.2 and 14.3). Classically, underlying lung disease presents as mildly to markedly abnormal perfusion that is "matched" by abnormal ventilation (Fig. 14.2). Acute PE affects perfusion only while ventilation should be preserved, resulting in the so-called V/Q mismatch pattern (Fig. 14.3). The PIOPED II criteria can be used to interpret V/Q lung scintigraphy (Table 14.3) [2].

In selecting the optimal radiological approach for suspected acute PE, the emergency physician should take into account multiple factors, not the least of which include sensitivity and specificity of the different imaging examinations, technical availability, and patient safety. First, for a patient with acute symptomatology, conventional chest radiography remains first-line. Patients with significantly abnormal chest radiographs should be directed to CTA and are not well suited for V/Q lung scintigraphy because there is greater likelihood of a nondiagnostic interpretation due to confounding underlying pulmonary conditions such as chronic obstructive lung disease, pneumonia, pleural effusion, or atelectasis [17]. Concomitantly, there can be considerable interobserver variability of V/Q interpretations, especially in low and intermediate categories. CTA has the distinct advantage of evaluating the entire chest and upper abdomen and can delineate alternate thoracic or abdominal pathologies.

Second, in most institutions today, CTA is available around the clock with an on-site CT technologist who can perform the examination in a timely manner. During the standard workday, V/Q lung scintigraphy can be performed relatively quickly; however, during the off-hours, the NM technologist usually needs to travel into the hospital, and the radiopharmaceuticals may need to be prepared in-house or delivered from an outside pharmacy, all requiring additional time.

Third, there is much concern about radiation dosimetry, and the risks related to iodinated contrast are well established [3]. With CTA, there is higher radiation exposure to the patient, particularly to the female breast. The tissue dose to the breasts of nonpregnant women can be 10–60 mGy (1–6 rad) and is probably higher in pregnancy. Conversely, the breast dose from V/Q lung scintigraphy can be much lower than 0.31 mGy (0.031 rad) or almost 200 times less than CTA, and during the first trimester of pregnancy, the fetal dose can be halved using a modified reduced dose V/Q lung scintigraphy protocol [3]. Thus, for selected patients with special medical considerations such as pregnancy, breast-feeding, poor renal function, or IV contrast allergy, V/Q lung scintigraphy may represent the most appropriate imaging examination.

In summary, V/Q lung scintigraphy can be considered as a primary imaging approach in patients with suspected acute PE when there is:

1. Normal chest radiography
2. No concurrent cardiopulmonary process
3. Available NM facilities and personnel
4. Relative contraindication to CTA regarding radiation exposure or use of iodinated contrast

Acute Coronary Syndrome: Myocardial Perfusion Imaging

Acute coronary syndrome (ACS) accounts for approximately 10 % of all emergency department visits, making it one of the most commonly encountered medical emergencies. ACS refers to a spectrum of clinical presentations ranging from ST-segment elevation myocardial infarction to unstable angina. Clinical presentation, electrocardiography (ECG), and cardiac biomarkers, such as troponin, guide initial risk stratification. Troponin has become the favored biomarker for determination of myocardial necrosis because of

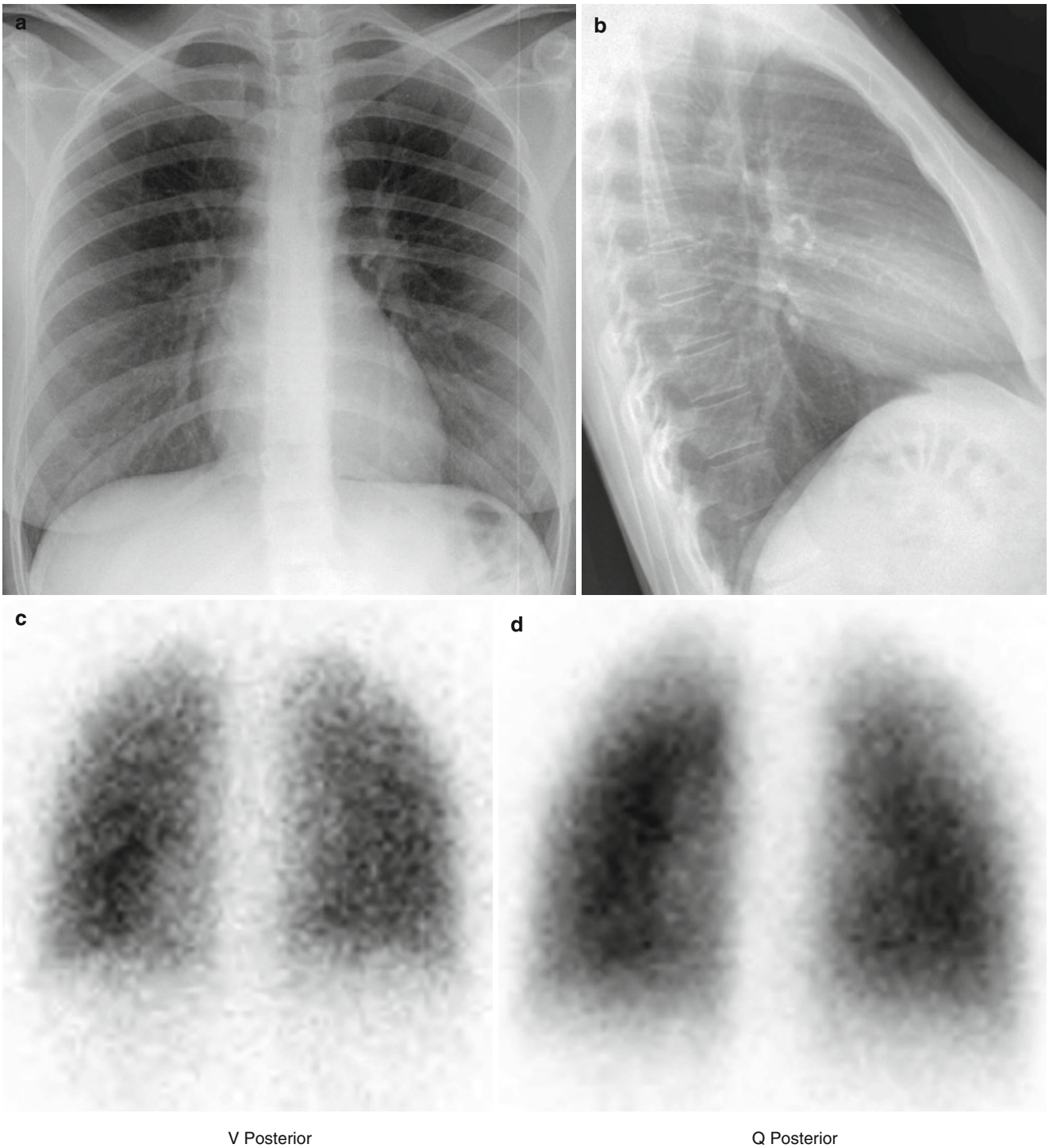


Fig. 14.1 Normal. Normal posterior-anterior (**a**) and lateral (**b**) chest radiographs. Normal ventilation (**c**) and perfusion (**d**) scintigraphy performed with ^{133} Xe gas (ventilation) and ^{99m}Tc MAA (perfusion)

the high sensitivity and specificity. However, myocardial biomarkers can only diagnose infarction and cannot identify ischemia in the absence of necrosis; also, laboratory evidence lags behind the physiological event. By convention, patients are stratified into three risk groups: high risk, moderate risk, and low risk.

The majority of patients with chest pain have no history of coronary artery disease and no ischemic ECG changes. Risk of ACS in such patients is low; however, it is not zero. Identification of high-risk patients within this cohort can be difficult clinically. Thus, many patients without ischemia are admitted for observation and further testing.

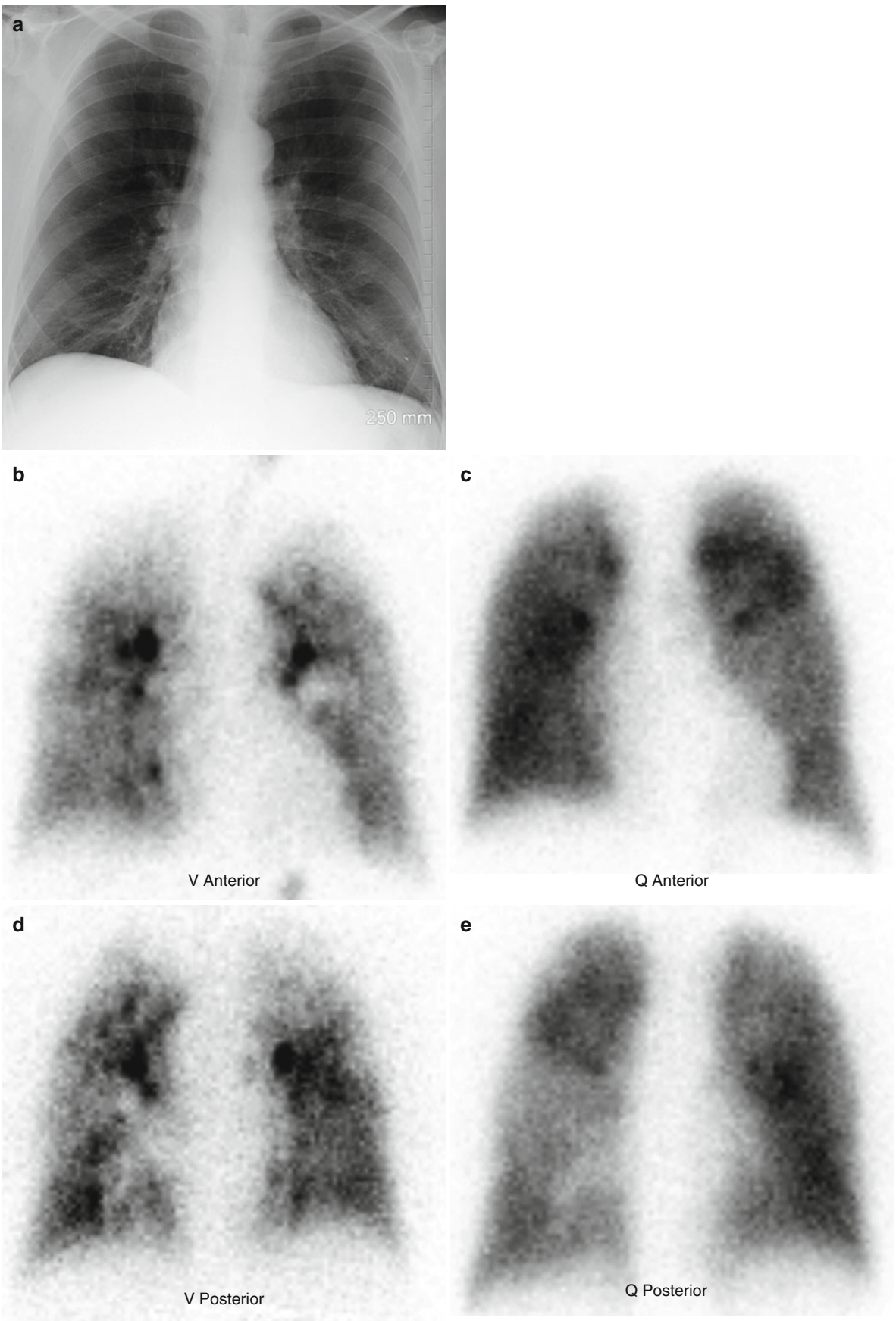


Fig. 14.2 Multiple matched V/Q abnormalities related to underlying airways disease. Normal chest radiograph (**a**). Heterogeneous ^{99m}Tc DTPA ventilation (*left panel*: **b**, **d**, **f**, **h**) and heterogeneous ^{99m}Tc MAA perfusion (*right panel*: **c**, **e**, **g**, **i**)

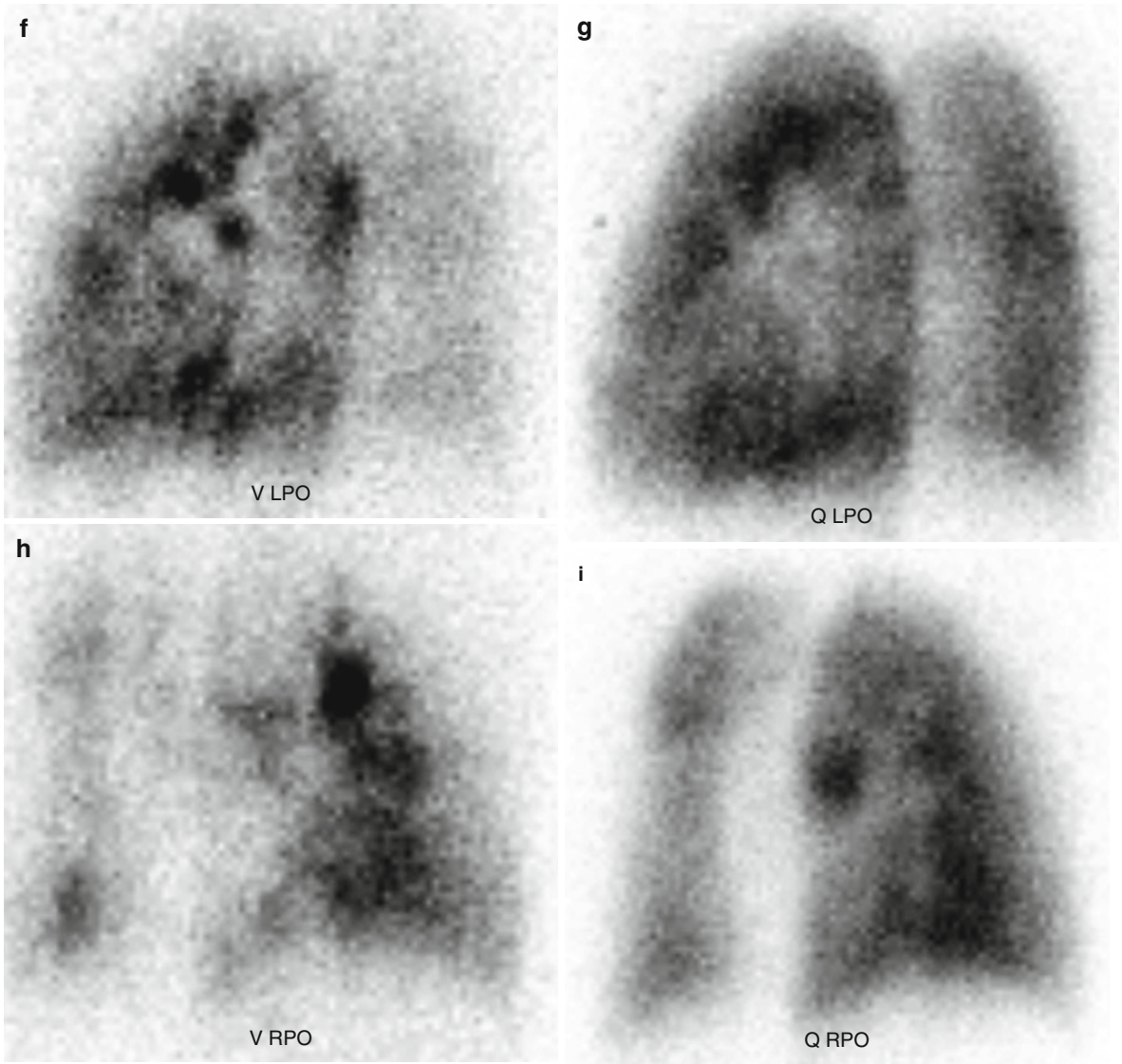


Fig. 14.2 (continued)

Conversely, despite a low threshold for admission, a significant minority of patients with atypical symptoms of ACS who actually have acute myocardial infarction are initially triaged as low risk and are unintentionally discharged home [18].

Myocardial perfusion imaging (MPI) can be effectively used as a triage tool in patients with chest pain of unclear etiology. MPI typically utilizes one of two available ^{99m}Tc radiopharmaceuticals, ^{99m}Tc sestamibi and ^{99m}Tc tetrofosmin (Table 14.4). The biodistribution within the left ventricular myocardium is generally proportional to coronary arterial blood flow at the time of IV administration; these tracers do not redistribute for several hours. Normally, there is uniform myocardial perfusion (Fig. 14.4). If a patient with ACS is injected at rest while experiencing coronary-related chest pain, the distribution of the perfusion agent will be altered and will demonstrate diminished regional perfusion corresponding to the vascular territory involved (Fig. 14.5). However, acute or prior myocardial infarction may produce a similar perfusion defect on rest MPI; therefore, differentiation between ischemia and infarction is not possible with rest MPI alone.

Rest MPI in symptomatic patients has reported sensitivities of 90–100 % with negative predictive values (NPV) of greater than 99 % for identifying patients without cardiac events [19]. The high sensitivity of rest MPI is dependent on the presence of chest pain during tracer injection; that is, MPI in patients injected after cessation of chest pain does not yield the same sensitivity, and that subgroup should undergo stress testing. Thus, the high NPV of rest MPI in patients with chest pain

allows the emergency physician to establish confidently the absence of myocardial ischemia or infarction as the etiology of the symptomatology. Specifically, negative rest MPI directs disposition of patients who might otherwise have a prolonged hospital stay, and, conversely, positive rest MPI identifies high-risk patients who might be categorized incorrectly as low risk and might have a delayed diagnosis of ACS.

Incorporation of MPI into the acute chest pain diagnostic algorithm is beneficial. The ERASE trial [20] demonstrated that MPI in the emergency setting reduced unnecessary admissions without increasing inappropriate discharges. MPI as a triage tool is most effective when used on low-risk patients who are experiencing active chest pain (i.e., hemodynamically stable, no ECG changes, no prior coronary disease).

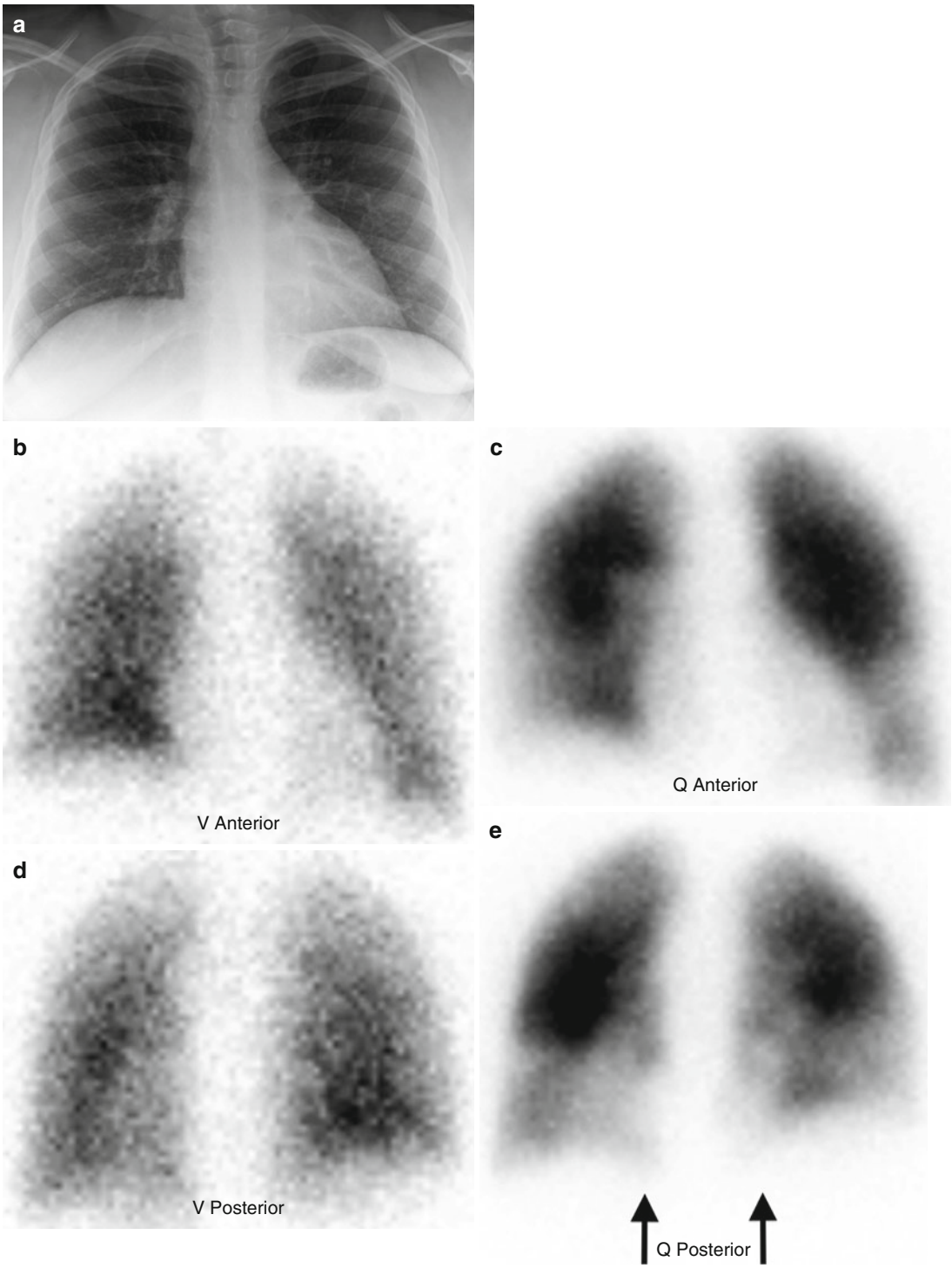
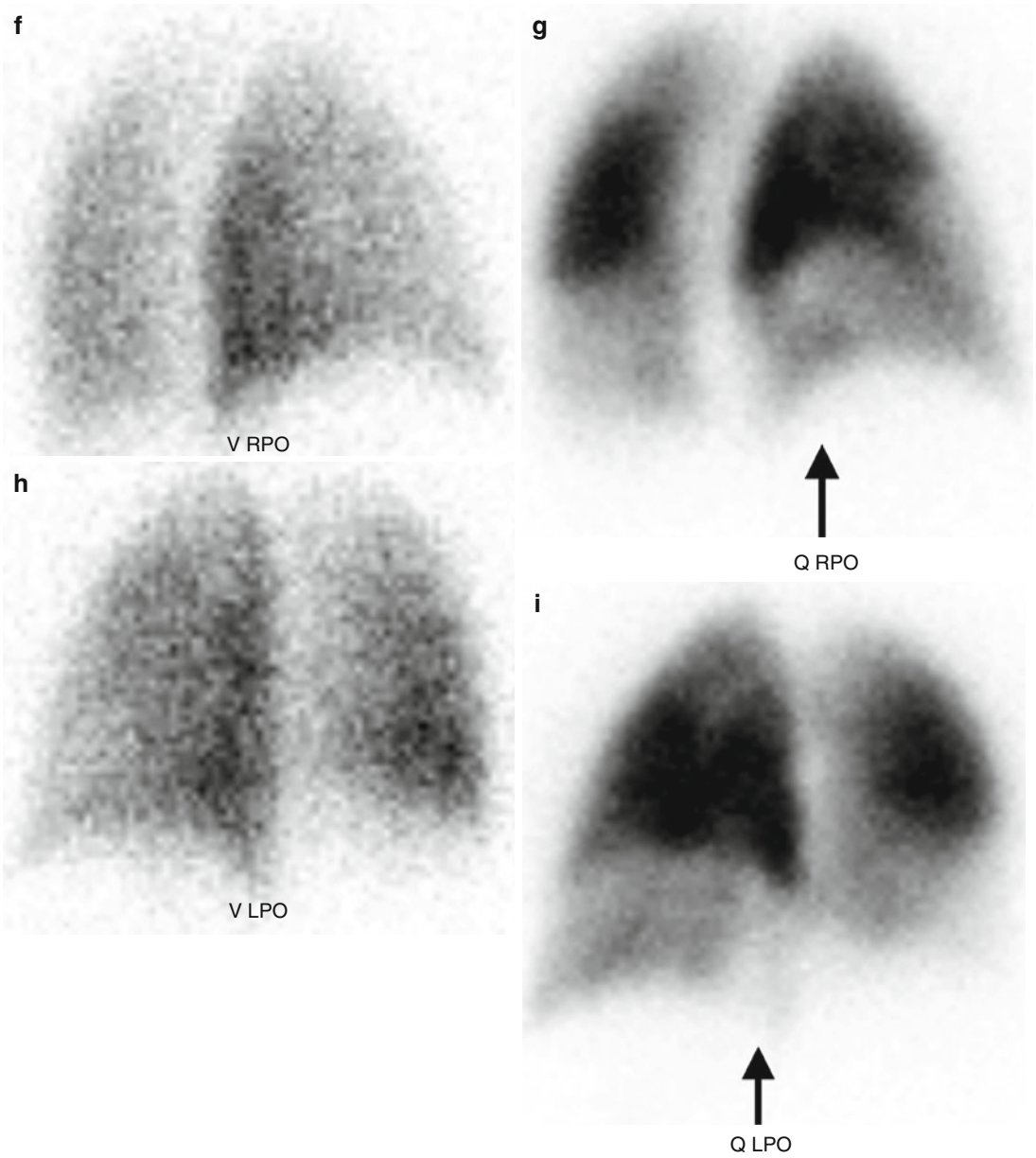


Fig. 14.3 High probability for acute PE (multiple V/Q mismatches). Normal chest radiograph (**a**). Normal ^{99m}Tc DTPA ventilation (*left panel*: **b**, **d**, **f**, **h**) and abnormal ^{99m}Tc MAA perfusion (*right panel*: **c**, **e**, **g**, **i**) with multiple bilateral lower lobe segmental perfusion defects (*arrows*)

Fig. 14.3 (continued)



Together, concordantly negative rest MPI and negative biomarkers identify patients who can safely be discharged, or, alternatively, undergo early stress testing with or without hospital admission depending on those results. MPI is the only commonly available imaging technique that provides a direct and accurate assessment of myocardium at risk [19]. The greatest benefit of MPI lies in its high NPV, which assists the emergency physician in effectively excluding ACS in low-risk patients, lowering costs, shortening length of hospital stay, and decreasing morbidity [7, 21, 22].

In summary, in conjunction with biomarkers such as troponin, MPI can be used as a triage tool to establish the absence of myocardial ischemia or infarction as the etiology of active chest pain in patients who meet the following criteria:

1. Hemodynamically stable
2. Chest pain of unclear etiology
3. Considered low risk for ACS
4. No ischemic ECG changes

Acute Biliary Conditions: Hepatobiliary Scintigraphy

Cystic Duct Obstruction (Acute Cholecystitis) and Common Bile Duct Obstruction

Greater than 95 % of acute cholecystitis is caused by complete obstruction of the cystic duct, typically related to one or multiple gallstones. The blockage results in potentially fatal

Table 14.3 Simplified criteria for interpretation of V/Q lung scintigraphy for diagnosis of acute PE

Interpretation	Patterns on V/Q lung scintigraphy
PE absent: "normal"	No perfusion defects
PE absent: "very low probability"	Nonsegmental perfusion defects (e.g., cardiomegaly, enlarged hila, elevated hemidiaphragm) Perfusion defect smaller than corresponding X-ray abnormality Two or more V/Q matches with corresponding normal chest X-ray and otherwise relatively normal perfusion Three or fewer small segmental perfusion defects Triple-matched V/Q/X-ray abnormality in upper/mid-lung Stripe sign (i.e., preserved perfusion to pleural surface) Large pleural effusion with otherwise normal perfusion
Nondiagnostic for PE: "low probability" or "intermediate probability"	All other patterns, including triple-matched V/Q/X-ray abnormality in lower lung
PE present: "high probability"	Two or more segmental V/Q mismatches

Adapted from Sostman et al. [2]

Table 14.4 Typical rest with chest pain myocardial perfusion imaging (MPI) technical protocol

1. Administer 25 mCi (925 MBq) of ^{99m}Tc sestamibi or ^{99m}Tc tetrofosmin IV while patient has chest pain at rest
2. Wait 15–30 min
3. Perform single-photon emission computed tomography (SPECT) imaging
4. Evaluate rest-only images

pathophysiologic changes including lymphatic and venous obstruction, mucosal congestion and edema, acute inflammatory leukocyte infiltration, hemorrhage and necrosis, and, finally, complications of gangrene, perforation, and abscess [23]. Therefore, early diagnosis and appropriate management are essential to reduce mortality and morbidity.

Hepatobiliary scintigraphy (HBS), colloquially known as HIDA scanning or cholescintigraphy (Table 14.5), provides a physiologic map of hepatocellular function and bile flow. Given IV, the ^{99m}Tc iminodiacetic acid (IDA) analogs are extracted by the liver and are rapidly secreted into the bile. Normally, radioactive bile enters the biliary system including the gallbladder and passes into the small bowel within 1 h (Fig. 14.6).

In acute cholecystitis, there is a high likelihood that the cystic duct is obstructed. Thus, the hallmark finding of acute cholecystitis on HBS is nonvisualization of the gallbladder yet prompt visualization of the common bile duct and duodenum (Fig. 14.7). Complicated acute cholecystitis is supported by the pericholecystic rim sign, which is manifested by increased hepatic radiotracer activity adjacent to the gallbladder fossa. The rim sign is seen in approximately 20 % of HBS with a nonvisualized gallbladder and is strongly associated with complicated acute cholecystitis; furthermore, approximately 40 % have a gangrenous or perforated gallbladder (Fig. 14.7). Delayed gallbladder visualization suggests chronic cholecystitis with resistance to bile flow within the cystic duct without true obstruction (Fig. 14.8). Causes of false-positive and false-negative interpretations of HBS for acute cholecystitis are listed in Table 14.6.

Sensitivity and specificity for the accurate HBS diagnosis of acute cholecystitis increase with time. For conventional HBS, the false-positive rate decreases from 10 % when imaging is completed at 1 h to less than 1 % when imaging is continued to 4 h, and the specificity improves from 88 to 99 % [23]. Consequently, delayed imaging became the standard methodology used to differentiate acute cholecystitis from chronic cholecystitis, the latter condition demonstrating delayed gallbladder visualization. The administration of IV morphine sulfate during HBS shortens the duration and increases the specificity for acute cholecystitis [24]. By constricting the sphincter of Oddi, morphine sulfate raises pressure within the common bile duct, thereby diverting bile through a patent cystic duct and facilitating gallbladder visualization (Fig. 14.8). The small bowel must be visualized to apply the morphine augmentation protocol. It is also important to ascertain what pain medications have been given to the patient in the emergency department to ensure that additional opiates are not administered inadvertently. Morphine-augmented cholescintigraphy has a high accuracy and is as accurate as delayed imaging [24–26].

When compared to ultrasonography for the diagnosis of acute cholecystitis, HBS has superior sensitivity (88 % vs. 50 %), specificity (93 % vs. 88 %), positive predictive value (85 % vs. 64 %), negative predictive value (95 % vs. 80 %), and accuracy (92 % vs. 77 %) [10]. However, as discussed earlier in this chapter, logistical challenges limit availability of NM during off-hours and impact on the clinical application of this excellent scintigraphic technique. Thus, right upper quadrant ultrasonography reigns as the first-line modality for acute cholecystitis; additionally, it can provide information regarding alternate non-biliary diagnoses.

When bile fails to flow from the liver, the differential diagnosis includes acute high-grade/complete common bile duct obstruction, often related to distally impacted gallstones, versus underlying hepatocellular dysfunction. HBS can continue up to 24 h; however, the clinical context may direct management after only a few hours of imaging. The classic HBS finding of common bile duct obstruction is a persistent liver ("hepatogram") without excretion into the bile ducts (Fig. 14.9) [23]. Up to 72 h might be required for

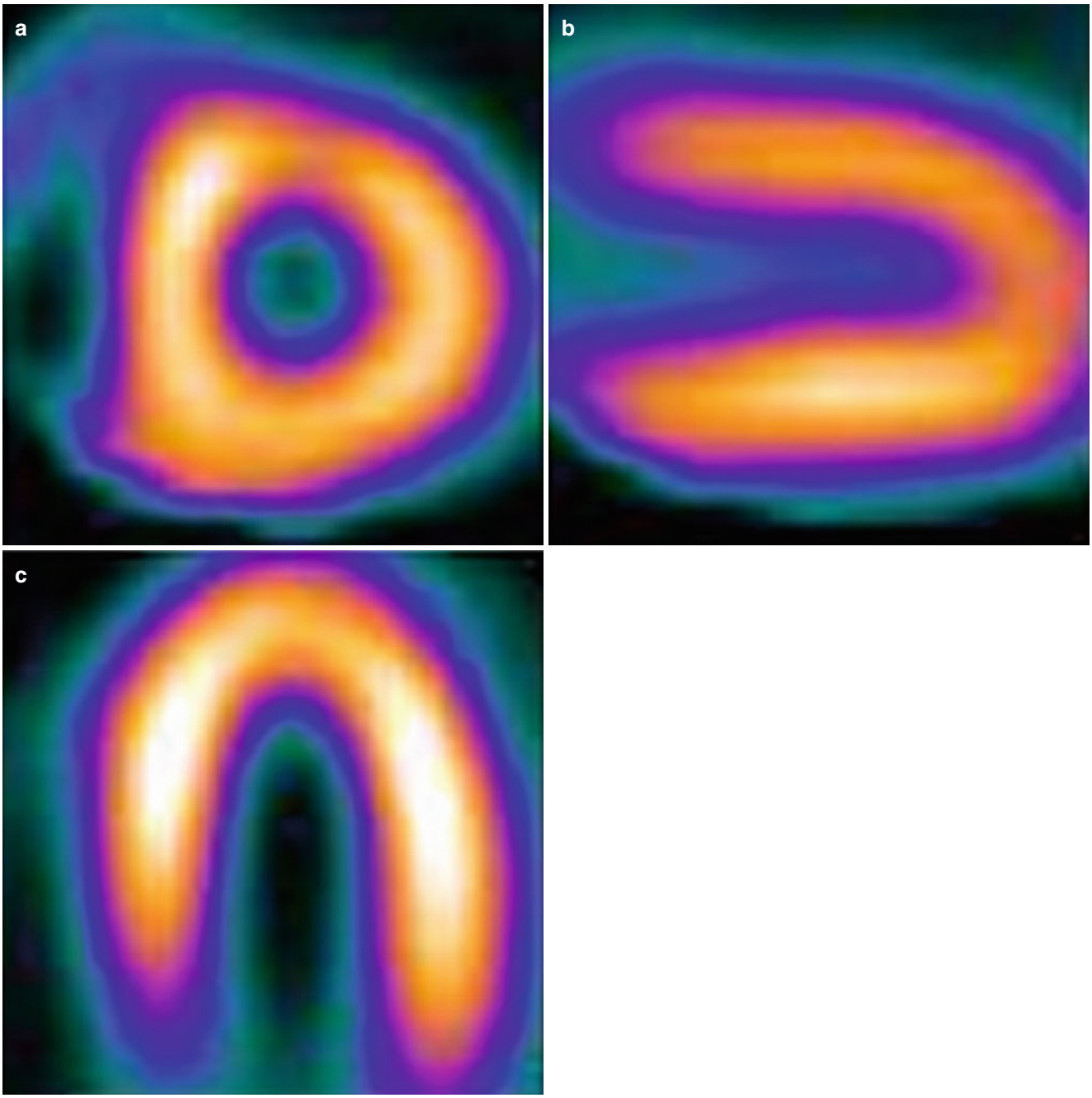


Fig. 14.4 Normal rest MPI. Uniform ^{99m}Tc sestamibi activity throughout the left ventricular myocardium. (**a**) Short-axis, (**b**) vertical long-axis, and (**c**) horizontal long-axis images

the common bile duct to dilate with a distal obstruction; thus, ultrasonography may be normal early on. It should be noted that the patency of the cystic duct cannot be established by HBS when bile flow from the liver is so severely impaired.

Bile Duct Injury

Bile duct injuries commonly occur after blunt abdominal trauma and are secondary to a shearing injury of the hepatobiliary system. A bile duct injury may lead to bile peritonitis, which may require days or weeks to develop; clinical diagnosis may be elusive. While CT and ultrasonography can identify and localize intra-abdominal fluid collections, they cannot characterize them as containing bile.

HBS is the noninvasive standard for diagnosis of bile leak [27]. As discussed earlier in this chapter, HBS uses ^{99m}Tc IDA analogs. For evaluating bile leaks, the technical protocol is modified (Table 14.7). HBS can detect free or localized bile collections (bilomas) as well as provide information on the rate and extent of the leak. Leaks may be slow or fast, active or intermittent. If radioactive bile

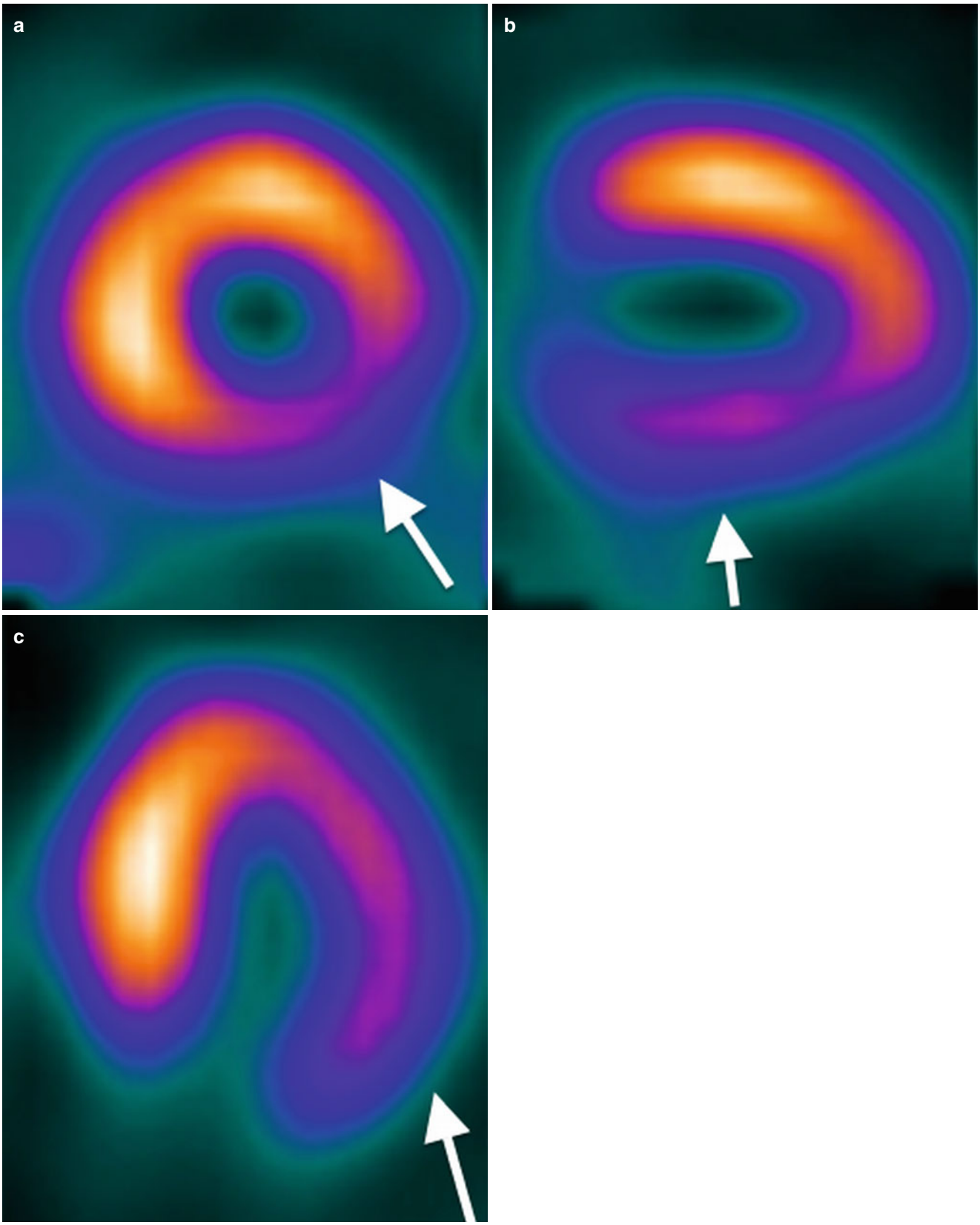


Fig. 14.5 Abnormal rest MPI. High-grade occlusion of left circumflex coronary artery as etiology of active chest pain during ^{99m}Tc sestamibi administration IV. Large, moderately severe perfusion defect in the inferior-lateral wall extending from apex to base (*arrows*). (**a**) Short-axis, (**b**) vertical long-axis, and (**c**) horizontal long-axis images

Table 14.5 Typical hepatobiliary scintigraphy technical protocol for acute cholecystitis or common bile duct obstruction

1. Fasting for 4 h; if fasting longer than 24 h, administer sincalide (synthetic CCK, 0.02 ucg/kg, IV) to prepare gallbladder
2. Administer 4 mCi (148 MBq) of ^{99m}Tc IDA analog IV
3. Acquire anterior images dynamically at 1 frame/min for 60 min or until gallbladder and small bowel are visualized
4. If common bile duct and small bowel are visualized, without gallbladder visualization, administer morphine sulfate (0.04 mg/kg IV)
5. Acquire anterior, left anterior oblique, and right lateral images 30 min later
6. If neither gallbladder nor small bowel is visualized, morphine sulfate is contraindicated
7. Acquire delayed images in multiple projections for an additional 2–4 h or up to 24 h in selected patients

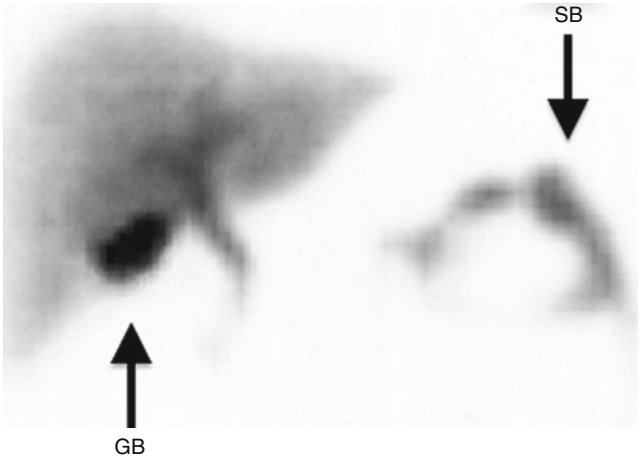


Fig. 14.6 Normal. Anterior image 20 min after ^{99m}Tc IDA analog IV. Visualization of gallbladder (*GB*) and small bowel (*SB*)

extravasates outside of the normal biliary and gastrointestinal tracts, there is an active bile leak (Fig. 14.10). Management may be conservative or may progress to percutaneous drainage, endoscopic retrograde cholangiography, or laparotomy.

In the emergency setting, particularly after blunt or penetrating trauma, HBS may be appropriate to identify an active bile leak or to characterize an abnormal fluid collection visualized on CT. For example, a liver laceration with significant bile duct injury may require different initial management compared to one without bile duct injury [28].

In summary, by providing a physiologic map of the biliary system, HBS should be strongly considered and utilized whenever available in the acute emergency setting to:

1. Establish patency of the entire hepatobiliary-small bowel axis
2. Provide a more specific diagnosis of acute cholecystitis as compared to ultrasonography
3. Evaluate for high-grade common bile duct obstruction
4. Detect an active bile leak, particularly after trauma

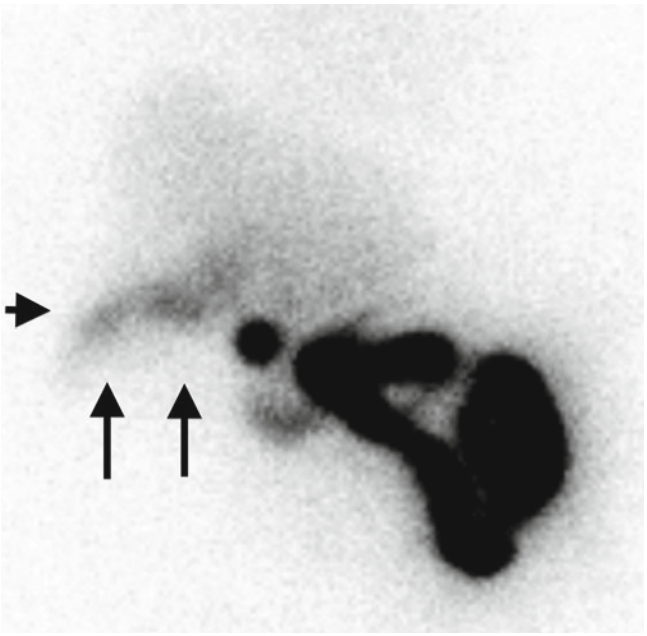


Fig. 14.7 Acute gangrenous cholecystitis. Anterior image at 2 h after IV ^{99m}Tc IDA analog. Nonvisualization of gallbladder with pericholecystic rim sign (*arrows*)

Gastrointestinal Hemorrhage: GI Bleeding Scintigraphy

Acute GI hemorrhage can be a life-threatening event and requires prompt diagnosis and appropriate intervention. Upper GI hemorrhage is defined as bleeding that originates proximal to the ligament of Treitz, whereas lower GI hemorrhage occurs distal to this landmark. Upper GI hemorrhage typically presents with either hematemesis or melanotic stools, whereas lower GI hemorrhage usually presents with bright red blood per rectum.

Endoscopy is a well-tolerated and generally successful first-line approach for patients with suspected upper GI hemorrhage; esophageal, gastric, or duodenal bleeding sites can be visualized and treated directly. Suspected lower GI hemorrhage presents different challenges. Prompt localization of the bleeding site is crucial to patient management; time to diagnosis is an important determinant of outcome in high-risk lower GI hemorrhage [29]. Endoscopy is an option, but is more limited in an unprepared colon that might be filled with blood from a proximal source, and the small bowel cannot be examined. Two diagnostic imaging modalities are available to identify and localize the lower GI source: ^{99m}Tc RBC scintigraphy and angiography. Despite the well-documented sensitivity, only 10–15 % of patients presenting with lower GI hemorrhage are evaluated with scintigraphy [14].

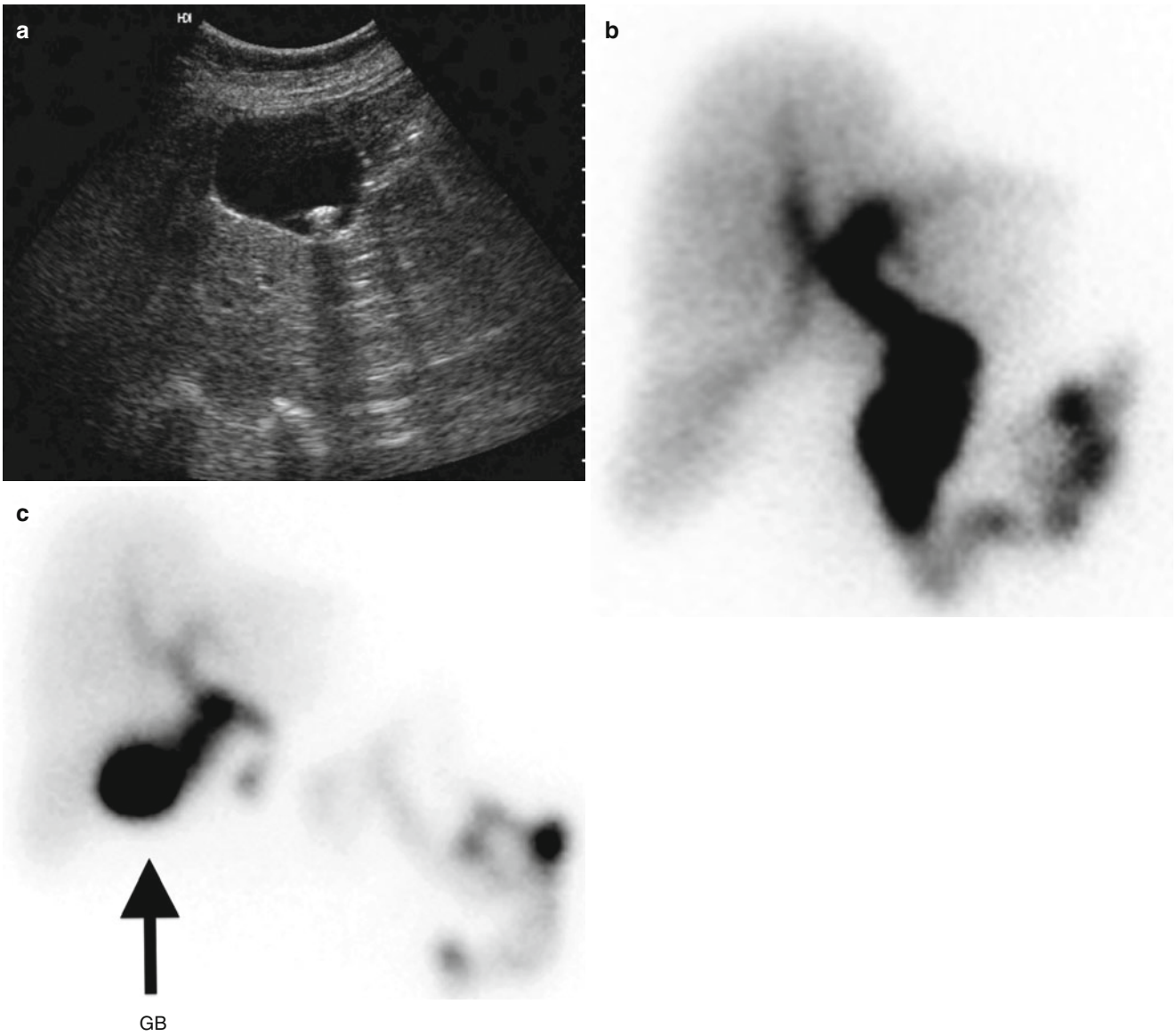


Fig. 14.8 Chronic calculous cholecystitis. Gallstones by ultrasound (**a**). On HBS, gallbladder nonvisualization at 1 h (**b**) after ^{99m}Tc IDA analog IV, but visualization (*GB*) at 20 min following morphine sulfate IV (**c**)

Table 14.6 False-positives and false-negatives on HBS for acute cholecystitis

Causes of false-positive interpretations (nonvisualized gallbladder)	Causes of false-negative interpretations (visualized gallbladder)
Recent meal (<4 h)	Acalculous cholecystitis
Prolonged fasting (>24 h)	Perforated acute cholecystitis
Hyperalimentation	Accessory cystic duct
Chronic cholecystitis	Duodenal diverticulum (misinterpretation)
Hepatic insufficiency	
Cystic duct cholangiocarcinoma	
Alcoholism	
Pancreatitis	

Dynamic GI bleeding scintigraphy utilizes ^{99m}Tc red blood cells (RBCs) (Table 14.8) and can effectively identify and localize slow or rapid, active or intermittent lower GI bleeding. Radiolabeled RBCs that extravasate from the normal circulatory system (referred to as the blood pool) are relatively easily identified because of a high target-to-background ratio. The extravasated radiolabeled RBCs will move in the bowel lumen over time, aiding in pinpointing the site of origin (Fig. 14.11).

RBC scintigraphy offers several advantages over angiography in localizing bleeding sites. First, bleeding rates as low as 0.1–0.3 mL/min are detectable with scintigraphy [30]; angiography requires rates at least tenfold higher. High

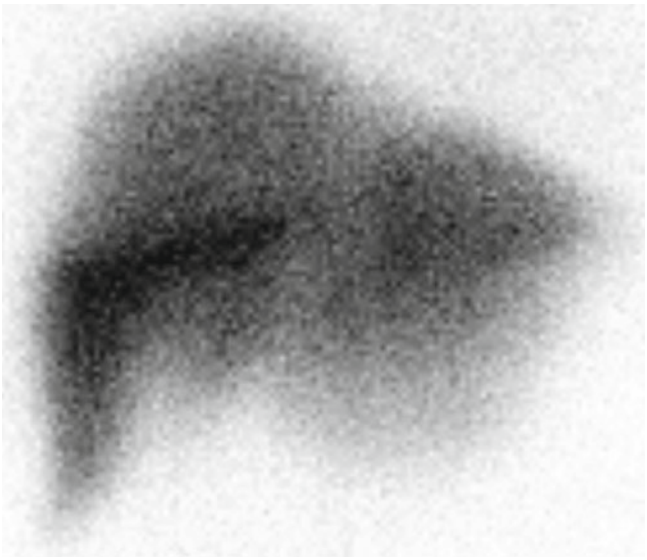


Fig. 14.9 Complete common bile duct obstruction. On HBS, uniform liver activity without biliary activity at 5 h after ^{99m}Tc IDA analog IV

Table 14.7 Typical hepatobiliary scintigraphy technical protocol for bile leak

1. Administer 4 mCi (148 MBq) of ^{99m}Tc IDA analog IV
2. Acquire anterior images dynamically at 1 frame/min for 60 min or until liver is cleared or bile leak is identified
3. Acquire anterior and posterior, right and left anterior oblique, and/or right lateral planar images up to 24 h, as needed

sensitivity (93 %) and specificity (95 %) have been reported for scintigraphy [15]. Second, RBC scintigraphy allows examination of the entire lower GI tract continuously for whatever period of time is needed and tolerated by the patient's clinical condition. Third, there are fewer complications compared with more invasive angiography, and the radiation exposure is significantly lower. Last, RBC scintigraphy can direct angiographic confirmation, expediting intervention [31].

As a noninvasive modality with high sensitivity, scintigraphy has been assessed as an important prognostic tool in GI hemorrhage. Negative results predict good clinical outcome [30]; positive results predict greater hospital morbidity and mortality [29, 32]. Positive results are accurate in localizing the bleeding site in approximately 75 % [30]. False-positives include horseshoe kidney, hepatic hemangiomata, ischemic bowel, uterine leiomyomata, and aneurysmal vasculature [33].

In summary, RBC scintigraphy should be considered as the primary imaging approach in patients presenting with GI bleeding under the following conditions:

1. Hemodynamically stable.
2. Localization of the source is desired to direct intervention.

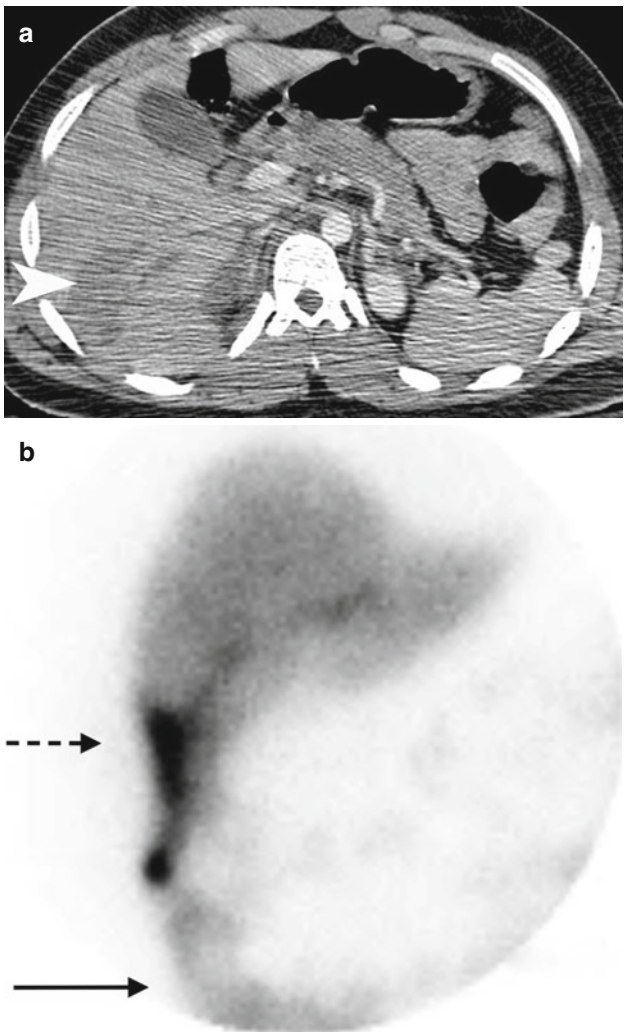


Fig. 14.10 Active bile leak. Liver laceration in right lobe (*arrowhead*) on CT (**a**) after blunt trauma. On hepatobiliary image at 30 min after ^{99m}Tc IDA analog IV (**b**), free leakage of bile (*dashed arrow*) into the right paracolic gutter (*long arrow*) and throughout the peritoneal cavity without expected intraluminal small bowel activity

Table 14.8 Typical dynamic red blood cell scintigraphy technical protocol

1. Remove blood for radiolabeling
2. Radiolabel red blood cells by in vitro method
3. Administer 25 mCi (925 MBq) of ^{99m}Tc red blood cells IV
4. Acquire anterior images dynamically at 1 frame every 10–60 s for 60–90 min
5. Review images in cinematic mode

Teaching Points

- Ventilation/perfusion (V/Q) lung scintigraphy should be considered as the primary imaging approach in patients with suspected acute PE and normal chest radiography, no concurrent cardiopulmonary process, relative contraindications

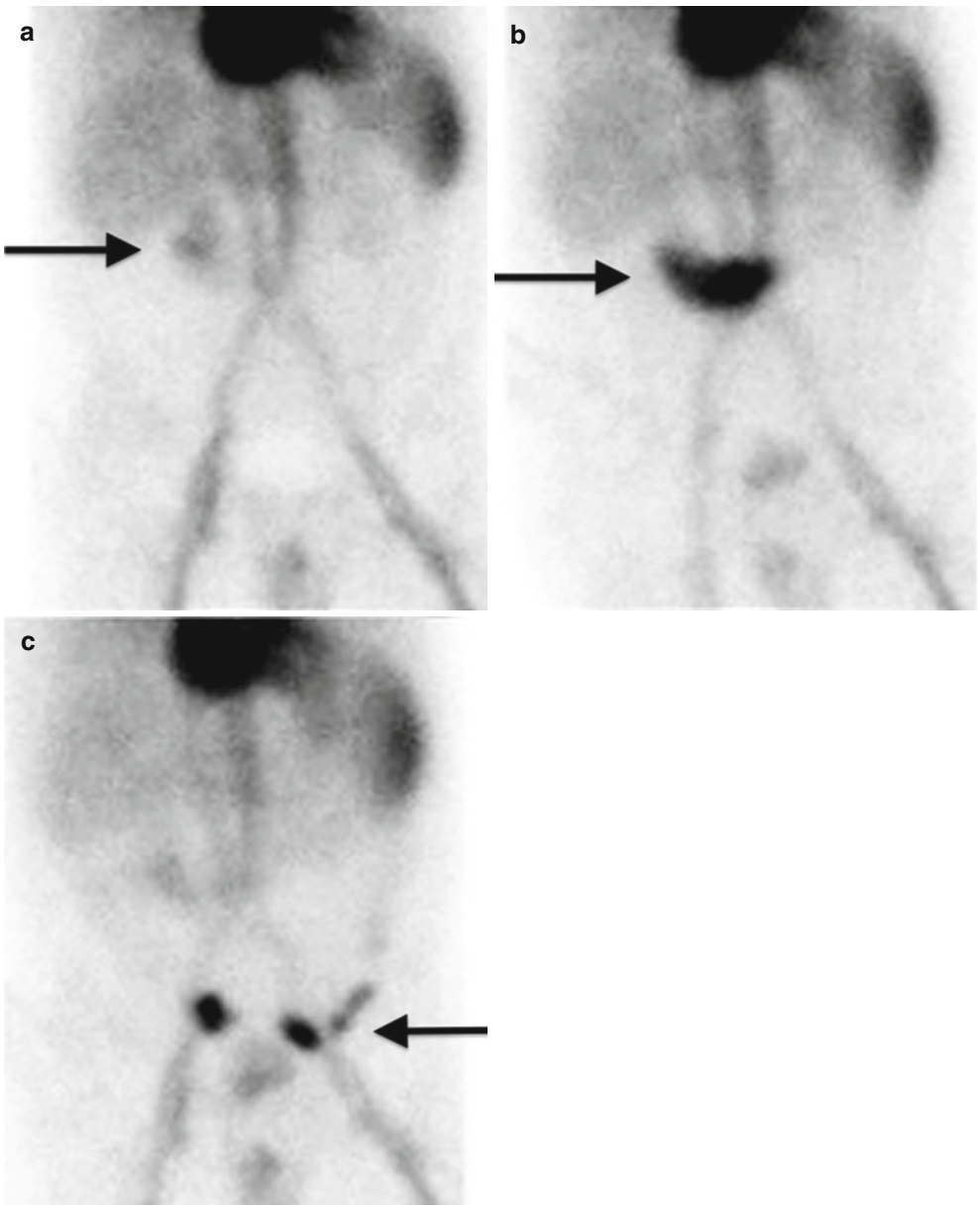


Fig. 14.11 Active bleed in proximal transverse colon. Selected images at 6 min (**a**), 38 min (**b**), and 50 min (**c**) after ^{99m}Tc RBCs IV. Active extravasation into right upper quadrant (**a**, *arrow*) with movement into the mid-abdomen (**b**, *arrow*) and further movement distally into the descending colon and sigmoid colon (**c**, *arrow*) over time

to iodinated contrast for CTA, or concerns related to radiation dosimetry.

- Rest myocardial perfusion imaging (MPI) is most effective as a triage tool when applied to low-risk patients who present with active chest pain; negative rest MPI and concordantly negative biomarkers identify patients who can safely be discharged or, alternatively, undergo early stress testing to determine need for admission.
- Hepatobiliary scintigraphy (HBS) provides a physiologic map of bile flow, uncovering normal or obstructive patterns, and boasts superior diagnostic capabilities as compared to ultrasonography for the diagnosis of acute cholecystitis. HBS can detect subtle bile duct injuries, particularly in the setting of blunt trauma.
- Dynamic ^{99m}Tc red blood cell (RBC) scintigraphy can pinpoint the source of active or intermittent lower gastrointestinal hemorrhage and directs angiographic or surgical intervention.

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