A Primer for Students Regarding Cardiothoracic Imaging: Primer 4 of 7

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Disclosures: The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

Received for publication Feb 19, 2023; revisions received March 7, 2023; accepted for publication April 3, 2023; available ahead of print May 7, 2023.

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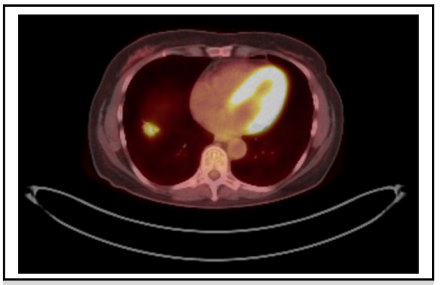
JTCVS Open 2023;14:331-8
2666-2736

https://doi.org/10.1016/j.xjon.2023.04.019



Positron emission tomography of a primary lung neoplasm and healthy left ventricle.

CENTRAL MESSAGE

Herein, we review indications and interpretation of plain films, computed tomography, magnetic resonance imaging, echocardiograms, and coronary angiography in cardiothoracic surgery patients.

A wide array of imaging modalities is used to evaluate both preoperative and postoperative cardiac and thoracic surgery patients, including radiographs ("plain films"), computed tomography (CT) and magnetic resonance imaging (MRI) scans, cardiac ultrasounds (echocardiograms), and coronary angiography.

CHEST RADIOGRAPHS (CXR)

In this imaging modality, high-energy electromagnetic radiation passes through the body before hitting a detector, and varying tissue densities absorb the radiation at different degrees.[1] This means that aerated lung parenchyma looks dark on a film, as it absorbs fewer photons, whereas more dense tissue (bone, any calcifications present) absorbs more photons and will appear bright.[1] (As a helpful reminder, the air around the patient is dark on film, indicating that there is no tissue to absorb the photons). CXR provides a wealth of information for both patients undergoing cardiac and thoracic surgery, and it is frequently ordered as part of the preoperative assessment.[2] The resulting image includes not only baseline anatomic information but also a preliminary indication of any pathology that might require further workup, such as intrinsic lung pathology, vascular calcifications, pulmonary edema, or pleural effusions.[2]

Included are both pre- and postoperative CXR scans (Figure 1, *A* and *B*, respectively) for a patient undergoing a coronary artery bypass graft operation. When reading any medical imaging, remember to view the image as one would be looking at a patient: the patient's left appears on the right of the image and vice versa. Of note, CXR views are named: PA, or "posterior-anterior," indicating that the source of the radiation is behind the patient at time of imaging, and as a result, the X-rays entered the patient posteriorly and exited anteriorly, then reaching the detector to create the image.[1,2] The opposite is true of the AP ("anterior-posterior") view, where the X-rays travel from the anterior to the posterior of the patient.[1,2] If a portable CXR is ordered postoperatively for a patient who is supine in the hospital bed, then the image acquired will be AP, as the detector is placed behind the patient with the X-ray machine positioned anteriorly. This becomes important knowledge when considering the size and silhouette of the heart, as the heart will appear larger and with less-defined borders via the AP versus the PA view.[1] When a CXR is ordered in the lateral view, by default the patient should be positioned with the left shoulder against the detector, so that better anatomic detail of the heart may be appreciated.[3] Therefore, when ordering a lateral CXR to investigate any right-sided process, the imaging should be ordered specifying that a right lateral view is desired.[3]

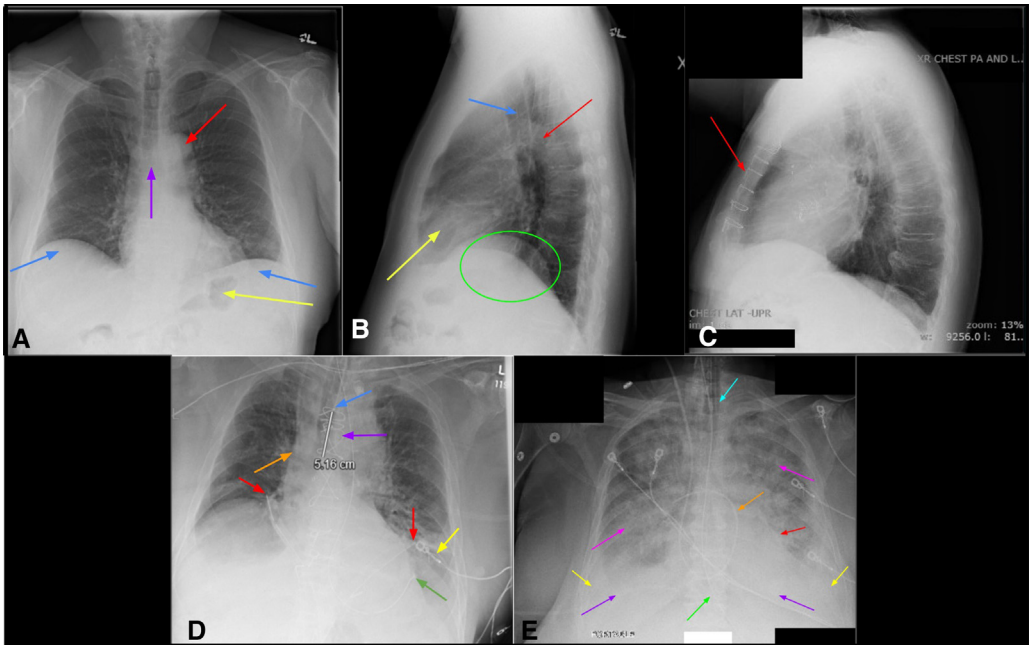


FIGURE 1. Examples of pre- and postoperative chest radiograph (CXR) images for a cardiac surgery patient as well as a CXR of a patient with acute decompensated heart failure. A, Preoperative CXR in posterior-anterior view. *Colored arrows* correspond to the following: *blue arrows*: left and right hemidiaphragms. Right hemidiaphragm sits superiorly to the left hemidiaphragm, due to the presence of the liver on the right. *Yellow arrow*: gas bubble in stomach or intestines. *Purple arrow*: carina of trachea. *Red arrow*: aorta as it curves posterolaterally to become the descending thoracic aorta; this appearance on posterior-anterior or anterior-posterior CXR is known as the "aortic knob." B, Same film in lateral view. *Colored symbols* represent the following: *Green circle*: the divergence of the 2 hemidiaphragms (see previous comment in posterior-anterior view as well), where the right hemidiaphragm sits superiorly to the left due to the liver on the right. *Yellow arrow*: patchy opacity in left anterolateral lung. *Red arrow*: aortic arch corresponding to the red label in posterior-anterior view. *Blue arrow*: trachea. C, Lateral postcardiotomy CXR with sternal wires (*red arrow*). D, Postoperative CXR in the anterior-posterior view. *Colored arrows* represent the following: *Blue arrow*: termination of endotracheal tube. The *white line* and annotation in the image indicate that the tube ends 5.16 cm above the carina. *Purple arrow*: sternal wires. *Orange arrow*: tip of central line in superior vena cava. *Red arrows*: chest tubes in left and right chest. *Yellow arrow*: one annotated example of an ECG lead on this patient. E, anterior-posterior CXR of a patient with acute decompensated heart failure. Notice the lack of clear demarcation of the cardiac silhouette (*red arrow*) and the inability to see clear costophrenic angles (*yellow arrows*). *Purple arrows*: Bilateral moderate-sized pleural effusions. *Pink arrows*: Bilateral airspace consolidations. *Orange arrow*: Right internal jugular (IJ) catheter terminates in proximal right pulmonary artery. *Blue arrow*: Endotracheal tube, which terminates at the thoracic inlet. *Green arrow*: Enteric tube, which courses into the abdomen, with tip not visualized in this image. All images included with permission from Dr Hamza Aziz of Johns Hopkins Hospital.

There is a benefit to ordering multiple views with chest radiographs such as is demonstrated previously; the patchy opacity in the left anterolateral lung base (indicated by a yellow arrow in Figure 1, *B*) is clearer in lateral view than in the PA. For comparison, see Figure 1, *C*, which shows a lateral CXR without notable pathology other than sternal wires. Another reason to order a frontal and lateral chest radiograph is that one view may not allow the viewer to distinguish between an object inside versus that which is superficial to the patient. For example, we see electrocardiogram (ECG) leads in the postoperative CXR (Figure 1, *D*) shown, but without clinical reasoning it would be impossible to tell that those leads are external to the patient. Comparing patient images across different modalities is also useful, as each modality has its strengths and weaknesses. This will be demonstrated in the section to follow on CT scans, which includes a scan of this same patient and illustrates a finding not visible in the CXR included above.

Postoperative CXRs are ordered to assess for the proper positioning of lines and drains.[4] We see an example of this in the postoperative CXR example, showing an enteric tube that ends in the stomach and an endotracheal tube positioned with its tip several centimeters above the carina of the trachea (as marked in Figure 1, *D*). This patient also has a central venous catheter ("central line") entering the internal jugular vein and ending in the distal superior vena cava, ECG leads, and bilateral chest tubes for drainage.

In the case of patients who are not preoperative or postoperative, the CXR still provides valuable insight regarding ongoing cardiothoracic pathology and lines. In Figure 1, *E*, we see several signs of severe cardiogenic shock, including airspace infiltrates and pleural effusions, and invasive patient monitoring via a central line terminating in the

pulmonary artery (likely to measure pulmonary artery pressure via a Swan-Ganz catheter [Edwards Lifesciences]).

We would like to note that when reading any clinical imaging, there exists the risk of failing to register additional pertinent findings once the first is noticed, known as a "satisfaction of search" bias. In order to reduce this risk, we recommend that medical students choose a framework for reading each type of clinical imaging, then use this framework consistently for all scans. For example, one typical framework for reading CXR includes "A" for the airway and lungs, "B" for bones (including not just the ribs, but also the clavicles and vertebral bodies), "C" for the cardiac silhouette and major vessels, "D" for the diaphragm (including both costophrenic angles), and "E" for everything else, which should include not only lines and drains, but also other devices and potential findings, such as gastric bubble size, pneumoperitoneum, or masses.[5]

CT AND MRI

A CT scan combines many individual x-ray images taken at levels of the body together producing one final set of images via computerized postprocessing. As a result, a CT scan represents a 3-dimensional image of the patient: each "slice" is a 2-dimensional image, like an X-ray, and the third dimension of the scan is represented by the multiple "slices" of each scan. (See Figure 2, for example, "slices" from the thoracic CT scan our patient had done preoperatively.) Figure 2, *A* shows labels for major thoracic structures. CT scans can be used to better visualize thoracic processes that may not have been captured by the CXR. In the case of the aforementioned patient, Figure 2, *B* reveals bright aortic calcifications at the level of the arch that were not visualized on CXR, thus allowing a surgeon to preoperatively assess risk of aortic cannulation and crossclamp locations as well as alternative cannulation strategies; Figure 2, *C*, reveals the bifurcation of the pulmonary trunk into the left and right pulmonary arteries, Figure 2, *D*, reveals a labeled slice of the 4 chambers of the heart.

MRI is produced by the variation of a magnetic field that surrounds the patient, as this variation in field then excites the water in the body to different degrees depending on (1) the tissue type and (2) the 3-dimensional location of the tissue in the body.[6] As a result, MRI scans are able to produce a high-resolution image of the body without the use of ionizing radiation.[6]

Furthermore, MRI includes the use of radiofrequency pulses to "tip" the magnetization vector generated by the spin of hydrogen nuclei towards the receiver coil, which detects the spin polarization. After this radiofrequency pulse, these spins "relax" back to their original state depending on

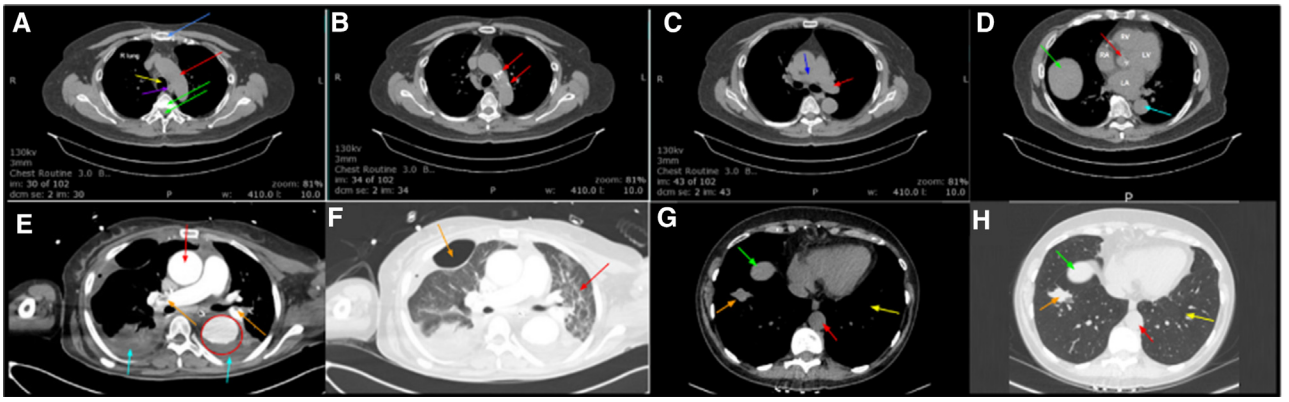


FIGURE 2. Examples of computed tomography (CT) slices in the axial view. A-D show a preoperative noncontrast CT scan of a patient who later underwent a coronary artery bypass graft surgery. A, The right lung is labeled in text in the image. *Blue arrow*: sternum. *Red arrow*: Aortic arch free of visible calcifications. *Yellow arrow*: trachea. *Purple arrow*: esophagus. *Green arrows*: vertebral body (anterior arrow) medial to the spinal cord (posterior arrow). B, *Red arrows* indicate aortic calcifications at the level of the aortic arch. C, Same study as previous panels, now at the level of the pulmonary trunk bifurcation. *Red arrow* indicates left pulmonary artery, whereas the *blue arrow* indicates the right pulmonary artery. D, Same study as previous panels, now at the level of the heart, with the following structures labeled: "LA" indicates the left atrium, "LV" indicates the left ventricle, "RA" indicates the right atrium, and "RV" indicates the right ventricle. Two portions of the aorta are visible in this slice: the ascending aorta with calcifications visible (*red arrow*), and the descending aorta (*blue arrow*). A portion of the patient's liver is also visible, indicated by the *green arrow*. E, CT of the chest with contrast in soft tissue window. *Orange arrows*: Filling defects in pulmonary vasculature indicating presence of pulmonary emboli. *Red arrow*: Aneurysm of ascending aorta. *Red circle*: type B aortic dissection, with the circle including both the true lumen (filled with contrast) and false lumen (*dark*). *Blue arrows*: Dependent fluid, concerning either for extensive pleural effusions or chronic hemothorax. F, CT of the chest with contrast in lung window. *Orange arrow*: subcutaneous air, consistent with recent insertion of chest tube in this patient. *Red arrow*: parenchymal changes consistent with chronic lung infection, best appreciated in the lung window of this scan. G, Noncontrast CT of the chest to visualize lung nodule in soft tissue window. Colored arrows represent the following: *orange arrow*: lung nodule. *Red arrow*: descending aorta. *Green arrow*: superior border of liver. *Yellow arrow*: inability to appreciate lung markings compared with H, which shows lung fields with lung windowing. *Orange arrow*: lung nodule. *Red arrow*: descending aorta. *Green arrow*: superior border of liver. *Yellow arrow*: lung markings. All images with permission of Dr Ahmet Kilic of Johns Hopkins Hospital.

factors (1) and (2) mentioned previously.[7] More specifically, each tissue may be characterized by 2 different relaxation times, known as T1 and T2 times.[7] T1 relaxation time, or spin-lattice relaxation time, is determined by the time required for each proton to return to alignment with the external magnetic field.[7,8] T2 relaxation time, or spin-spin relaxation time, is determined by the time required for protons to reach equilibrium with other neighboring protons.[7] Most MRI scans in clinical use are either T1-weighted, which emphasizes fat-containing tissues (such as subcutaneous fat or bone marrow), or T2-weighted, which emphasizes tissues with higher water content (including fatty tissues).[7] Clinical decisions are then typically made via comparison of the same anatomic "slice" between both scan types. Clinical contrast agents are substances that may be administered to patients via different routes (orally for enteral contrast, intravenously, etc) in order to alter either T1 or T2 relaxation times for specific tissue characterization.[7,8] Although a variety exist, the most common MRI contrast agents are gadolinium-based, thus functioning on the basis of shortening the tissue T1 relaxation time.[7,8] As the effect of contrast varies depending on how much time has elapsed since administration, the administration of contrast and scan acquisition is a time sensitive process.[7,8]

When weighing whether to choose a CT scan or MRI to evaluate thoracic anatomy or pathology, there are risks and benefits of both to consider. Although a CT is less time-consuming than an MRI and is not contraindicated with certain medical implants (for example, some pacemakers), CT scans involve ionizing radiation and do not provide as high of spatial or temporal resolution as MRI does.[4,6] When specifically considering the evaluation of cardiac anatomy, MRI does not experience the interference from lung or bone that a CT does, but MRI acquisition must be timed with the ECG and respiratory cycle in order to produce clear imaging, and accurate ECG monitoring is often not available during the scan due to magnetic field interference.[4] Furthermore, CT has the ability to be "quantitative," where specific tissues in the body have a consistent value assigned to them across scanners, known as Hounsfield units. This can then be used to enhance image analysis and visualization of specific tissue types (see discussion on "windowing" to follow).

When ordering a CT scan of any anatomic region, one must also consider whether to order the CT with or without "contrast." Contrast refers to any foreign material introduced to the patient's body before imaging, in order to differentiate local tissue and structures of interest. This is based on the fact that contrast media is highly radiopaque and thus visible on CT imaging. Within the scope of chest CT imaging, this often takes the form of either swallowed contrast (often barium) for the purposes of esophageal imaging, or intravenous contrast (often iodinated) for the purpose of evaluating vascular structures. The classic example of using a chest CT with contrast to evaluate a vascular structure is the evaluation of a patient with possible pulmonary emboli. As we see in Figure 2, *E* and *F*, any embolus within pulmonary vasculature of a large enough size to be seen on imaging will appear as a "filling defect" on the scan. (The example included below also shows other pathology, such as a significant aortic aneurysm, dissection, dependent fluid, subcutaneous emphysema, and bilateral lung parenchymal changes). Figure 2, *E* and *F*, also demonstrates how different "windowing" of the same CT scan provides different information to the reader of the image. By selecting which Hounsfield units are considered maximum brightness in each view, one can emphasize certain tissues while de-emphasizing others, such as windowing to best view soft tissue structures in Figure 2, *E*, or lung tissue in Figure 2, *F*.

The classic example of when a noncontrast CT of the chest is useful is in the case of lung cancer screening or the following of known lung nodules. Please compare the noncontrast CT of the chest shown below in Figure 2, *G*, to the contrast CT of the chest examples in Figure 2, *E* and *F*, to notice the lack of contrast in the vasculature. (One additional example of the use of a noncontrast CT of the chest may be found in Figure 2, *B*, where the lack of contrast allows calcifications in the aortic arch to be visualized preoperatively, thus guiding cannulation strategies.) Figure 2, *G* and *H*, also serves as additional examples of differential windowing of the same CT slice.

POSITRON EMISSION TOMOGRAPHY (PET)

Although imaging modalities such as plain films and CT provide anatomic and morphologic information, PET provides functional information regarding metabolic activity of tissues.[9,10] PET uses a radiolabeled glucose analog, ^{18}F-fluorodeoxyglucose (FDG), to display the uptake of glucose into tissues in the body in standardized uptake values.[9,10] Acquiring both PET and CT imaging at the same time is known as PET-CT; this allows the uptake of FDG into tissues to be mapped onto a CT image of the body, thus providing a 3-dimensional visualization of where "hotspots" of FDG uptake are located.[9]

The primary use of PET-CT in cardiothoracic surgery is for the diagnosis and staging of lung malignancies.[9] The proportion of CXR and thoracic CT scans that incidentally reveal lung nodules is approximately 1%.[9] For nodules of larger than negligible size or with suspicious features, PET-CT may be warranted as the next diagnostic step, given that malignant lesions often have much greater metabolic activity than that of benign lesions such as hamartomas or granulomas.[9,10] Recently, there has been increasing interest in the use of FDG update to characterize the "biological aggressiveness" of non–small cell lung cancers, with several studies reporting a statistically significant

association between quantitative whole-body FDG uptake and both survival and risk of recurrence.[11]

With respect to the staging of lung malignancies, PET-CT can provide useful information regarding both lymph node spread and the presence of metastases while also helping providers plan for tissue biopsy in order to reach a definitive diagnosis.[11] However, just as with any clinical test, the use of PET-CT to assess whether a lymph node should be considered "positive" for disease introduces the possibility for a false-positive result, which must be discussed with patients during preprocedure counseling. Typically, any lymph node or mass with a maximum standardized uptake value of greater or equal to 2.5 may be considered to be malignant.[12] At this threshold, both the sensitivity and specificity for the detection of true malignancy have been reported to be approximately 80%.[12] Therefore, the false-positive rate, or type I error, associated with this measure is approximately 20%.[12]

Figure 3, *A*, shows an example axial PET-CT slice from the same patient described in Figure 2, *G* and *H*. The slice in Figure 3, *A*, provides an important reminder regarding the specificity of PET-CT: not all tissues with high FDG uptake are neoplastic, as demonstrated by the high uptake in the patient's left ventricle. Therefore, the distribution of uptake (especially regarding symmetry) and the known metabolic activity of local tissues are important factors to consider when evaluating PET-CT with concern for malignancy. Figure 3, *B*, shows an example coronal PET-CT slice of the same lung nodule shown in Figure 3, *A*.

ECHOCARDIOGRAPHY

Echocardiography uses ultrasound imaging for structural evaluation of the heart. This imaging modality produces images in real time, allowing assessment of wall motion and cardiac function. A special mode of echocardiography, called doppler imaging, may be used to evaluate valvular function through the calculation of flow rates and pressure gradients across valves, and determine effective orifice area.

There are 2 forms of echocardiographic evaluation, both of which are commonly used. These are the transthoracic echocardiogram (TTE) and the transesophageal echocardiogram (TEE). The less-invasive TTE allows images to be obtained by placing the ultrasound probe at specific positions on the chest wall to evaluate the heart from different vantage points or "windows." TTE is noninvasive and easy to perform; therefore, it is typically the initial imaging method used for cardiac imaging. Conversely, TEEs are more invasive and are performed in a controlled environment, such as a procedure suite, because the ultrasound probe is located at the end of a device that is inserted into the esophagus down to the level of the heart. TEEs allow for greater-resolution image production because, below the level of the carina, the esophagus lies immediately posterior to the heart without any musculoskeletal structures or lung tissue between them.

There are various indications for performing an echocardiogram and whether to use TTE or TEE. Echocardiography is an integral part in the diagnostic workup of cardiac valvular and/or aortic pathologies that commonly lead to surgical consultation and intervention. Examples of the standard views obtained by TTE and TEE are shown in Figure 4.

Echocardiographic assessment of the heart's valves provides important data that is necessary for deciding whether or not a patient will require invasive cardiac procedures such as a transcatheter or surgical valve replacement. See the "Adult Cardiac: Aortic Valve Replacement" section of this primer for more details regarding specific indications, risks, benefits, and procedural steps of these interventions.

Although echocardiography allows the clinician to visually appreciate overall cardiac structure and function, many quantifiable parameters may be assessed as well. A

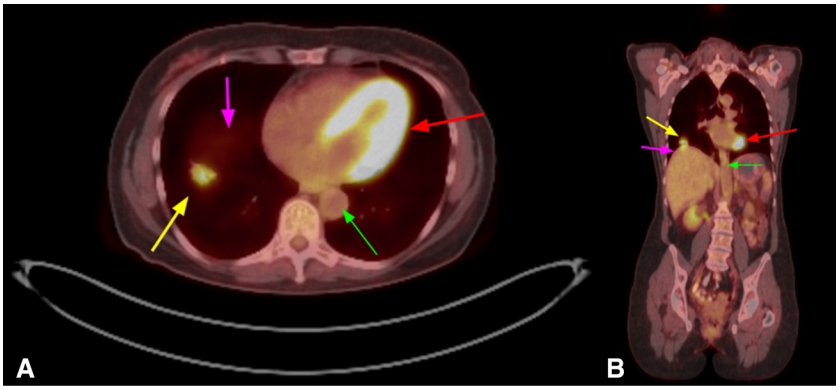


FIGURE 3. Positron emission tomography computed tomography (PET-CT) imaging of a patient with a primary lung lesion. A, Axial slice of PET-CT with *yellow arrow* indicating primary lung neoplastic lesion. *Purple arrow*: faint uptake at this level indicates superior border of liver. *Green arrow*: descending aorta. *Red arrow*: left ventricular wall. B, Coronal slice of same PET-CT shown in panel A, with *colored arrows* indicating same structures as in panel A: *Yellow*: primary lung neoplastic lesion. *Purple*: superior border of liver. *Green*: descending aorta. *Red*: apex of heart. Both images obtained with permission from Dr Errol Bush of Johns Hopkins Hospital.

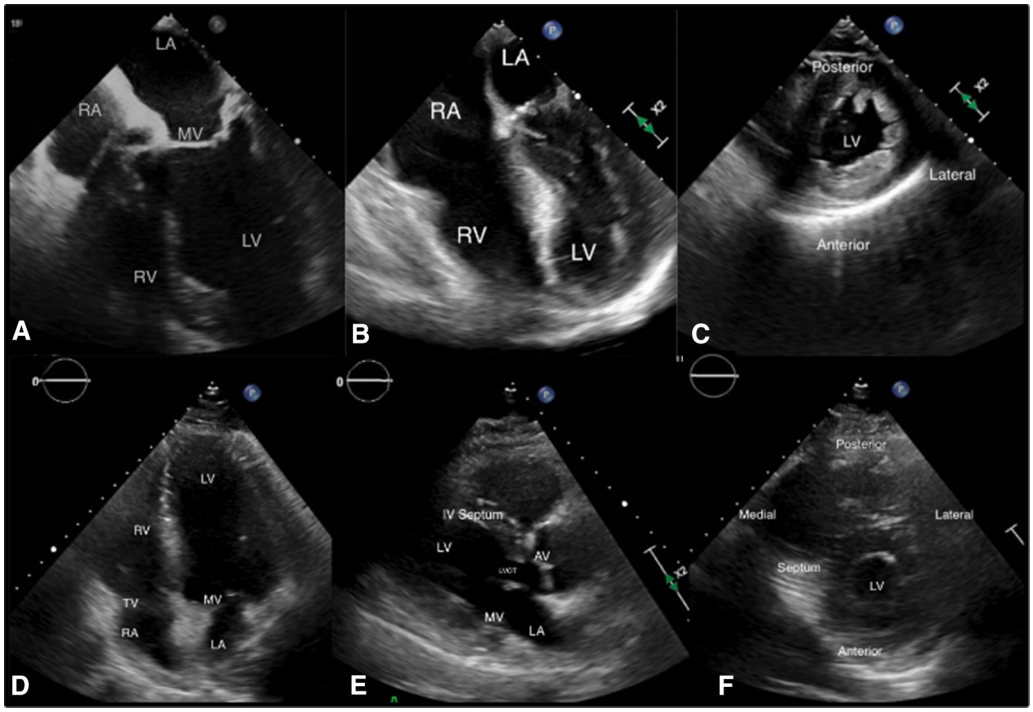


FIGURE 4. Examples of the standard views obtained by transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE). From A to F, alphabetically, the views are as following: TEE 4-chamber, TEE long-axis, TEE short-axis, TTE apical 4-chamber, TTE parasternal long- axis, and TTE parasternal short-axis. *LA/RA*, Right/left atria; *MV/TV*, mitral/tricuspid valves; *RV/LV*, right/left ventricles. Images used with permission of Dr Ahmet Kilic of Johns Hopkins Hospital.

summary of key parameters which may be measured via echocardiography is presented in Table 1, together with expected normal values.[13]

LEFT HEART CATHETERIZATION

Left heart catheterization is a routine diagnostic procedure that allows for visualization of coronary artery blood flow using fluoroscopic imaging (coronary angiography).[14] This allows a physician to assess a patient's coronary anatomy and evaluate for any filling defects. In general, a 70% projected narrowing is considered a significant blockage as the cross-sectional area has decreased by 90%.[14] Note: The main exception to this rule is the left main coronary artery, where a 50% projected narrowing is significant because the left circumflex and left anterior descending arteries originate from the left main coronary artery. Coronary angiography is obtained before nearly every adult cardiac surgery, including valvular operations in addition to coronary artery bypass grafting. Careful evaluation of the coronary vessels allows surgeons to assess a patient's coronary anatomy, disease significance, calcifications, and allows for the identification of distal targets for anastomosis of grafted vessels. For example, although in most cases the posterior descending artery is a branch of the right coronary artery (meaning that the heart is "right dominant"), in approximately 20% of cases the posterior descending artery branches of the left circumflex artery (called "left dominance") or even from both right and left systems (called "codominance").

Patients are typically awake during the procedure with only local anesthetic at the insertion site and general sedation, which allows for the patient to express any discomfort or pain that can be quickly addressed.

TABLE 1. Quantifiable parameters during echocardiographic assessment

Parameter name	Male normal range	Female normal range
Fractional shortening	28% to 44%	
Systolic velocity integral, cm	15-35	
Mitral valve E:A ratio	0.7-3.1	
Tricuspid valve E:A ratio	0.8-2.9	
Isovolumic relaxation time, ms	54-98	
Left atrium length, cm	3.0-4.5	2.7-4.0
Left ventricle diastolic diameter, cm	4.3-5.9	4.0-5.2
Left ventricle systolic diameter, cm	2.6-4.0	2.3-3.5
Intraventricular septum (diastolic dimension), cm	0.6-1.3	0.5-1.2
Left ventricular ejection fraction	52%-72%	54%-74%

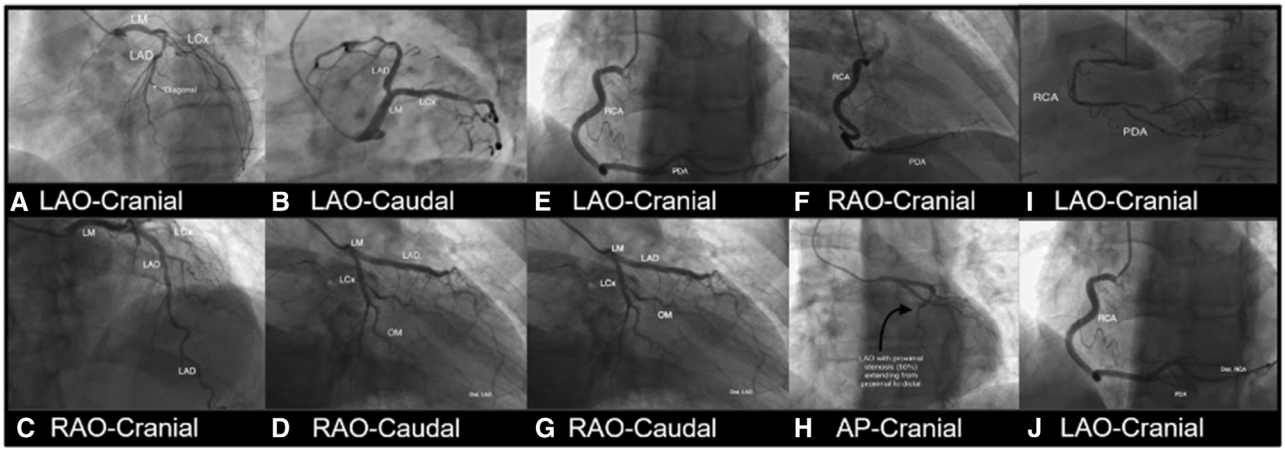


FIGURE 5. Examples of standard angiographic views are demonstrated in A-J. A, Note the area of stenosis within the proximal LAD. B, Note the area of stenosis at the origin of the LAD as it branches from the left main coronary artery. C, Note that there is mild stenosis in the middle portion of the LAD. D, Note this example of relatively healthy coronary arteries in a patient with no previous history of angina or myocardial infarction. E, This is an example of a healthy RCA with minimal disease. F, This image displays an RCA with significant stenosis in the middle portion of the RCA. G, Right dominant circulation in an elderly male patient with no history of CAD or MI. H, Angiographic image of an elderly female patient with a medical history including diabetes and hypertension, undergoing left heart catheterization for evaluation of chest pain and syncope. I, Image of the right coronary system from a patient with no history of CAD or MI. J, Images from the same elderly female patient as in (H) demonstrating significant stenoses of 60% to 90% throughout the right coronary system. *LM*, Left main; *LCx*, left circumflex; *LAD*, left anterior descending; *RCA*, right coronary artery; *PDA*, posterior descending artery; *LAO*, left anterior oblique; *RAO*, right anterior oblique; *OM*, obtuse marginal. Images used with permission of Dr Ahmet Kilic of Johns Hopkins Hospital.

The procedure is as follows[14]:

1. A catheter is introduced through a peripheral artery (typically the radial vs femoral) and advanced to the aortic root.
2. Contrast dye is injected to visualize the location of the coronary artery ostia.
3. Each coronary artery is then interrogated by shooting dye into each ostia under fluoroscopic imaging, visualizing the flow.
4. Grading of flow:
    a. This is typically recorded as a Thrombolysis in Myocardial Infarction flow grade and percentage of occlusion.
    b. Other, more physiologic metrics, are the fractional flow reserve and instant wave free ratio, which is used to assess lesion severity and need for intervention.

Note. Other access points include the brachial artery and radial artery.

The insertion of coronary artery stents via percutaneous coronary intervention (PCI) can be accomplished during this procedure, in particular in the setting of a ST-segment myocardial infarction or in a patient with significant coronary artery disease (CAD) and culprit vessel not otherwise indicated for coronary artery bypass graft. Indications for coronary angiography differ from the indications for coronary revascularization via PCI and include but are not limited to: CAD demonstrated on ECG or stress testing, presurgical assessment, unstable angina, and CAD unresponsive to medical therapy. The only true absolute contraindication is patient refusal of the procedure. Risk of adverse events such as acute myocardial infarction, cerebrovascular accident, or contrast reaction are low, 1% to 2% overall.

The procedure is relatively safe, albeit complications can arise. Coronary angiography is the preferred diagnostic modality for diagnosing CAD, although coronary CT imaging does exist. Patients eligible for stenting via PCI can receive immediate treatment during the procedure, whereas those with indicated lesions undergo diagnostic assessment for potential CABG preoperative planning. See the "Adult Cardiac" section of this primer for more information regarding the various indications for interventional catheter-based procedures, as well as the procedural details of both percutaneous and surgical treatments of coronary artery or valvular pathologies.

Angiographic images are obtained using a C-arm that is able to rotate around the patient in multiple directions. The combination of these C-arm movements allows viewing of the coronary arteries from different viewpoints. The standard images obtained during coronary angiography include 4 views of the left coronary system and 2 views of the right coronary system, listed to follow.[14] The coronary arteries that are assessed by each view are in parentheses. The right coronary system views have a small cranial component (10-30°) that is not always specified in the description of these views. *Hint: left anterior oblique (LAO) views can be identified by noting when the spine is

on the right side of the image, whereas right anterior oblique (RAO) images will show the spine on the left; cranial angulation will be less likely to show a diaphragmatic shadow than caudal angulation.

Left

1. LAO-cranial (left anterior descending and diagonal)
2. LAO-caudal (proximal left anterior descending, proximal left circumflex, distal left marginal)
3. RAO-cranial (left marginal, left circumflex)
4. RAO-caudal (proximal and mid-left anterior descending)

Right

5. LAO (proximal and mid-right coronary artery)
6. RAO (proximal and mid-right coronary artery)

Examples of standard angiographic views are demonstrated in Figure 5.

RIGHT HEART CATHETERIZATION

Although less commonly performed than its left-sided counterpart, right heart catheterization is an important way to directly measure right-sided cardiac pressures. Patients undergoing this procedure most often require evaluation for heart failure or lung transplantation. The procedure for the performance of a right-sided catheterization for the measurement of the pulmonary artery pressure is as follows[15]:

1. A pulmonary artery catheter is inserted via Seldinger technique through peripheral venous access and advanced; after the catheter is advanced 15 cm, the balloon may be inflated so as to allow for easier advancement to the right atrium. Correct positioning in the right atrium may be assessed via observation of the pulsatile right atrial waveform.
2. The catheter may continue to be advanced after manipulation to turn the tip towards the patient's right; upon reaching the right ventricle (where position may again be confirmed via observation of the pressure waveform), right ventricular pressure may be recorded.
3. The catheter may then be advanced towards the "wedge position" ("wedged" into a small branch of the pulmonary artery) in order to measure the pulmonary capillary wedge pressure (which approximates the left atrial pressure).
4. The balloon may then be deflated, allowing for the clinician to pull the catheter back several centimeters in order to measure the pulmonary artery pressure.
5. Following the measurement of all desired pressures or collection of any desired blood samples, the catheter may be removed in one smooth motion.

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