APPENDIX

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Knowledge-Based Objectives

Normal Anatomy—

1. Name and define the three zones of the airways.
2. Define a secondary pulmonary lobule and identify it on CT.
3. Define an acinus.
4. Name the lobar and segmental bronchi of both lungs.
5. Identify the following structures on the posteroanterior (PA) chest radiograph:

● Lungs—right, left, right upper, middle, and lower lobes, left upper (including lingula) and lower lobes
● Fissures—minor, superior accessory, inferior accessory, azygos
● Airway—trachea, carina, main bronchi
● Heart—right atrium, left atrial appendage, left ventricle, location of the four cardiac valves
● Pulmonary arteries—main, right, left, interlobar, truncus anterior
● Aorta—ascending, arch, descending
● Veins—superior vena cava, azygos, left superior intercostal (“aortic nipple”)
● Bones—spine, ribs, clavicles, scapulae, humeri
● Right paratracheal stripe
● Junction lines—anterior, posterior
● Aortopulmonary window
● Azygoesophageal recess
● Paraspinal lines
● Left subclavian artery

6. Identify the following structures on the lateral chest radiograph:

● Lungs—right, left, right upper, middle and lower lobes, left upper (including lingula) and lower lobes
● Fissures—major, minor, superior accessory
● Airway—trachea, upper lobe bronchi, posterior wall of bronchus intermedius
● Heart—right ventricle, right ventricular outflow tract, left atrium, left ventricle, the location of the four cardiac valves
● Pulmonary arteries—right, left
● Aorta—ascending, arch, descending
● Veins—superior vena cava, inferior vena cava, left brachiocephalic (innominate), pulmonary vein confluence

Bones—spine, ribs, scapulae, humeri, sternum

● Retrosternal line
● Posterior tracheal stripe
● Right and left hemidiaphragms
● Raider’s triangle

● Brachiocephalic (innominate) artery

Signs in Thoracic Radiology—

1. Define, identify and state the significance of the following on a radiograph:

● air bronchogram—indicates a parenchymal process, including nonobstructive atelectasis, as distinguished from pleural or mediastinal processes

● air crescent sign—indicates a lung cavity, often resulting from fungal infection or saprophytic colonization

● deep sulcus sign on a supine radiograph—indicates pneumothorax

● continuous diaphragm sign—indicates pneumomediastinum

● ring around the artery sign (air around pulmonary artery, particularly on lateral chest radiograph)— indicates pneumomediastinum

● fallen lung sign—indicates a fractured bronchus

● flat waist sign—indicates left lower lobe collapse

● gloved finger sign—indicates bronchial impaction, which can be seen in allergic bronchopulmonary aspergillosis

● Golden S sign—indicates lobar collapse caused by a central mass, suggesting an obstructing bronchogenic carcinoma in an adult

● luftsichel sign—indicates upper lobe collapse with lucency due to hyperinflated left lower lobe, suggesting an obstructing bronchogenic carcinoma in an adult

● Hampton's hump—peripheral, wedge-shaped opacity indicating a pulmonary infarct

● silhouette sign—loss of the contour of the heart, aorta or diaphragm allowing localization of a parenchymal process (e.g. a process involving the medial segment of the right middle lobe obscures the right heart border, a lingular process obscures the left heart border, a basilar segmental lower lobe process obscures the diaphragm)

● cervicothoracic sign—a mediastinal opacity that projects above the clavicles is retrotracheal and posteriorly situated, whereas an opacity effaced along its superior aspect and projecting at or below the clavicles is situated anteriorly

● tapered margins sign/incomplete border sign—a lesion in the chest wall, mediastinum or pleura may have smooth tapered borders and obtuse angles with the chest wall or mediastinum while parenchymal lesions usually form acute angles

● figure 3 sign—abnormal contour of the descending aorta, indicating coarctation of the aorta

● fat pad sign or sandwich sign—indicates pericardial effusion on lateral chest radiograph

● scimitar sign—an abnormal pulmonary vein in venolobar syndrome

● double density sign— opacity projecting over the right side of the heart, indicating enlargement of the left atrium

● hilum overlay sign and hilum convergence sign— used to distinguish a hilar mass from a non-hilar mass

- reversed halo sign- aka **atoll sign**, defined as central ground-glass opacity (GGO) surrounded by denser consolidation that thought to be specific for organizing pneumonia but can be seen in other conditions
- signet ring sign (aka pearl ring sign)- bronchiectasis next to artery creating appearance of signet ring
- split pleura sign- separation of enhancing visceral and parietal pleura suggestive of empyema or other inflammatory pleural processes
- headcheese sign- 3 different densities seen in chronic hypersensitivity pneumonitis
- thoracoabdominal sign- a lung lesion which has its caudal end visible below the dome of diaphragm must be in the posterior part of the thorax because the posterior costophrenic sulcus extends below the anterior lung
- Westermark sign- abrupt termination/change in caliber and oligemia in an area of lung due to pulmonary embolism
- CT angiogram sign- branching pulmonary vessels in a homogeneous low-attenuating consolidation of lung parenchyma relative to the chest wall muscles
- bulging fissure sign- lobar consolidation where the affected portion of the lung is expanded
- Fleischner sign- enlargement of central pulmonary arteries on chest radiographs or angiography secondary to pulmonary embolism
- Comet tail sign- curving of pulmonary vessels and bronchi toward an area of rounded atelectasis
- Thymic sail sign- appearance of normal thymus on chest radiograph in pediatric population
- Positive bronchus sign- computed tomography appearance of a tubular air-filled bronchus leading to a lung nodule and creates an air bronchogram

● halo sign—suggesting invasive pulmonary aspergillosis in a leukemic patient

2. Define, identify, and state the significance of the following on a thoracic MRI:

●A thymic mass chemical shift ratio (CSR) of ≤ 0.7 (compatible with normal thymus or thymic hyperplasia, rather than thymic tumor or lymphoma

●Early time-to-peak enhancement versus gradual enhancement of a solid thymic mass--favors low grade thymoma over lymphoma

●The "dark lymph node sign" --suggestive of sarcoidosis

Interstitial Lung Disease—

1. List and identify on a chest radiograph and thoracic CT four patterns (nodular, reticular, reticulonodular, and linear) of interstitial lung disease (ILD).
2. Make a specific diagnosis of ILD when supportive findings are present in the history or on radiologic imaging (e.g. dilated esophagus and ILD in scleroderma, enlarged heart and a pacemaker or defibrillator in a patient with prior sternotomy, and ILD secondary to amiodarone drug toxicity).
3. Identify Kerley A and B lines on a chest radiograph and explain their etiology.
4. Recognize the changes of congestive heart failure on a chest radiograph—enlarged cardiac silhouette, pleural effusions, vascular redistribution, interstitial or alveolar edema, Kerley lines, enlarged azygos vein, increased ratio of artery-to-bronchus diameter.
5. Define the terms “asbestos-related pleural disease” and “asbestosis” (exudative effusion, pleural plaques, diffuse pleural thickening, and mesothelioma), rounded atelectasis; identify each on a chest radiograph and chest CT.
6. Describe what a “B” reader is as related to the evaluation of pneumoconioses. Recognize progressive massive fibrosis/conglomerate masses secondary to silicosis or coal worker’s pneumoconiosis on radiography and chest CT.
7. Identify honeycombing on a radiograph and thoracic CT, state the significance of this finding (end-stage lung disease or definite versus possible UIP pattern), and list the common causes of honeycomb lung.
8. Describe the radiographic classification of sarcoidosis.
9. Identify and give appropriate differential diagnoses when the patterns of septal thickening, perilymphatic nodules, bronchiolar opacities (“tree-in-bud”), air-trapping, cysts, and ground glass opacities are seen on CT.
10. Be able to identify the characteristic CT patterns of usual interstitial pneumonia (UIP) and nonspecific interstitial pneumonia (NSIP).
11. Make a specific diagnosis of ILD when supportive findings are present in the history or on imaging (e.g. dilated esophagus and ILD in scleroderma, history of connective tissue disorder, enlarged heart and a pacemaker or defibrillator in a patient with prior sternotomy, and ILD secondary to amiodarone drug toxicity).
12. Be able to identify the CT patterns of smoking-related interstitial lung disease: respiratory bronchiolitis, desquamative interstitial pneumonitis, Langerhans cell histiocytosis.
13. Recognize the common CXR and CT imaging patterns of cryptogenic organizing pneumonia.
14. Hypersensitivity pneumonitis – recognize the CXR and CT imaging patterns of acute, subacute and chronic hypersensitivity pneumonitis.

15. Recognize findings of cystic lung disease on a chest radiograph and CT: Langerhans cell histiocytosis, lymphangioleiomyomatosis (LAM), lymphocytic interstitial pneumonia (LIP).
16. Recognize the typical appearance and upper lobe predominant distribution of irregular lung cysts or nodules on CT in a patient with Langerhans cell histiocytosis.
17. List four causes of unilateral ILD.
18. List three causes of lower lobe predominant ILD.
19. List two causes of upper lobe predominant ILD.

Alveolar Lung Disease—

1. List four broad categories of acute alveolar lung disease (ALD).
2. List five broad categories of chronic ALD.
3. Name three pulmonary-renal syndromes.
4. List five of the most common causes of acute respiratory distress syndrome.
5. Name four predisposing causes of cryptogenic organizing pneumonia.
6. Suggest a specific diagnosis of ALD when supportive findings are present in the history or on the chest radiograph (e.g. broken femur and ALD in fat embolization syndrome, ALD and renal failure in a pulmonary-renal syndrome, ALD treated with bronchoalveolar lavage in alveolar proteinosis).
7. Recognize a pattern of peripheral ALD on radiography or CT and give an appropriate differential diagnosis, including a single most likely diagnosis when supported by associated radiologic findings or clinical information (e.g. peripheral lung disease associated with paratracheal and bilateral hilar adenopathy in an asymptomatic patient with “alveolar” sarcoidosis, peripheral lung disease associated with a markedly elevated blood eosinophil count in a patient with eosinophilic pneumonia, peripheral opacities associated with multiple rib fractures and pneumothorax in a patient with acute thoracic trauma and pulmonary contusions).

Atelectasis, Airways, and Obstructive Lung Disease—

1. Recognize partial or complete atelectasis of the following on a chest radiograph:
- right upper lobe
- right middle lobe
- right lower lobe
- right upper and middle lobe
- right middle and lower lobe
- left upper lobe
- left lower lobe

2. Recognize complete collapse of the right or left lung on a chest radiograph and list an appropriate differential diagnosis for the etiology of the collapse.

3. Distinguish lung collapse from massive pleural effusion on a frontal chest radiograph.
4. Name the four types of bronchiectasis and identify each type on a CT.
5. Name five common causes of bronchiectasis.
6. Recognize the typical appearance of cystic fibrosis on chest radiography, CT, & MRI
7. Name the important things to look for on a chest radiograph when the patient history is “asthma.”
8. Define tracheomegaly.
9. Recognize tracheal and bronchial stenosis on CT and name the most common causes.
10. Name the three types of pulmonary emphysema and identify each type on a thoracic CT.
11. Recognize alpha-1-antitrypsin deficiency on a chest radiograph and CT.
12. Recognize Kartagener syndrome on a chest radiograph and name the three components of the syndrome.
13. Define the term giant bulla, differentiate giant bulla from pulmonary emphysema, and state the role of imaging in patient selection for bullectomy.
14. State the imaging findings used to identify surgical candidates for giant bullectomy and for lung volume reduction surgery.
15. Recognize and describe the significance of a pattern of mosaic lung attenuation on thoracic CT.

1. *Mediastinal Masses and Mediastinal/Hilar Lymph Node Enlargement—*

a. State the anatomic boundaries of the anterior, middle, posterior, and superior mediastinum.
b. Name the four most common causes of an anterior mediastinal mass and localize a mass to the anterior mediastinum on a chest radiograph, CT, and MRI.
2. Calculate the chemical shift ratio (CSR) of a solid thymic mass to help distinguish normal and hyperplastic thymus from thymic tumor, including lymphoma. Be aware of the pitfalls of chemical shift ratio assessment, with regard to both ROI placement and interpretation.
a. Demonstrate awareness of the sex difference in thymic appearance women in young adults, ages 20-30 years.

3. Name the three most common causes of a middle mediastinal mass and localize a mass in the middle mediastinum on a chest radiograph, CT, and MRI.
4. Name the most common cause of a posterior mediastinal mass and localize a mass in the posterior mediastinum on a chest radiograph, CT, and MRI.
5. Name two causes of a mass that straddles the thoracic inlet and localize a mass to the thoracic inlet on a chest radiograph, CT, and MRI.
6. Identify normal vessels or vascular abnormality on cardiothoracic CT and MRI that may mimic a solid mass. Recognize that well-circumscribed,

homogeneous attenuation mediastinal masses with solid attenuation values on CT may be proven cystic on MRI.

7. Name five etiologies of bilateral hilar lymph node enlargement.
8. State the three most common locations (Garland's triad) of thoracic lymph node enlargement in sarcoidosis.
9. List the four most common etiologies of "egg-shell" calcified lymph nodes in the thorax.
10. Recognize a cystic mass in the mediastinum and suggest possible differential diagnosis of bronchogenic foregut duplication cyst, thymic cyst, mesothelial cyst, and lymphangioma, with narrowing of this differential diagnosis based on location and appearance.
11. Recognize the findings of mediastinal fibrosis on CT and MRI.

Solitary and Multiple Pulmonary Nodules—

1. Define the terms pulmonary nodule and pulmonary mass.
2. Name the three most common causes of a solitary pulmonary nodule. Be aware of the use of chemical shift MRI to diagnose macroscopic fat-poor pulmonary hamartomas and of MR features that may suggest a chondroid hamartoma.
3. Name four important considerations in the evaluation of a solitary pulmonary nodule.
4. Name six causes of cavitary pulmonary nodules.
5. Name four causes of multiple pulmonary nodules.
6. Describe the indications for percutaneous biopsy of a solitary pulmonary nodule. For diagnosis of most malignant lesions, 20-22G fine needle aspiration is sufficient. Cores (18-20G) are required if suspected diagnosis is lymphoma, other non-epithelial malignancy, benign disease, or if tissue is needed for genomic profiling of lung cancer.
7. Describe the indications for percutaneous biopsy when there are multiple pulmonary nodules.
8. Describe the complications and the frequency with which complications occur because of percutaneous lung biopsy using CT or fluoroscopic guidance. Understand how to manage complications such as pneumothorax, hemoptysis, air embolism.
9. Describe the indications for chest tube placement as a treatment for pneumothorax related to percutaneous lung biopsy. Understand risk factors that predispose the patient to develop a large post procedure pneumothorax (e.g. severe emphysema).
10. Describe the role of positron emission tomography in the evaluation of a solitary pulmonary nodule.
11. Describe an appropriate imaging algorithm to evaluate a solitary pulmonary nodule.

Benign and Malignant Neoplasms of the Lung and Esophagus—

1. Name the four major histologic types of bronchogenic carcinoma and state the difference between non-small cell and small cell lung cancer.

2. Name the type of non-small cell lung cancer that most commonly cavitates and which are usually central.

3. Understand the revised adenocarcinoma nomenclature (published in 2011), which addressed advances in oncology, molecular biology, radiology, pathology and surgery of lung adenocarcinoma. For example, the terms bronchioloalveolar carcinoma (BAC) and mixed subtype adenocarcinoma are no longer used. Understand the definitions of atypical adenomatous hyperplasia, adenocarcinoma in situ (formerly BAC), minimally invasive and invasive adenocarcinoma, and their subtypes. Understand the CT and MR morphologic and signal correlates of the pre-invasive versus the invasive forms of primary lung adenocarcinoma.

4. Be familiar with the current Fleischner Society management guidelines for solid and sub-solid nodules based on current understanding of different clinical behaviors and prognoses of solid, part-solid, and ground-glass nodules.

5. Describe the TNM classification for staging non-small cell lung cancer, including the components of each stage (I, II, III, IV, and substages) and the definition of each component (T1-4, N0-3, M0-1).

6. Describe the staging of small-cell lung cancer.

7. Name the four most common extrathoracic sites of metastases for non-small cell and small cell lung cancer.

8. Name the stages of non-small cell lung cancer that are potentially resectable.

9. Recognize abnormal contralateral mediastinal shift on a post-pneumonectomy chest radiograph and state five possible etiologies for the abnormal shift.

10. Name the most common thoracic locations for adenoid cystic carcinoma and carcinoid tumors to occur.

11. Suggest the possibility of radiation change as a cause of new apical opacification on a chest radiograph of a patient with evidence of mastectomy or axillary node dissection.

12. Describe the acute and chronic radiographic, CT, and MR appearances of radiation injury in the thorax (lung, pleura, pericardium, esophagus) and the temporal relationship to radiation therapy.

13. State the role of MRI in lung cancer staging (e.g. chest wall invasion, superior sulcus,/Pancoast tumor, lymphadenopathy assessment by short *tau* inversion recovery and diffusion-weighted MR imaging).

14. Describe the role of positron emission tomography in lung cancer staging.

15. Describe the TNM classification for staging esophageal carcinoma, including the components of each stage (I, II, III, IV) and the definition of each component (T, N, and M).

16. Describe the role of imaging in the staging of esophageal carcinoma.

17. Name the stages of esophageal carcinoma that are potentially resectable.

18. Describe the classification of lymphoma, the role of imaging in the staging of lymphoma, and the typical and atypical imaging findings of thoracic lymphoma.

19. Define primary pulmonary lymphoma.

20. Describe the typical chest radiograph, thoracic CT and MR appearances of Kaposi sarcoma.

Lung Cancer Screening:

1. Describe the benefits and potential harms of lung cancer screening.
2. Name the eligibility criteria for lung cancer screening.
3. Describe CT radiation exposure levels consistent with low-dose CT for lung cancer screening.
4. Define a negative, positive, and false positive test result in CT screening for lung cancer.
5. Describe appropriate follow-up, additional diagnostic evaluation, and intervention of lung cancer CT screening results.
6. Describe appropriate reporting and communication of lung cancer screening results.

Genomic Profiling of Lung Cancer:

1. Basic understanding of advances in lung cancer therapy
2. General understanding of how genomic profiling of various types of lung cancer and knowing the genetic mutational status of lung cancer (EGFR, ALK etc.) determines what type of chemotherapy is used.
3. Understand limitations of conventional tumor response assessment methods in patients receiving targeted therapies
   a. RECIST
   b. WHO

Thoracic Trauma—

1. Identify a widened mediastinum on a trauma radiograph and state the differential diagnosis (including aortic/arterial injury, venous injury, fracture of sternum or spine).
2. Identify and describe the indirect and direct signs of aortic injury on contrast-enhanced CT and MR.
3. Identify and state the significance of chronic traumatic pseudoaneurysm of the aorta on a chest radiograph, CT, or MRI.
4. Identify fractured ribs, clavicle, spine, and scapula on a chest radiograph and CT, or MRI.
5. Name five common causes of abnormal lung opacity on a trauma radiograph, CT, or MRI.
6. Identify an abnormally positioned diaphragm or loss of definition of a diaphragm on a trauma chest radiograph and suggest the diagnosis of a ruptured diaphragm.

7. Recognize and describe the signs of diaphragmatic rupture on CT and MRI.
8. Identify a pneumothorax, pneumopericardium, and pneumomediastinum on a trauma chest radiograph.
9. Identify the fallen lung sign on a chest radiograph, CT, and MRI and suggest the diagnosis of tracheobronchial tear.
10. Identify a cavitary lesion on a post-trauma radiograph, CT, or MRI and suggest the diagnosis of laceration with pneumatocele formation, hematoma, or abscess secondary to aspiration.
11. Name the three most common causes of pneumomediastinum in the setting of trauma.
12. Recognize and distinguish between pulmonary contusion and laceration on CT.

Chest Wall, Pleura, and Diaphragm—
1. Recognize and name four causes of a large unilateral pleural effusion on a chest radiograph, CT and MRI.
2. Recognize a pneumothorax on an upright and supine chest radiograph.
3. Recognize a pleural mass with bone destruction or infiltration of the chest wall on a chest radiograph, CT, and MRI and name four likely causes.
4. Recognize pleural calcification on a chest radiograph or CT and suggest the diagnosis of asbestos exposure (bilateral involvement) or old tuberculosis or trauma (unilateral involvement).
5. Recognize the typical chest radiographic appearances of pleural effusion, given differences in patient positioning, and describe the role of the lateral decubitus view to evaluate pleural effusion.
6. Recognize apparent unilateral elevation of the diaphragm on a chest radiograph and suggest a specific etiology with supportive history and associated chest radiograph findings (e.g. sub-diaphragmatic abscess after abdominal surgery, diaphragm rupture after trauma, phrenic nerve involvement with lung cancer).
7. Recognize imaging findings suggesting a tension pneumothorax and understand the acute clinical implications.
8. Recognize diffuse pleural thickening, as seen in fibrothorax, malignant mesothelioma, and pleural metastases.
9. Describe and recognize the radiographic, CT, and MRI findings of malignant mesothelioma.
10. Describe the difference in appearance of a pulmonary abscess and an empyema CT and MRI and how the two are managed differently.
11. Distinguish pleural from intraperitoneal fluid on CT and MRI.

Infection and Immunity—
1. Describe the radiographic manifestations of primary pulmonary tuberculosis.
2. Name the most common segmental sites of involvement for post-primary tuberculosis in the lung.

3. Define a Ghon lesion (calcified pulmonary parenchymal granuloma) and Ranke complex (calcified node and Ghon lesion); recognize both on a chest radiograph and CT and describe their significance.
4. Name and describe the types of pulmonary aspergillus disease.
5. Identify an intracavitary fungus ball on chest radiography, CT, and MRI.
6. Describe the radiographic appearances of cytomegalovirus pneumonia.
7. Name the major categories of disease causing chest radiograph, CT, and MR abnormalities in the immunocompromised patient.
8. Other than bacterial infection, name two important infections and two important neoplasms to consider in patients with AIDS and associated chest radiograph, CT,and MR abnormalities.
9. Describe the chest radiograph and CT appearances of Pneumocystis carinii (jiroveci) pneumonia.
10. Name the four most important etiologies of hilar and mediastinal lymphadenopathy in patients with AIDS.
11. Describe the time course and chest radiographic appearance of a blood transfusion reaction.
12. Describe the radiographic appearances of mycoplasma pneumonia.
13. Describe the chest radiographic and CT appearance of a miliary pattern and provide a differential diagnosis.
14. Name the diagnostic considerations in a patient who presents with recurrent or persistent pneumonias.
15. Name the endemic mycoses and the specific geographic regions where they are found, and describe their radiographic manifestations.
16. Name the most common pulmonary infections seen after solid organ (i.e. liver, renal, lung, cardiac) and bone marrow transplantation.
17. Describe the chest radiographic, CT, and MRI findings of post-transplant lymphoproliferative disorders.

Unilateral Hyperlucent Hemithorax—

1. Recognize a unilateral hyperlucent hemithorax on a chest radiograph or CT.
2. Identify the common causes for unilateral hyperlucent hemithorax on a chest radiograph.
3. Give an appropriate differential diagnosis when a hyperlucent hemithorax is seen on a chest radiograph, and suggest a specific diagnosis when certain associated findings are seen (i.e. absence of a breast in a patient after mastectomy, absence of a pectoralis muscle in a patient with Poland syndrome, unilateral bullous disease/emphysema, or air-trapping on expiration in a patient with Swyer-James Macleod syndrome or an endobronchial foreign body).

Congenital Lung Disease—

1. Name the components of pulmonary venolobar syndrome.
2. Recognize venolobar syndrome on a frontal chest radiograph, CT, and MRI and explain the etiology of the retrosternal band of opacity seen on the lateral radiograph.
3. Recognize a mass in the posterior segment of a lower lobe on a chest radiograph, CT, and MRI and suggest the possible diagnosis of pulmonary sequestration.
4. Describe the differences between intralobar and extralobar sequestration.
5. Recognize bronchial atresia on a chest radiograph, CT, and MRI and name the most common lobes in which it occurs.

Pulmonary Vasculature—

1. Recognize enlarged pulmonary arteries on a chest radiograph and distinguish them from enlarged hilar lymph nodes.
2. Recognize enlargement of the central pulmonary arteries with diminution of the peripheral pulmonary arteries on a chest radiograph and suggest the diagnosis of pulmonary arterial hypertension.
3. Name five common causes of pulmonary arterial hypertension.
4. Recognize lobar and segmental pulmonary emboli on CT and MRI (including magnetic resonance angiography).
5. Define the role of ventilation-perfusion scintigraphy, CT, MRI/MRA, CT venography, and lower extremity venous ultrasound studies in the evaluation of a patient with suspected venous thromboembolic disease, including the advantages and limitations of each modality depending on patient presentation.
6. Describe the anatomy of and identify the right and left superior and inferior pulmonary veins on CT and MRI and the use of radiofrequency ablation of pulmonary veins for treatment of atrial fibrillation.
7. Recognize variations in pulmonary venous anatomy, such as a separate right middle lobe vein and common ostium of the left superior and inferior pulmonary veins.

Thoracic Aorta and Great Vessels—

1. State the normal dimensions of the thoracic aorta.
2. Describe the classifications of aortic dissection (DeBakey I, II, III; Stanford A, B) and implications for classification on medical versus surgical management.
3. Describe and recognize the findings of, and distinguish between each of the following on CT and MR:

- aortic aneurysm
- aortic dissection
- aortic intramural hematoma
- penetrating atherosclerotic ulcer
- ulcerated plaque

● ruptured aortic aneurysm
● sinus of Valsalva aneurysm
● subclavian or brachiocephalic artery aneurysm
● aortic coarctation
● aortic pseudocoarctation
● pulsation artifact at aortic root

4. Recognize a right aortic arch and a double aortic arch on a chest radiograph, CT and MRI.
5. State the significance of a right aortic arch with mirror image branching versus with an aberrant subclavian artery.
6. Recognize a cervical aortic arch on a chest radiograph, CT, and MRI.
7. Recognize an aberrant subclavian artery on CT, and MRI.
8. Recognize normal variants of aortic arch branching, including common origin of brachiocephalic and left common carotid arteries ("bovine arch"), and separate origin of vertebral artery from arch on CT and MRI/MRA.
9. Define the terms aneurysm and pseudoaneurysm and their common causes (atherosclerotic disease versus mycotic, etc).
10. Describe the cardiac anomalies commonly associated with aortic coarctation.
11. Describe and identify the findings of vasculitis involving large and medium-sized vessels, such as Takayasu arteritis or giant cell arteritis, on CT and MRI.
12. Describe the advantages and disadvantages of CT, MRI/MRA, and transesophageal echocardiography in the evaluation of the thoracic aorta.

Monitoring and support devices—"tubes and lines"—
1. Describe and identify on chest radiography the normal appearance and complications associated with each of the following:
● endotracheal tube
● central venous catheter
● peripherally inserted central venous catheter
● pulmonary artery catheter
● feeding tube
● nasogastric tube
● chest tube
● intra-aortic balloon pump
● aortic endografts
● pacemaker generator and leads (including triple lead devices)
● automatic implantable cardiac defibrillator
● left ventricular assist device
● left atrial appendage occlusion devices
● atrial septal defect closure device
● pericardial drain
● extracorporeal life support cannulae
● intraesophageal manometer, temperature probe, or pH probe
● tracheal, bronchial, or esophageal stent

2. Explain how an intra-aortic balloon pump works.
3. Describe the venous anatomy and expected course of veins from the axillary vein to the right atrium relative to anatomic landmarks.
4. Recognize the difference between a skinfold and pneumothorax on a portable chest radiograph.

Postoperative thorax—

1. Identify normal postoperative findings and complications of the following procedures on chest radiography, CT, and MRI:
● wedge resection, lobectomy, pneumonectomy
● coronary artery bypass graft surgery
● cardiac valve replacement
● aortic graft
● aortic stent
● transhiatal esophagectomy
● lung transplantation
● heart transplantation
● lung volume reduction surgery

SPECIFIC MEDICAL KNOWLEDGE FOR CARDIAC CT:
1. Practice Guidelines
● Describe current appropriate use criteria and accepted indications for cardiac CT.
● Describe the role of cardiac CT for the most common indications:
● Non-acute symptoms of ischemia: coronary artery assessment with low -to-intermediate risk of coronary artery disease (CAD).
● Acute chest pain/symptoms of ischemia: coronary artery assessment with low-to-intermediate risk of CAD with normal or equivocal biomarkers/ECG.
● Reduced left ventricular ejection fraction: coronary artery assessment with low or intermediate probability of CAD.
● Coronary artery bypass graft (CABG): assessment of patency.
● Coronary artery stent: assessment of patency.
● Adult congenital heart disease: anomalous coronary artery, complex congenital heart disease.
● Cardiac valve disease: assessment of native or prosthetic valves, inadequate other noninvasive imaging.
● Cardiac masses: assessment of cardiac chamber or pericardial masses, inadequate noninvasive imaging.
● Describe the role of non-contrast calcium scoring in coronary event risk stratification.

● Surgical planning:Transcatheter valve implantation, pulmonary vein ablation mapping, Coronary vein mapping for biventricular pacemaker, Redo chest/cardiac surgery, survey of anatomy

2. Cardiac CT acquisition methods

● Describe patient selection and preparation for cardiac coronary CTA, including the role of beta-blockade for optimal heart rate/rhythm.
● Describe medications and IV contrast used for cardiac CT, including appropriate dosing and contraindications for each.
● Master treatment of adverse reactions to IV contrast and other medications administered during coronary CTA.
● Describe the roles and typical radiation doses of prospective and retrospective ECG gating for coronary CTA and the role of tube current modulation in decreasing dose. Have awareness of other radiation dose reduction techniques commonly used such automatic exposure control, iterative reconstruction techniques that minimize the appearance of image noise (adaptive statistical and model based methods).
● Describe the steps in acquiring coronary CTA.
● Understand the role of ECG editing.
● Understand post-processing methods.
● Appreciate common artifacts seen in coronary CTA and methods used for mitigation.
● Appreciate most common methods of cardiac CT dose reduction (automatic tube exposure control, prospective ECG gating, 80-100kV acquisitions, iterative reconstruction algorithms etc.).

3. Cardiac CT Interpretation

a. Coronary arteries

● Describe normal anatomy of the coronary arteries.
● Identify right, left, and co-dominant coronary arterial systems.
● Identify anomalies of origin, course, and termination, including benign and malignant anomalous courses, myocardial bridging, and coronary fistulas.
● Recognize coronary arterial calcified and noncalcified plaque, identify and grade coronary artery stenosis (mild/moderate/severe), and describe implications for management.
● Identify positive coronary remodeling.
● Describe normal and abnormal stent and bypass graft appearances on CCTA; recognize stenosis, occlusion, aneurysms, and pseudoaneurysms.

b. Cardiac chambers

● Describe normal cardiac chamber and great vessel anatomy, and normal appearances of the right and left ventricular myocardium.
● Appreciate normal and abnormal left and right ventricular wall thickness and chamber size on CT, and use CT post-processing to create standard cardiac planes and calculate left and right ventricular ejection fractions.

● Recognize dilated cardiomyopathy, hypertrophic cardiomyopathy, and myocardial infarction (acute vs chronic).
● Recognize and know types of atrial septal defects and ventricular septal defects.
● Understand the differential diagnosis for cardiac masses, and distinguish mass from thrombus on CT.
● Appreciate the evolving role of CT for myocardial perfusion analysis.

c. Cardiac valves
● Describe the normal appearance of the aortic, pulmonic, tricuspid, and mitral valves on CT.
● Identify valvular pathology seen on CT, including valvular stenosis and insufficiency, endocarditis, and tumors.
● Appreciate normal CT appearances of prosthetic cardiac valves. Identify prosthetic valve pathology, including perivalvular leak and pseudoaneurysm, bioprosthetic valve stenosis, malfunction of mechanical valve, and endocarditis.

d. Pericardial disease
● Describe the anatomy and normal appearance of the pericardium on CT, including normal pericardial thickness.
● Identify abnormal pericardial fluid on CT and describe the differential diagnosis of pericardial effusions, hemopericardium, and pneumopericardium.
● Describe the differential diagnosis of pericardial thickening, calcification, and enhancement.
● Describe CT findings suggestive of constrictive pericarditis.
● Identify congenital complete and partial absence of the pericardium.
● Identify and characterize pericardial masses, including pericardial cysts, hematomas, metastases, and primary tumors of the pericardium.

e. Adult congenital heart disease (see MRI list)

4. Selected pre- and post-procedural indications for cardiac CT

a. Transcatheter aortic valve replacement/implantation (TAVR/TAVI)
● Describe indications and methods for performing TAVR/TAVI, including transfemoral, transaortic, and transapical approaches.
● Describe the role of CT in pre-procedural planning, including most important measurements performed.
● Appreciate the normal post-procedural appearance of TAVR/TAVI on chest radiography and CT.
● Identify the potential intraoperative and postoperative complications of TAVR/TAVI, including vascular injury, annular rupture, valve embolization, perivalvular leak.

b. Pulmonary vein isolation / ablation

- Describe the role pulmonary vein isolation/ablation in treatment of atrial fibrillation.
- Describe the role of CT in pre-procedural mapping of the pulmonary veins.
- Describe potential pos-toperative complications, including recurrent atrial fibrillation, pulmonary vein stenosis, and esophago-atrial fistulas.

c. Left ventricular assist device evaluation (LVAD)

- Describe indications for LVAD placement.
- Appreciate the normal appearance of LVAD on CT (inflow cannula,pump, outflow graft, drive line).
- Identify LVAD complications on CT, including hemorrhage, drive line infection, outflow/inflow thrombosis, inflow malposition, and bend-relief dislocation.

MORE SPECIFIC MEDICAL KNOWLEDGE FOR CARDIOTHORACIC MRI

A. Physics

1)Magnets (1.5T, 3T), Radiofrequencies,coils, gradients
2)MRI safety issues- Safety of cardiac devices
3)Gadolinium- Safety issues, use in renal dysfunction, pregnancy, lactation.
4)Cardiothoracic MRI sequences- Physics, applications, limitations, pitfalls

- Steady state free precession
- Double inversion recovery black blood imaging- T1, T2, STIR
- Velocity encoded phase contrast imaging
- Dynamic first pass myocardial perfusion
- Delayed enhancement sequence
- MR angiography
- 3D navigator-gated whole heart SSFP acquisition
- T2* imaging
- Emerging sequences- Myocardial tagging, T1 and T2 mapping, 4D flow.

5)ECG gating and challenges in arrhythmias
6)Spatial resolution, temporal resolution, contrast resolution, acquisition time
7)Parallel imaging
8)MR artifacts in cardiothoracic imaging- Physics, optimization.

B. Anatomy

1) Segmental anatomy of the heart
2) Cardiac chambers- Left ventricle, right ventricle, left atrium, right atrium, left atrial appendage, right atrial appendage
3) Valves- Mitral, aortic, tricuspid, pulmonic
4) Coronary arteries- vascular distribution and variations
5) Pulmonary arteries
6) Pulmonary veins
7) Cardiac veins, coronary sinus

8) Pericardium, pericardial recesses
9) Aorta- Annulus, sinus of Valsalva, ascending aorta, arch, descending aorta, ductus arteriosus
10) Arteries- Brachiocephalic, common carotid, subclavian, axillary, vertebral, internal mammary, intercostal
11) Systemic veins- SVC, IVC, azygos, hemiazygos, brachiocephalic, subclavian, axillary, internal jugular, external jugular, intercostal, internal mammary
12) Cardiac MRI planes- 2 chamber, 3 chamber, 4 chamber, short axis, right ventricle horizontal long axis, right ventricle vertical long axis, coronal oblique
13) Normal measurements- Atria, ventricles, aorta, pulmonary arteries

C. Physiology

1) Normal cardiac cycle
2) ECG landmarks
3) Physiology of cardiac muscle and contraction
4) Blood flow, pressure, resistance
5) Cardiac and vascular function

D. Protocols and post-processing

I. Identify and understand the acquisition of cardiac MRI imaging planes
- Left ventricle- 2 chamber, 3 chamber, 4 chamber, short axis
- Right ventricle- vertical long axis, horizontal long axis, outflow tract
- Aorta- sagittal oblique, coronal oblique

II. Understand the sequences involved in the standard cardiac MRI protocols
- Viability
- Cardiomyopathy
- ARVD
- Pericardial disease
- Cardiac mass
- Congenital heart disease
- Aorta

III. Perform post-processing of cardiovascular MRI
- Ventricular – end-diastolic volume, end-systolic volume, stroke volume, ejection fraction, cardiac output, ventricular mass
- Flow- forward flow, reverse flow, regurgitation volume, regurgitation fraction, velocity, pressure gradient
- Aorta- measurements at different levels
- Multiplanar reconstruction, maximum intensity projection, volume rendering

E. Pathologies

Ischemic heart disease

1. Describe the anatomy of the coronary arteries and their distribution.
- *Left main coronary artery, right coronary artery, left anterior descending coronary artery, left circumflex coronary artery, obtuse marginal, diagonals, acute marginals, septal perforators.*
2. Risk factors, primary prevention, and screening
3. Define the role of MRI in the evaluation of ischemia and infarction.
4. Understand the advantages and limitations of MRI compared to other modalities such as CT, SPECT, and PET in the evaluation of ischemic heart disease.
5. Recognize ischemia in dynamic stress perfusion MRI.
6. Define regional wall motion abnormalities- hypokinesis, akinesis, dyskinesis.
7. Understand the MRI appearances of infarction, both acute and chronic, in cine imaging, T2-weighted imaging, and delayed enhancement.
8. Differentiate viable and non-viable myocardium on MRI.
9. Understand the role of delayed enhancement in prognostic determination and suitability for revascularization.
10. Describe complications of myocardial infarction.
LV failure, ventricular rupture, septal rupture, papillary muscle dysfunction/rupture, mitral regurgitation, thrombus, pericarditis, aneurysm, pseudoaneurysm.

Non-ischemic cardiomyopathies

1. Describe the classification of non-ischemic cardiomyopathies.
Dilated, hypertrophic, restrictive
2. Describe the role of MRI in the evaluation of non-ischemic cardiomyopathies.
3. Describe the role of delayed enhancement imaging in the diagnosis and risk stratification of non-ischemic cardiomyopathies.
4. Describe the findings of idiopathic dilated cardiomyopathy.
5. Describe the role of MRI in the evaluation of hypertrophic cardiomyopathy.
6. Diagnosis, morphological evaluation, accurate quantification, quantification of flow gradient and mitral regurgitation, systolic anterior motion of mitral valve, delayed enhancement patterns, papillary muscle abnormalities*.*
7. Describe the role of MRI in the evaluation of acute myocarditis, including T2-weighted imaging and delayed enhancement, patterns of enhancement.
8. Describe the findings of cardiac sarcoidosis, in acute and chronic stages.
9. Describe the MRI findings of cardiac amyloidosis, including delayed enhancement and altered T1 kinetics, emerging role of T1 mapping.
10. Define arrhythmogenic right ventricular dysplasia. Describe the role of MRI in identification of fat in T1-weighted imaging, define wall motion abnormalities, 2010 task force criteria for diagnosis.

11. Describe the role MRI in iron overload cardiomyopathy- T2* imaging and significance of myocardial T2* value.
12. Recognize the MRI appearances of LV non-compaction and its complications.
13. Recognize stress-induced (Takotsubo) cardiomyopathy.

Valvular heart disease

1. Describe the role of MRI in the evaluation of valvular heart disease, comparison with echocardiography.
2. Causes, MRI findings, grading, and quantification of:

- Mitral stenosis
- Mitral regurgitation
- Tricuspid stenosis
- Tricuspid regurgitation
- Aortic stenosis
- Aortic regurgitation
- Pulmonic stenosis
- Pulmonic regurgitation

Role of phase contrast and volumetric SSFP in the evaluation of valvular and ventricular function. Definitions of dephasing, regurgitant volume, regurgitant fraction, regurgitant orifice area.

3. Recognize bicuspid aortic valve and other congenital valvular abnormalities.
4. Describe MRI findings of mitral valve.
5. Understand findings of rheumatic and radiation heart disease.
6. Describe the MRI findings of endocarditis.
7. Describe the MRI findings of valvular masses.

Cardiac masses

1. Describe the role of MRI in the diagnosis and characterization of cardiac masses.
2. Identify anatomical variants and pseudomasses
Crista terminalis, Chiari network, Coumadin ridge, hypertrophied muscles, extrinsic lesions.
3. MRI findings of non-neoplastic masses
Thrombus, lipomatous hypertrophy of atrial septum, septal aneurysm.
4. MRI findings of benign versus malignant lesions.
5. Identify benign neoplasms
Myxoma, lipoma, fibroelastoma, hemangioma, paraganglioma, rhabdomyoma, fibroma.
6. Identify malignant neoplasms
Metastasis, sarcoma, lymphoma, leukemia.

Pericardial disease

1. Describe the role of MRI in the evaluation of pericardial disease.
2. Comparison with other imaging modalities- CT, echocardiogram, catheterization.
3. Describe the MRI findings of acute and chronic pericarditis.
4. Understand the role of MRI in identifying pericardial inflammation using contrast enhancement.
5. Describe the role of MRI in the evaluation of constrictive pericarditis.
6. Recognize findings of constrictive pericarditis.
Diastolic bounce, abrupt diastolic cessation, exaggerated ventricular interdependence, deformity of ventricles.
7. Role of real-time imaging of the ventricular septum in distinguishing constrictive pericarditis from restrictive cardiomyopathy.
8. Describe the findings of pericardial effusion and quantification of the effusion.
9. Recognize the findings of cardiac tamponade.
10. Pericardial masses and tumors.
11. Pericardial cyst and congenital absence of pericardium.

Congenital heart disease

1. Describe the role of MRI in the evaluation of congenital heart disease, including definition of anatomy and functional quantification.
2. Understand the role of MRI compared to echocardiography.
3. Describe the imaging findings and role of MRI in:

- Tetralogy of Fallot, pulmonary atresia, major aortopulmonary collaterals
- Transposition of great arteries

D- Transposition, L-transposition

- Coarctation- including hemodynamic grading, role of phase contrast MRI, distinguish from pseudocoarctation, aortic interruption, hypoplasia
- Shunt lesions

Atrial septal defect, ventricular septal defect, patent ductus arteriosus, AV canal defect, Gerbode defect

- Eisenmenger physiology
- Partial and total anomalous pulmonary venous connection
- Truncus arteriosus
- Persistent left superior vena cava
- Ebstein anomaly
- Visceral heterotaxy syndromes
- Coronary artery anomalies
  Origin- From opposite sinus, single artery

Course- Interarterial, intramural, retroaortic, septal, prepulmonic, pre-pulmonic
Termination-Fistulas

- Arch anomalies

Double arch, right arch (mirror image, aberrant left subclavian), aberrant right subclavian artery

- Pulmonary sling
- Single ventricle

Tricuspid atresia, hypoplastic left heart, common AV canal

4. Understand the descriptions and MRI findings of common surgical procedures:

- Tetralogy of Fallot repair
- Aortopulmonary shunts- Blalock-Taussig shunt, Modified Blalock-Taussig shunt, Waterston, Potts
- Glenn procedure
- Fontan
- Rastelli
- Mustard
- Senning
- Jatene arterial switch and LeCompte maneuver
- Norwood, Damus-Kaye-Stansel
- Ross

5. Great vessels

- Describe sequences for evaluation of thoracic aorta.
- Aneurysm and ectasia of various segments, pseudoaneurysms
- Define the sinus of Valsalva aneurysm.
- Recognize MRI findings of acute aortic pathologies.
  Dissection, intramural hematoma, penetrating atherosclerotic ulcer, rupture.
- Connective tissue diseases
  Marfan syndrome, Ehler Danlos syndrome, Loeys-Dietz syndrome
- Recognize the role of MRI in the evaluation of large vessel vasculitis.
  Giant cell arteritis, Takayasu arteritis, Behcet
- Role of MRI in pulmonary artery aneurysm, hypertension
- Sequences for MRI evaluation of pulmonary artery embolism- acute, chronic
- Evaluation of pulmonary venous anatomy for radiofrequency ablation for atrial fibrillation

New Technologic Advances

Objectives: The resident should be aware of the following areas of new technologic advances but not required to know each topic in detail.

1. Digital tomosynthesis

Technical parameters and acquisition
b. Nodule detection and characterization

2. Dual-energy CT
a. Technique and acquisition protocols (such as rapid kV switching, dual spin, dual layer, photon counting)
b. Post-processing and interpretation
c. Monochromatic versus iodine images
d. Applications:
- Pulmonary embolism, acute and chronic
- Diffuse lung disease, including COPD and pulmonary fibrosis
- Thoracic malignancy
- Ventilation imaging using noble gases
- Aortic imaging - virtual non-contrast reconstructions for intramural hematoma and endovascular stent graft evaluation
- Myocardial perfusion

3. Thoracic PET/MR
a. Technique and acquisition protocols
b. Applications:
- Oncologic staging
- Mediastinal mass characterization
- Myocardial stress perfusion
- Cardiac infiltrative and inflammatory diseases
- Prognostic information
- Treatment monitoring

c. Potential benefits over PET/CT
d. Limitations, including artifacts, attenuation correction, misregistration

4. Thoracic MR ventilation imaging
a. Technique and acquisition protocols
b. Applications in diffuse lung disease - COPD

5. Quantitative imaging
a. Quantitative imaging protocols and processing
b. Imaging biomarkers
c. RECIST criteria
d. Nodule volumetrics