1 Applied Respiratory Anatomy

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Imaging Modalities

Chest Radiographs

The plain chest radiograph (CXR) is the most commonly performed imaging procedure. The standard, routine postero-anterior (PA) CXR examination consists of an erect radiograph taken with the patient upright and in full inspiration with the front of their chest positioned against the imaging plate. The beam passes through the patient from back to front, hence the name postero-anterior.

The left lateral chest radiograph used to be performed as a routine with a PA film but is now infrequently obtained and somewhat undervalued in the age of computed tomography. It can, however, be crucial in identifying abnormalities in the posterior costophrenic angles, within the mediastinum, and in areas closely related to the spine and sternum. Relatively blind areas on frontal views make up 40% of the lung area and 25% of the lung volume. It is important that if a lateral CXR is obtained it is reported with the PA CXR taken at the same sitting.

Chest radiographs are frequently required to be taken at the patient bedside or in the emergency department and consequently, antero-posterior (AP) chest radiographs comprise almost 50% of chest radiographic examinations. Patients lie or sit with their back against the imaging plate and the X-ray beam passes through them from anterior to posterior.

AP radiographs are of inferior quality to PA CXRs for a variety of reasons. Patients are typically too ill to sit upright and are therefore positioned semi-recumbent or supine. They may find it difficult to hold their breath, and the divergent geometry of the X-ray beam results in magnification of structures at the front of the chest. Mobile equipment uses lower energy X-rays, and the exposure factors are longer, increasing the probability of image degradation by motion artefact. The above factors lead to magnification of the cardiomediastinal structures and poor visualisation of both mediastinal structures and pulmonary parenchyma. Diagnostic difficulty is increased for the reporting radiologist, particularly with respect to identifying pleural effusions and pneumothoraces, and excluding lesions behind the heart and beneath the diaphragm.

The Silhouette Sign

In conventional radiography it is possible to differentiate four basic physiological densities from one another: air, fat, soft tissue, and calcium. Non-physiological denser mediums such as iodine, barium, or metal add a fifth.

When looking at plain films it should be remembered that adjacent anatomical structures

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of different densities have a well-defined demarcating interface between them. For example, on a chest radiograph, the lateral border of the left ventricle can be clearly distinguished from the adjacent air-filled lung parenchyma. Conversely, anatomical structures that are contiguous and the same density (for example the soft tissue density chambers of the heart) will appear as one mass, with no line of demarcation between them. This is referred to as the silhouette sign and can be useful in locating abnormalities within the thorax.

Computed Tomography

Current computed tomography (CT) scanners have multiple rows of detector elements allowing for the simultaneous acquisition of data as the patient moves through the rotating gantry. The speed of scanning has markedly increased as a consequence of faster rotation times and the multiple detector arrays. The entire chest can now be imaged in a single breath hold, decreasing motion artefacts and allowing for optimization of contrast enhancement.

Multidetector CT scanners (MDCT) generate large volume data sets which enable sophisticated multiplanar and three-dimensional reconstructions. Multiplanar reconstructions (for example in coronal and sagittal planes) may enable better appreciation of anatomical structures than a series of individual cross-sectional transaxial images.

Volume rendering uses all of the data from the CT acquisition in the final image. This is a truly three-dimensional reconstruction that conveys depth perception. The images produced are particularly useful in clarifying vascular morphology and complex three-dimensional anatomic relationships. Their use can enable communication between radiologist and clinician by displaying scan information in a more familiar form to the non-imager.

Thoracic CT scans are routinely performed with the patient in the supine position during suspended full inspiration. Additional scans may be acquired in forced expiration, to demonstrate air trapping or central airway collapse, or with the patient prone, to differentiate true parenchymal disease from normal gravitational atelectasis in posterior basal lung.

CT evaluation can be performed with or without intravenous contrast administration. Iodinated contrast is essential for the diagnosis of pulmonary emboli and aortic dissection and can allow for easier discrimination of lymph nodes from vessels.

The normal thorax contains structures with a wide range of densities from bone to air, and in contrast to plain radiographs, a CT image can display a wider range of these in black, white, and shades of grey. Unfortunately the human eye can discriminate relatively few shades of grey and to evaluate all the available information, CT images are typically viewed on at least two, and usually three, different "window" settings optimised for soft tissue, lung, and bone.

High-Resolution CT

High-resolution CT is widely used for the evaluation of a variety of diffuse parenchymal and airway diseases, as it enables more detailed visualisation of the pulmonary parenchyma. It is performed using a conventional CT scanner with imaging parameters chosen to maximise spatial resolution. These include using a thin slice width (0.625–1.25 mm) reconstructed with a sharp, high-resolution image reconstruction algorithm. HRCT allows for depiction of lung morphology at a level comparable to gross macrosopic anatomy.

Conventionally, HRCT is performed by acquiring the thin slices at 1–2 cm gaps, as this is an examination typically used to diagnose diffuse lung disease. With the introduction of MDCT scanners, there has been a tendency to move towards volumetric acquisition through the entire thorax. This latter allows for detection of all abnormalities present, including small lung nodules, but at the price of higher patient radiation. Although there is improved diagnostic accuracy of volume HRCT for the diagnosis and exclusion of bronchiectasis when compared with conventional HRCT it is uncertain if this technique is better for evaluating diffuse interstitial lung disease.

Ultrasound

Thoracic ultrasound involves no ionising radiation, is relatively cheap, and readily available at the bedside.

It is more sensitive than a plain radiograph at detecting pleural fluid and is typically better than CT in differentiating pleural fluid from pleural thickening and in evaluating the complexity of pleural effusions. Ultrasound can also be used to diagnose pneumothoraces.

It is an invaluable tool for the detection and localization of pleural fluid. Ultrasound guidance during thoracentesis and chest drain placement can minimise complications, and it is increasingly used for peripheral lung, pleural, and supraclavicular nodal biopsies. Diaphragmatic paralysis can be diagnosed effectively with ultrasound as an alternative to X-ray fluoroscopy.

Imaging Anatomy and Interpretation

It is necessary to have a systematic approach to reading both chest radiographs and CT. The precise methodology can be very individual, but should include evaluation of the lungs, pleura, airways, hila, heart and great vessels, mediastinum, diaphragm, and chest wall, the anatomy of which are detailed below.

The Lungs, Lobes, and Fissures

Each lung is conical in shape, having a blunt apex which reaches above the sternal end of the first rib, a concave base overlying the diaphragm, a costovertebral surface moulded to the chest wall, and a mediastinal surface which is concave to accommodate the mediastinum.

The right lung is slightly larger than the left and is divided by the minor and major fissures into three lobes: upper, middle, and lower. The left lung only has a major fissure, and hence only two lobes: upper and lower. The lobes are further divided into segments, each of which is supplied by a segmental bronchus and a tertiary branch of the pulmonary artery. They are named according to the segmental bronchus that supplies them and are wedge-shaped with their apices at the hilum and bases at the lung surface.

The major or oblique fissures begin at the level of the fifth thoracic vertebra and extend downwards, obliquely and forward, roughly paralleling the sixth rib and ending at the diaphragm a few centimetres from the anterior pleural gutter. The right is more obliquely orientated, the left more vertical. The right contacts the minor fissure. This separates the anterior segment of the right upper lobe from the middle lobe and runs, roughly horizontally, from the edge of the lung towards the hilum at the level of the fourth anterior rib.

There are several accessory fissures. These are of little more than academic interest but it is worthwhile being able to recognise them as normal variants. The most easily identifiable is the azygos fissure, which occurs in approximately 0.5% of individuals. In early fetal life the embryonic precursor of the azygos vein migrates over the apex of the right lung to its usual position in the right side of the mediastinum. Occasionally, instead of migrating over the lung apex, it invaginates the apical right upper lobe, taking visceral and parietal pleura with it. The fissure is then seen as a curvilinear structure extending obliquely across the superomedial right upper lobe, terminating in a tear-drop shaped opacity caused by the vein itself.

Although the fissures may extend to the hilum resulting in complete lobar separation, they are commonly incomplete. This can be important, as regions of parenchymal continuity from lobe to lobe can provide a ready pathway for collateral air drift or disease spread. Fissural incompleteness can also reduce the effectiveness of bronchial valve placement for volume reduction procedures.

Fissures are easily seen on plain radiographs and CT and can be useful in identifying and localising volume loss. If the volume of a lobe is decreased, the adjacent fissure will be displaced towards the collapsed region. Fissures become reoriented and may appear as lines or interfaces, depending upon whether or not the partially collapsed lobe is air or fluid containing. The right upper lobe is bounded inferiorly by the minor fissure and posteriorly by the major fissure. As the right upper lobe loses volume, the minor fissure moves superiorly and medially on the frontal chest radiograph. Typically the lateral portion of the fissure is higher than the medial.

The Pleura

The normal visceral and parietal pleura are not visible on a CXR apart from the double layer of visceral pleura forming the interlobar fissures.

On CT, the pleural layers are visualised as part of the intercostal stripe, a 1–2 mm line of soft tissue attenuation seen at the point of contact between the lung and the chest wall. This is composed of the visceral pleura, the parietal pleura, normal pleural fluid, the endothoracic fascia and the innermost intercostal muscles; most of the visible stripe is due to the intercostal muscles. In the paravertebral regions, the innermost intercostal muscle is lacking and the thin line seen on CT represents pleura and endothoracic fascia. Extrapleural fat pads can be seen internal to ribs on both chest radiographs and CT, and can easily be confused with pleural thickening (as can the transverse thoracic and subcostal muscles on CT).

The costophrenic angles should be clearly defined and be sharp. It should be remembered that the posterior costophrenic angles are more inferior than the lateral. As such, small amounts of fluid will accumulate posteriorly and not blunt the lateral costophrenic recesses on a frontal radiograph. A lateral radiograph is therefore more sensitive for diagnosing tiny effusions blunting the posterior costophrenic angles.

On ultrasound the parietal and visceral pleura normally appear as a single bright line no wider than 2 mm, and normal air-filled lung can be seen sliding with respiration.

The lymphatic drainage of the pleura is important in the assessment of the spread of pleural malignancy. The visceral pleura drains to the same nodal groups as the lung parenchyma; bronchopulmonary, hilar, mediastinal, supraclavicular, and scalene. The parietal pleura however, has a different drainage into internal thoracic, subpleural, costophrenic, and cardiophrenic nodes.

The Airways

Only the trachea, main, and lobar bronchi can be identified with certainty on the plain radiograph, and are visible as black tubular structures containing air.

The trachea begins at the C6 level and is a midline structure that has a slight deviation to the right after entering the thorax. Its walls are parallel except for a smooth indentation on its left side produced by the aorta. If the trachea is significantly deviated it is important to establish if this is positional or a consequence of true pathology such as right upper lobe fibrosis or a thyroid goitre.

The trachea divides into the two main bronchi at the carina. This lies at the level of the sternal angle (T5). In adults the right main bronchus has a steeper angle than the left, hence aspiration is more frequent on the right. The carinal angle is in the region of 60°; greater than 90° is pathological.

On the frontal chest radiograph the upper lobe bronchi usually leave the main bronchi in a horizontal plane, the right lying higher than the left.

On a lateral chest radiograph the trachea can be easily seen descending slightly posteriorly. The anterior wall is often indistinct but the posterior wall can be seen as it abuts the air-filled lung. The posterior wall, together with fat, forms the posterior tracheal stripe. This is seldom useful clinically, as the normal oesophagus may be interposed thickening it. Thickening on serial chest radiographs is, however, more concerning.

The tracheal air column on a lateral radiograph often terminates in two rounded lucencies. The upper one represents the orifice of the right upper lobe bronchus, and the lower one the left upper lobe bronchus. The left upper lobe bronchus is typically more easily seen, as it is outlined by the left main pulmonary artery arching over it. Since the right and left main bronchi almost superimpose, the carina is difficult to identify on the lateral view, but usually approximates to the level of the sternal angle.

CT is used to evaluate the major airways and the images are typically viewed on lung windows.

On CT the trachea (Fig. 1.1) can be visualised extending from the inferior aspect of the cricoid cartilage to the carina. It contains 16–22 horseshoe-shaped cartilaginous rings which are

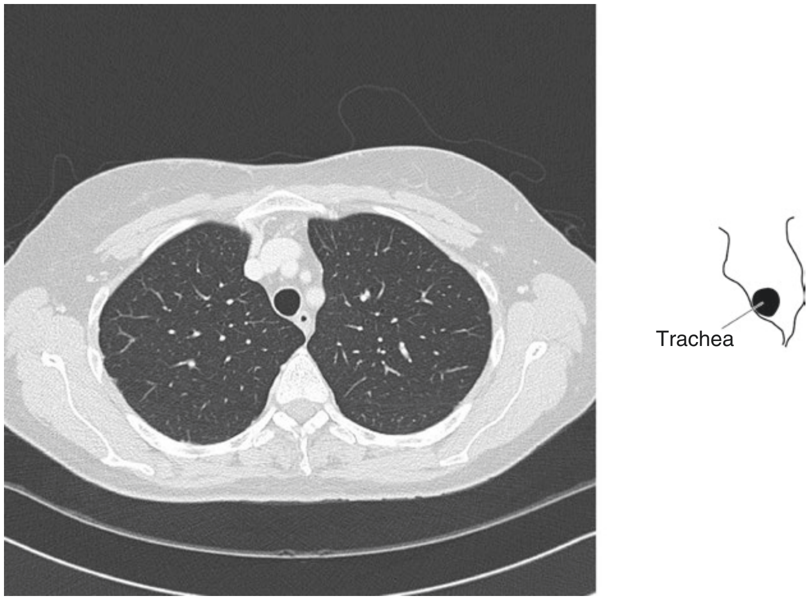

Fig. 1.1 Axial CT (lung window) at the level of the mid trachea

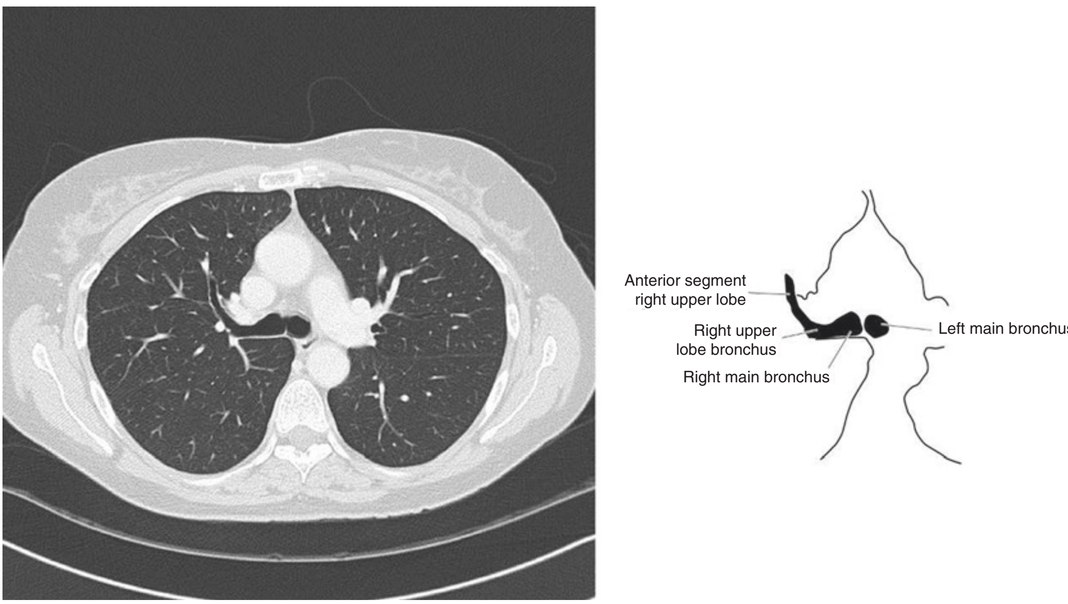

Fig. 1.2 Axial CT (lung window) at the level of the right upper lobe bronchus

incomplete posteriorly, the posterior wall of the trachea being a thin fibromuscular membrane. It is most commonly seen as a round or oval structure on CT with a flattened posterior wall that becomes concave in expiration. Calcification of the cartilages becomes more common with age.

The right upper lobe bronchus arises from the lateral aspect of the main stem bronchus, approximately 2.5 cm from the carina (Fig. 1.2). It divides approximately 1 cm from its origin into three segmental branches: the anterior, posterior, and apical.

The bronchus intermedius (Fig. 1.3) continues distally for 3–4 cm and then bifurcates into the right middle and right lower lobe bronchi.

The middle lobe bronchus (Fig. 1.4) arises from the right lateral wall of the bronchus intermedius almost opposite the origin of the superior segmental bronchus of the lower lobe. If you can find one you can easily identify the other. It is typically 1–2 cm long and bifurcates into its medial and lateral segmental branches.

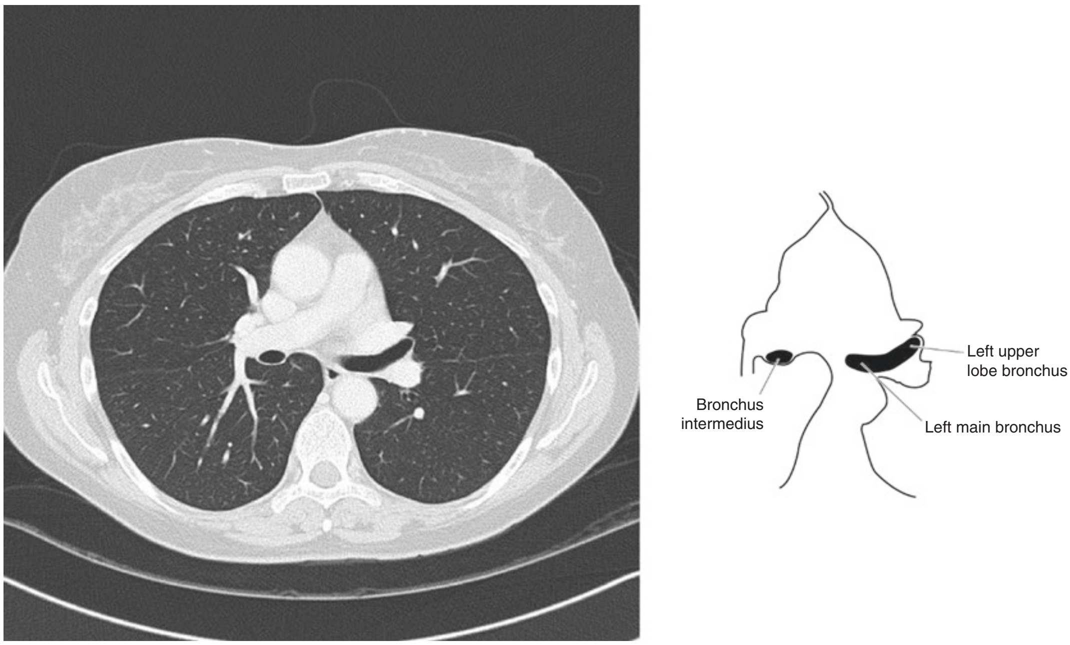

Fig. 1.3 Axial CT (lung window) at the level of the bronchus intermedius and left upper lobe bronchus

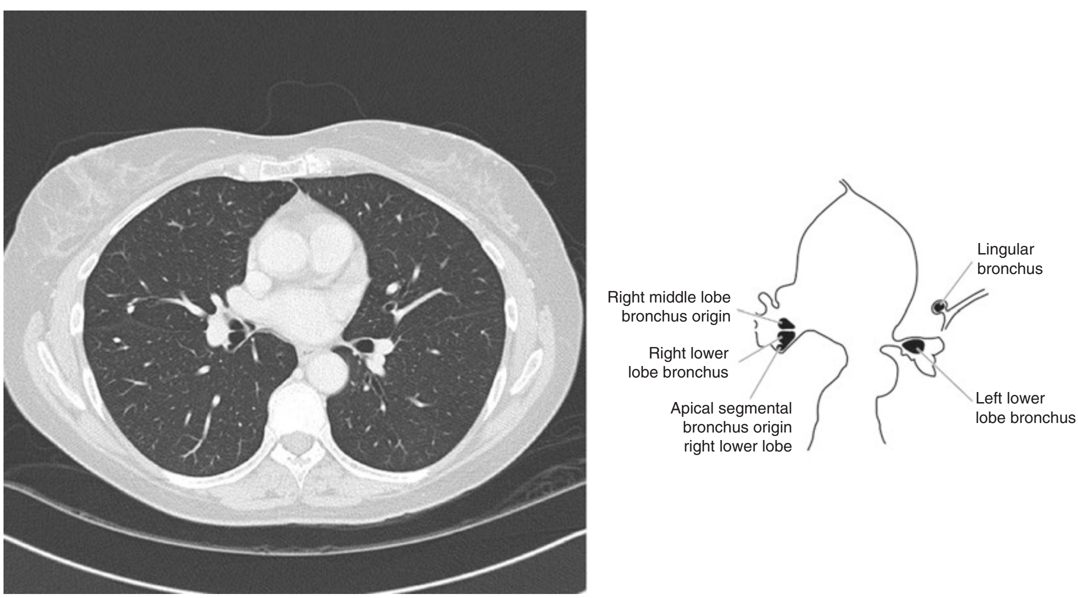

Fig. 1.4 Axial CT (lung window) at the level of the right middle lobe bronchus

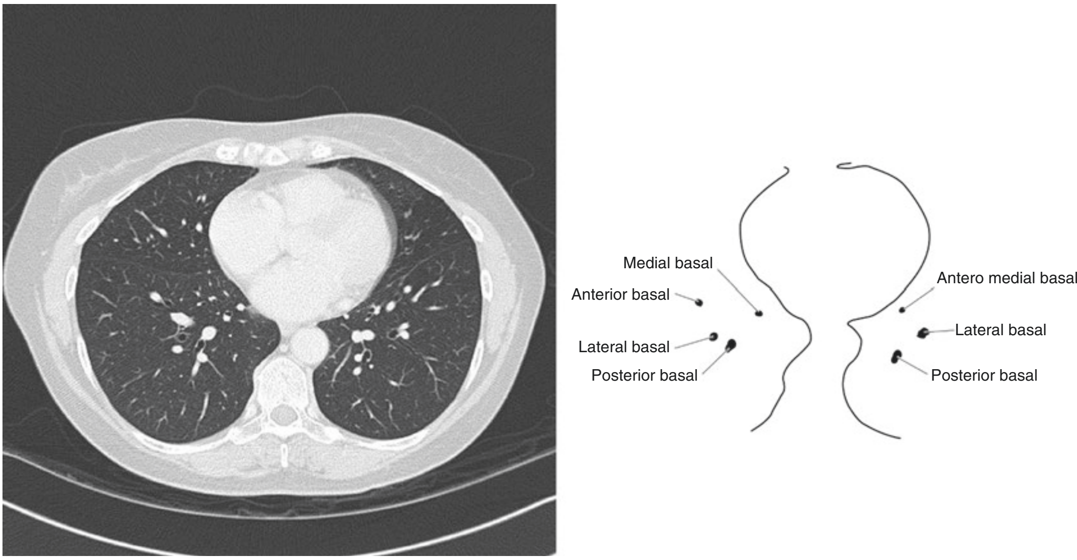

Fig. 1.5 Axial CT (lung window) at the level of the lower lobe basal segmental bronchi

The right lower lobe bronchus is the continuation of the bronchus intermedius beyond the right middle lobe bronchial take-off. The superior segmental bronchus arises from its posterior aspect (almost opposite the right middle lobe bronchus) and it then further divides into four basal segmental bronchi, the anterior, lateral, posterior and medial (Fig. 1.5).

The left upper lobe bronchus (shown in Fig. 1.3) usually trifurcates into the apico-posterior, anterior and lingular bronchi. The lingular bronchus (shown in Fig. 1.4) can usually be visualised at approximately the same level as the origin of the superior segmental bronchus of the lower lobe. Again, if you can find one you can usually identify the other.

The lingular bronchus extends for 2–3 cm before bifurcating into superior and inferior divisions. The left lower lobe branching pattern is similar to the right although there are typically only three segmental bronchi, anteromedial, posterior and lateral (shown in Fig. 1.5).

The bronchi divide in an asymmetric dichotomous manner. As they branch and get smaller their walls become thinner and less easy to identify, and in normal individuals it should not be possible to identify bronchi within 1 cm of the costal pleura on CT. Normal bronchioles cannot be visualised.

The Hila

The hila are complicated structures consisting mainly of the major bronchi and the pulmonary arteries and veins. They are not symmetrical but have the same components on each side. Normal hilar nodes cannot be visualised on plain radiographs but do become identifiable when enlarged. The hila should be checked for position, size, and density on every chest radiograph and closely evaluated on CT, as they are common sites for lymph node enlargement and tumours.

Each lung has a large pulmonary artery supplying blood to it, and typically two pulmonary veins. These comprise the majority of the hilar shadows on a chest radiograph but are clearly seen to best advantage on CT (Fig. 1.6).

The pulmonary arteries carry deoxygenated blood at low pressure. They supply 99% of the blood flow to the lungs and participate in gas exchange at the alveolar capillary membrane.

The main pulmonary artery originates in the mediastinum at the pulmonary valve and passes upwards, backwards, and to the left. On CT the diameter of the main pulmonary artery should be less than or equal to 29 mm, and is usually smaller than the ascending thoracic aorta at the

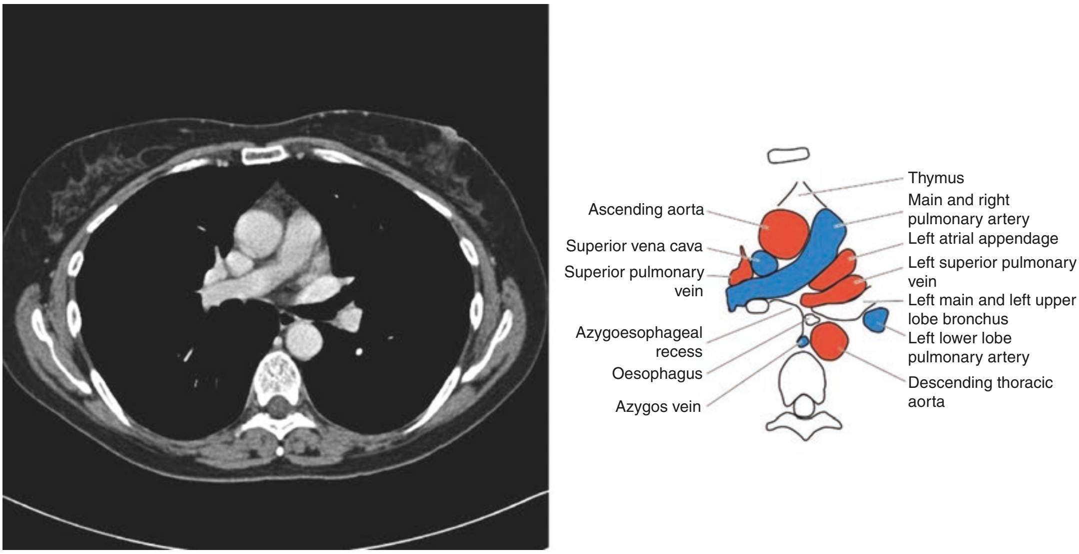

Fig. 1.6 Axial contrast-enhanced CT (soft tissue window) at the level of the right main pulmonary artery demonstrating hilar and mediastinal anatomy

same level. A larger calibre than this suggests pulmonary hypertension. The pulmonary trunk bifurcates within the pericardium, into a shorter left and longer right pulmonary artery.

The right pulmonary artery divides behind the superior vena cava into the artery to the right upper lobe (truncus anterior) and the right interlobar pulmonary artery. The interlobar pulmonary artery courses caudally in the major fissure anterolateral to the bronchus intermedius and right lower lobe bronchus giving segmental branches to the right middle and lower lobes.

On a frontal chest radiograph, the upper limit of the transverse diameter of the interlobar artery from its lateral aspect to the air column of the bronchus intermedius is 16 mm in men and 15 mm in women. Enlargement suggests increased pressure or flow.

The higher left main pulmonary artery passes over the left main bronchus and continues as the vertically orientated left interlobar pulmonary artery from which the segmental arteries to the upper and lower lobes arise. The left interlobar artery lies posterolateral to the lower lobe bronchus. On lateral radiographs the left pulmonary artery can usually be easily identified as it courses over the left main and upper lobe bronchi forming an arch smaller and parallel to the aortic arch.

The right pulmonary artery appears as a rounded density since it is viewed end on. The more posterior location of the left pulmonary artery with respect to the right explains why the bulk of the left pulmonary artery projects behind the upper lobe bronchial orifices and the right pulmonary artery projects in front of them.

The pulmonary veins carry recently oxygenated blood from the lungs to the left atrium.

The segmental pulmonary veins from the right upper lobe form the right superior pulmonary vein. The middle lobe vein usually joins the right upper lobe vein just prior to entry into the left atrium, although occasionally it may drain separately.

On the left, the upper lobe segmental veins join to form the left superior pulmonary vein incorporating the lingular vein also.

The horizontally orientated lower lobe segmental veins form the right and left inferior pulmonary veins which drain into the left atrium. The normal superior and inferior pulmonary venous confluences are sometimes large enough to simulate nodules on chest radiographs.

Whilst arteries and veins are relatively easily distinguished on CT, this can be very difficult on the chest radiograph. It is worth remembering, however, that the lower lobe veins are horizontally orientated, whereas the lower lobe arteries are more vertical.

The hilar point on chest radiographs is the angle formed by the superior pulmonary veins (draining the upper lungs) and the lower lobe pulmonary arteries. The more superior location of the left main pulmonary artery results in the left hilum lying higher than the right on a frontal chest X-ray. This relationship is seen in 97% of normal people; in the other 3% they are at the same level.

On CT the arteries can be seen to accompany the bronchi as they divide and progress distally. In addition to this there are additional pulmonary arteries which do not lie adjacent to a bronchus and these become more numerous peripherally.

The pulmonary veins are always separated from the bronchoarterial bundles. This relationship commences in the lung periphery where the bronchi and arteries are in the central portion of the secondary pulmonary lobule and the veins are located within the interlobular septa (see "Secondary Pulmonary Lobule").

The Heart and Great Vessels

The heart and pericardial sac are situated obliquely about two-thirds to the left and one-third to the right. On a frontal chest radiograph the position of the heart largely depends upon the patient's age and build. In younger, slim individuals the heart is more upright and central, whereas in older persons it tends to be more horizontally orientated and projects more to the left of midline. The cardiothoracic ratio is a commonly used measurement of overall heart size in relation to chest cavity. This is calculated as being the widest diameter of the heart to the widest internal diameter of the bony thorax on an erect PA chest radiograph. A cardiothoracic ratio larger than 50% has a sensitivity of approximately 80% for detecting left ventricular dilatation, but a specificity of only 50%. The heart size will appear larger on AP chest radiographs (as magnified by the divergent X-ray beam) and on chest radiographs taken at less than full inspiration.

The right heart border on a frontal chest radiograph is formed by the right atrium extending between the superior vena cava (SVC) and the inferior vena cava (IVC).

The left heart border is more complex, with three convexities above the left ventricle. These are formed by the aortic knuckle, the pulmonary trunk (above the left main bronchus), and the left atrial appendage (below the left main bronchus). This latter region should be straight or concave; any bulge in this region implies dilatation of the left atrial appendage. If the left atrium enlarges, it typically elevates the left main bronchus, widening the carinal angle.

The junction of the heart with the diaphragm produces cardiophrenic recesses on both sides. These contain fat and a few small nodes. Fat density is less than soft tissue, so the heart borders can usually be seen clearly though them.

The right ventricle forms the largest part of the anterior surface of the heart, and the left atrium is situated posteriorly, meaning that these chambers are not border forming on a frontal chest radiograph. They can, however, be seen on a left lateral view and on CT (Fig. 1.7). The right ventricle lies anteriorly and contacts the lower third of the sternum. If it contacts more than one-third of the sternum, right ventricular dilatation should be suspected. An enlarged left atrium can be seen to bulge posteriorly.

The pericardium (Fig. 1.8) is a double-walled fibro-serous membrane that encloses the heart and the roots of its great vessels. It helps optimise cardiac motion and chamber pressures and serves as a barrier to pathology. The tough fibrous outer layer is contiguous with the central tendon of the diaphragm, fused with the adventitia of the great vessels entering and leaving the heart and attached to the posterior surface of the sternum. The internal surface of the fibrous pericardium is lined with the parietal layer of serous pericardium, which is reflected onto the heart and great vessels as the visceral layer. The closer apposition of the visceral layer to the cardiac structures results in normal pericardial recesses which can be identified as containing small amounts of fluid. The pericardial cavity usually contains 15–50 ml of serous fluid.

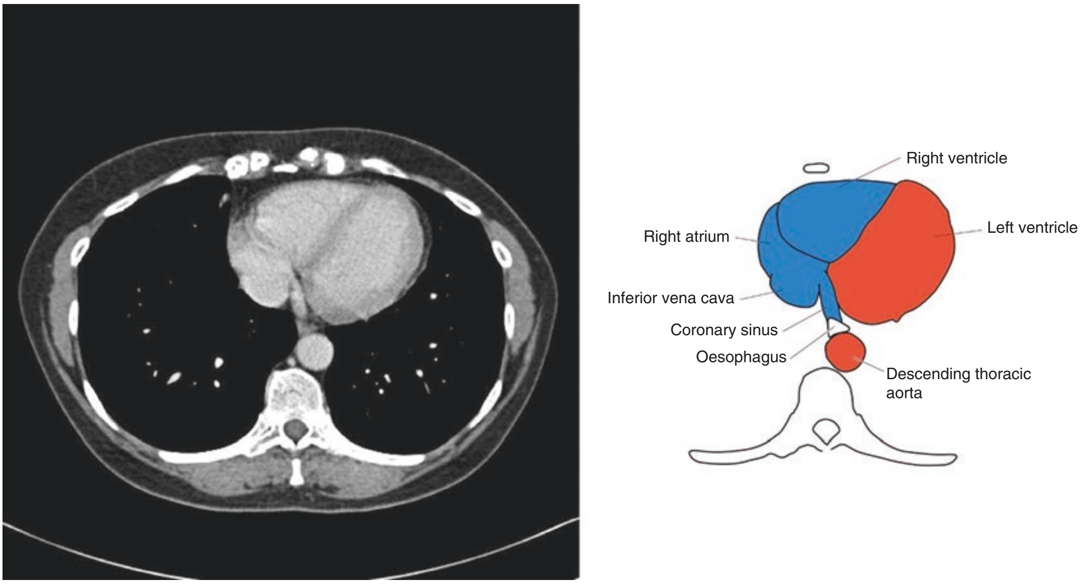

Fig. 1.7 Axial contrast-enhanced CT (soft tissue window) at the level of the right and left ventricles

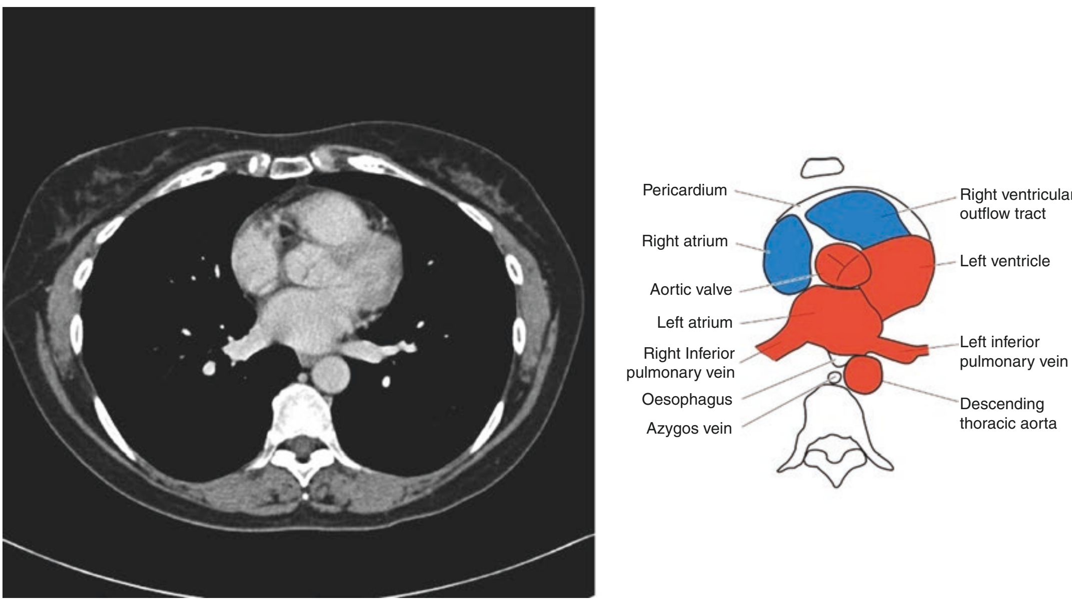

Fig. 1.8 Axial contrast-enhanced CT (soft tissue window) at the mid cardiac level. The portion of the pericardium anterior to the right ventricular outflow tract is seen as a fine line

The normal combined pericardial thickness is 2 mm or less; 4 mm is definitely abnormal, often suggesting a pericarditis. The normal pericardium cannot be appreciated on chest radiographs but can be easily identified on CT. Discrimination of pericardium from myocardium requires the presence of epicardial fat or pericardial fluid. It is usually easily visible over the right atrium and right ventricle, but often difficult to see adjacent to the lateral and posterior walls of the left ventricle.

Systemic Arterial Supply of the Thorax

The aorta provides the main systemic arterial supply of the thorax. This vessel is divided into the ascending aorta, arch, and descending aorta. It begins at the root of the aorta where the three aortic sinuses are located and courses upwards with a slight inclination forwards and to the right. The arch of the aorta (Fig. 1.9) lies in an almost sagittal plane in the upper mediastinum behind the lower part of the manubrium. It is visualised radiographically as the aortic knob or knuckle, and indents the left side of the trachea. A right-sided aortic arch is rare (less than 1%), may be associated with congenital heart disease, and typically indents the right side of the trachea.

Inferiorly, the arch is related to the pulmonary trunk (Fig. 1.10) and is connected to the left pulmonary artery by the ligamentum arteriosum (the fetal ductus arteriosum). The left recurrent laryngeal nerve is looped around this structure.

The three main branches of the arch are the right brachiocephalic trunk (also known as the innominate artery), the left common carotid artery, and the left subclavian artery (Fig. 1.11). The brachiocephalic trunk divides behind the right sternoclavicular joint into the right subclavian and right common carotid arteries.

Variations in the branching patterns of the arch vessels are not uncommon. Frequently the right branchiocephalic trunk and the left common carotid artery have a common origin or trunk. It is not uncommon to see an aberrant right subclavian artery arising as the fourth branch of the aortic arch and passing behind the trachea from left to right to ascend to its normal position in the upper thorax.

The thoracic aorta descends in the posterior mediastinum to the left of the midline before moving centrally to lie behind the oesophagus. It traverses the diaphragm at the T12 vertebral level to become the abdominal aorta. The aorta gives off posterior intercostal arteries, subcostal, and phrenic arteries. It also supplies viscera via the bronchial, oesophageal, pericardial, and mediastinal arteries.

Bronchial Circulation

The bronchial arteries are responsible for supplying the majority of the oxygenated blood to

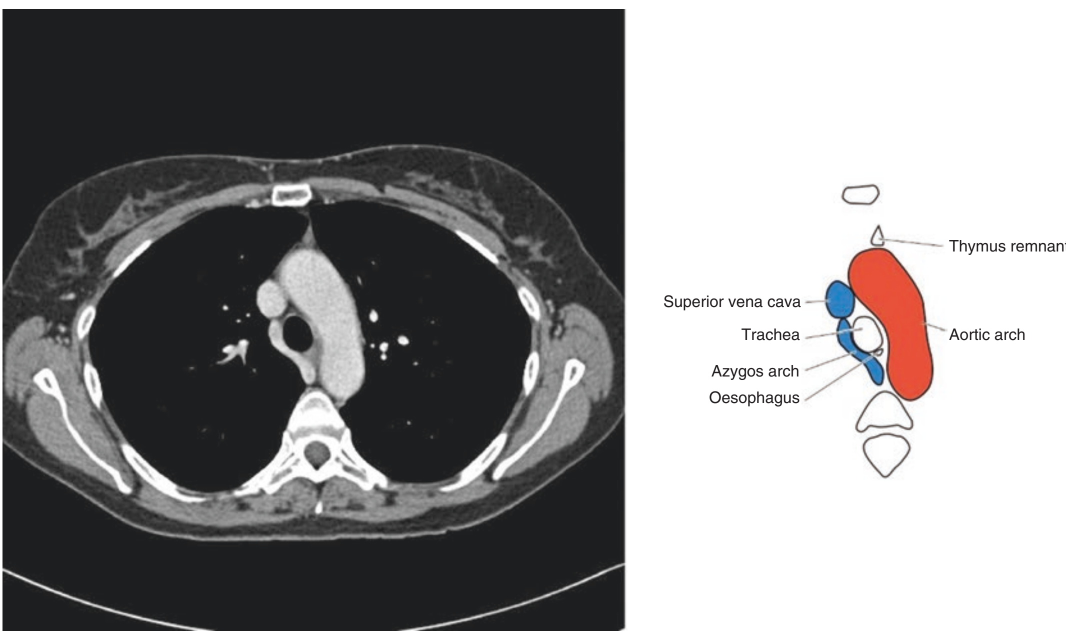

Fig. 1.9 Axial contrast enhanced CT (soft tissue window) through the upper thorax at the level of the aortic arch

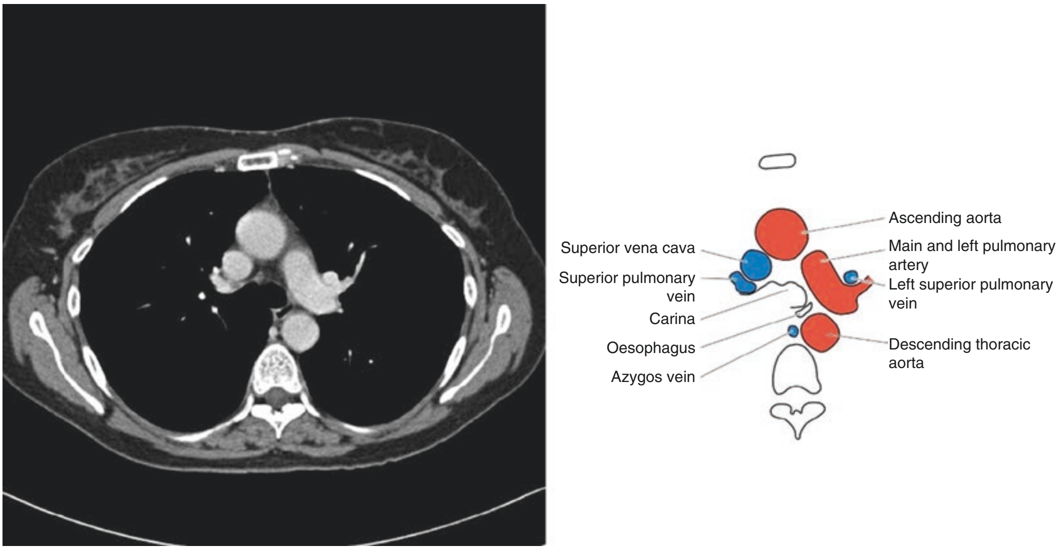

Fig. 1.10 Axial contrast-enhanced CT (soft tissue window) through the upper thorax at the level of the pulmonary trunk and left main pulmonary artery

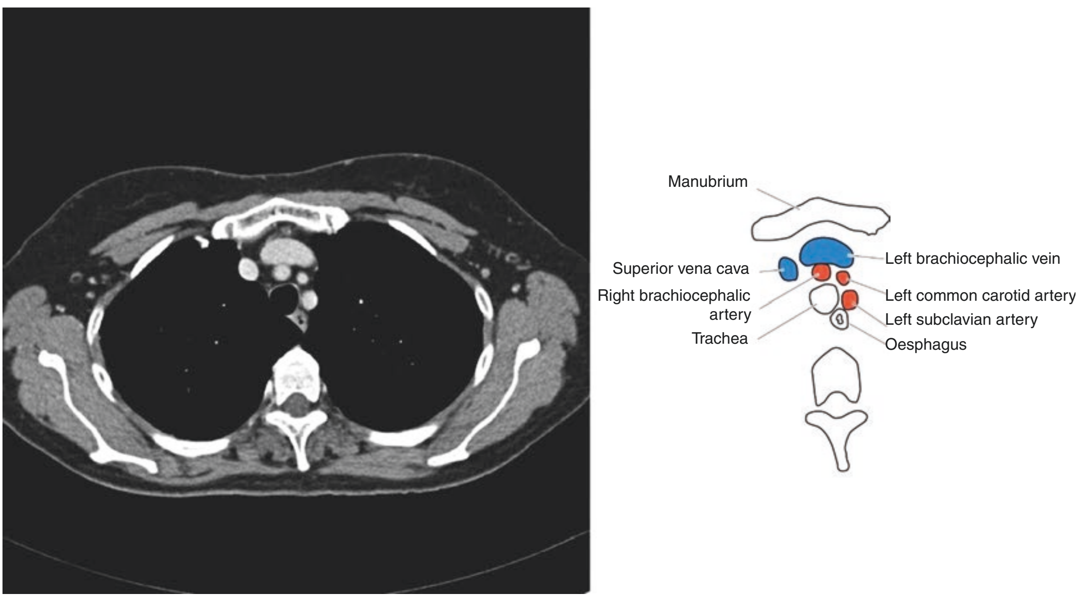

Fig. 1.11 Axial contrast-enhanced CT (soft tissue window) through the upper thorax just above the arch of the aorta demonstrating the proximal arch vessels

the pulmonary parenchyma and carry oxygenated blood to the lungs at a pressure six times that of the pulmonary arteries. They supply the central airways, the lymph nodes, visceral pleura, the oesophagus, posterior mediastinum, and the vagus nerves. They also supply the vasa vasorum of the aorta, pulmonary artery, and pulmonary veins. As a rule they do not participate in gas exchange. Bronchial arteries are connected to the pulmonary arteries through microvascular anastomoses at the level of the alveoli and respiratory bronchioles.

There is considerable variability in their number and precise site of origin; usually from the thoracic aorta between the T3 and T6 vertebral levels. In 70% of patients, two arise from the left and one from the right. On the right the bronchial artery usually arises from the right posterolateral aspect of the aorta in conjunction with an intercostal artery as an intercostobronchial trunk. On the left, superior and inferior bronchial arteries arise from the anteromedial arch and the thoracic aorta, respectively. The superior lies posterior to the left main bronchus, the inferior below it. The normal bronchial arteries can usually be identified on contrast-enhanced CT scans as they arise from the aorta.

Bronchial arteries may also arise from the internal mammary arteries, the thyrocervical trunk, the subclavian artery, and the coronary arteries. This has implications for the interventional radiologist when performing diagnostic and therapeutic procedures.

The intraparenchymal bronchial arteries branch with the airways, continuing as distally as the terminal bronchioles.

Normal bronchial arteries are small, measuring less than 2 mm at their origin, and are seen on CT as small undulating enhancing structures. The right bronchial arteries run to the right of the oesophagus and the left to the left. The bronchial and other collateral vessels (such as the intercostal and internal mammary arteries) hypertrophy in response to chronic inflammatory lung diseases such as bronchiectasis and aspergilloma, and the total systemic cardiac output through the bronchial arteries can increase dramatically. Bronchial arteries become very much more conspicuous on CT when hypertrophied and their visualisation should prompt the exclusion of longstanding ischaemic states, congenital cardiovascular anomalies, and chronic inflammatory conditions.

Systemic Veins of the Thorax

The superior vena cava (shown in Fig. 1.10) drains all the blood from the head and neck, the upper limbs, and the walls of the thorax and upper abdomen. It is formed by the union of the right and left brachiocephalic veins behind the sternal end of the first right costal cartilage. The right brachiocephalic vein descends vertically, whereas the left crosses in an oblique orientation anterior to the branches of the arch of the aorta. The SVC ends in the superior part of the right atrium at the level of the third right costal cartilage close to the sternum. It receives the azygos vein (shown in Fig. 1.9) which enters its posterior aspect at its mid-point, just before it enters the pericardium. The SVC lies on the right, anterolateral to the trachea and lateral to the ascending thoracic aorta. Occasionally, a left superior vena cava may persist and drain into the right atrium via the coronary sinus.

The intrathoracic inferior vena cava is short and can occasionally be seen on PA and lateral chest radiographs. It pierces the central tendon of the diaphragm at the approximate level of T8.

The azygos vein drains blood from both sides of the diaphragm to the heart. In the thorax it receives blood from the bronchial veins, the posterior intercostal veins, and the mediastinal structures.

Identification of the azygos vein on plain chest radiographs can be useful in confirming or helping to exclude pathology. Its course as it ascends in the mediastinum can be seen on the frontal chest radiograph as the azygo oesophageal line (see lines and stripes). The vein itself can be identified as a small oval density adjacent to the inferior right lateral wall of the trachea as it arches from front to back to join the SVC.

The Mediastinum and Its Contours

The mediastinum is the central component of the thoracic cavity containing all the thoracic viscera (except for the lungs), blood and lymphatic vessels, nodes, connective tissue and fat. It is covered on each side by the mediastinal pleura and is bounded by the two lungs, the sternum and the vertebral column. For diagnostic and descriptive purposes it is usually divided into several compartments, as many mediastinal lesions have characteristic locations, and it enables development of a compact differential diagnosis. There are, however, no physical boundaries between

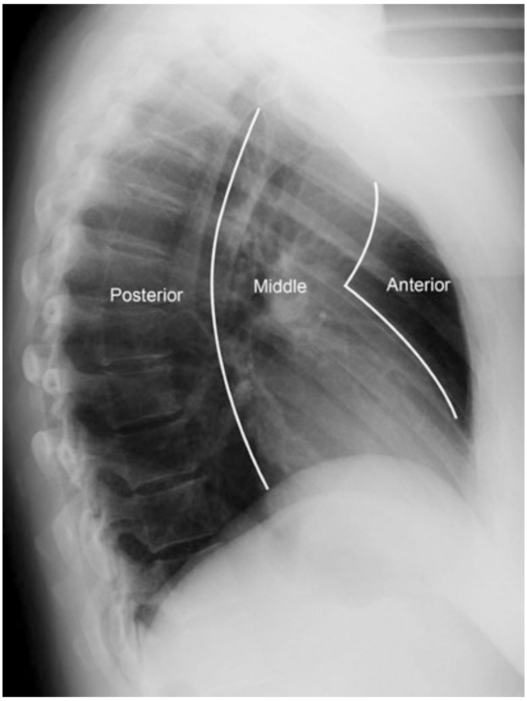

Fig. 1.12 Lateral chest radiograph demonstrating a basic anatomic method of dividing the mediastinum into compartments. This process is useful for the differential diagnosis of mediastinal pathology

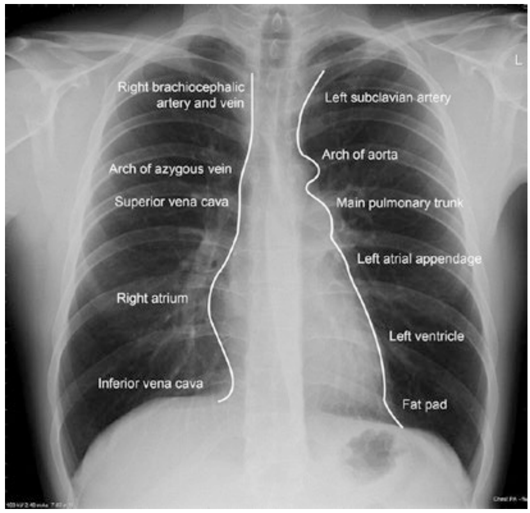

Fig. 1.13 Frontal chest radiograph with line tracing the various anatomic components forming the mediastinal borders

compartments, and disease can spread freely between them.

There are many different ways of dividing up the mediastinum, but one of the most practical and simplest is the modified anatomical method, which identifies three compartments: anterior, middle, and posterior (Fig. 1.12). The anterior mediastinal compartment is bounded anteriorly by the sternum and posteriorly by the pericardium, aorta, and brachiocephalic vessels. It merges superiorly with the anterior aspect of the thoracic inlet and extends inferiorly to the diaphragm. It contains the thymus, branches of the internal mammary artery and vein, lymph nodes, and fat.

The middle mediastinum contains the pericardium and its contents, the ascending aorta and the arch, the superior and inferior vena cava, the brachiocephalic arteries and veins, the phrenic nerves and upper portions of the vagus nerves, the trachea, and main bronchi with their lymph nodes and the central pulmonary arteries and veins.

The posterior mediastinum includes the paraspinous area and is bounded anteriorly by the pericardium, laterally by mediastinal pleura, posteriorly by the bodies of the thoracic vertebra, and includes the paravertebral gutters. It contains the descending thoracic aorta, the oesophagus, the thoracic duct, the azygos and hemiazygos veins, autonomic nerves, fat, and lymph nodes.

On a frontal chest radiograph (Fig. 1.13) the right superior mediastinal border is formed by the right brachiocephalic vessels, and the SVC with the contour of the lower mediastinal border being formed by the heart. On the left, the convexity of the mediastinum is formed by the aortic arch, a small concavity called the aortopulmonary window and inferior to that the main pulmonary trunk. A small round bump on the lateral wall of the aortic knuckle is seen on approximately 1% of chest radiographs and represents the left superior intercostal vein. Its sudden appearance, particularly in patients who have had instrumentation of their veins, raises the possibility of SVC or left brachiocephalic venous obstruction. The outer border of the left mediastinum more inferiorly is formed by the left heart.

Mediastinal pathology is often difficult to appreciate directly on plain radiographs as most lesions will be of soft tissue density and therefore

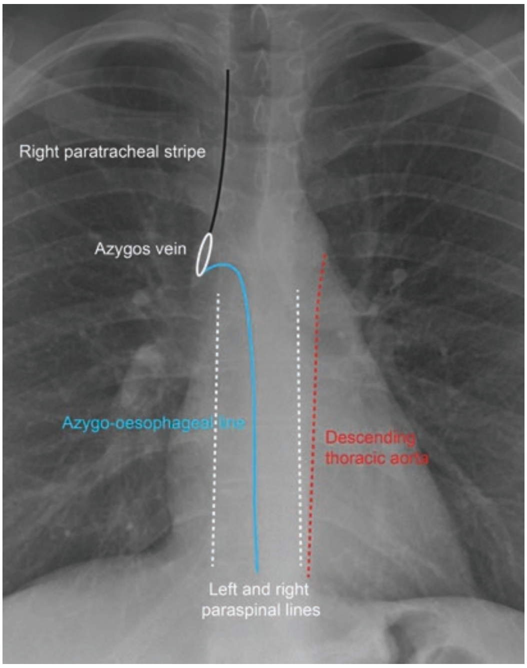

Fig. 1.14 The normal mediastinal lines and stripes as seen on a frontal chest radiograph. Displacement or loss of these can indicate disease

inseparable from normal structures. They may, however, change the appearance of mediastinal contours, and it is for this reason that interpreting physicians should have an awareness of normal contours and interfaces. Displacement or loss of clarity of these interfaces can indicate disease. Mediastinal contours and lines that should be routinely checked are as follows.

The right paratracheal stripe (Fig. 1.14) is an easy to identify, linear opacity produced by the right upper lobe abutting the right lateral wall of the trachea. Air within the tracheal lumen and the right upper lobe contrast with the soft tissue density of the tracheal wall and the mediastinal soft tissue. It can be seen on the majority of normal chest radiographs and projects as a well-defined line extending from the level of the sternoclavicular joint to the azygos arch. The width of this line should not exceed 4 mm (the thickness of the visceral and mediastinal pleura, the tracheal wall, and the soft tissues in between). Widening most typically is secondary to right paratracheal lymphadenopathy although tracheal wall disease and primary mediastinal masses are other causes.

The aortopulmonary window. This is the space between the aortic arch and the main pulmonary trunk and has a concave contour. It contains fat, the ligamentum arteriosum, the recurrent laryngeal nerve, and lymph nodes. A convexity in this region is usually abnormal and most commonly due to lymphadenopathy.

The paraaortic stripe. This is the interface of the descending thoracic aorta with the air in the left lower lobe. Distortion of this line may be caused by thoracic aneurysms and obliteration by parenchymal disease in the adjacent left lower lobe.

The azygo-oesophageal interface or recess is produced by a tongue of right lower lobe lying anterior to the vertebral bodies and adjacent to the azygos vein and oesophagus. It can frequently be identified as a long interface that extends from the diaphragm to the level of the azygos arch. Its right side is sharply delineated by air in the right lower lobe, the left side is of soft tissue density produced by the adjacent vein, oesophagus, aorta, and surrounding posterior mediastinal connective tissue. Viewed from the front its superior aspect forms a deep arc concave to the right. Any loss of concavity or increased density of this region below the azygos arch should be regarded with suspicion, as it most commonly results from lymphadenopathy in the subcarinal region.

Paravertebral stripes are a consequence of contact between lung and paravertebral soft tissues, and usually parallel the thoracic spine. The left is usually longer and more conspicuous than the right, being seen halfway between the lateral margin of the descending thoracic aorta and the spine. Displacement or focal contour abnormalities of these lines may result from vertebral pathology, such as osteophytes or fracture, paravertebral masses such as neurogenic tumours, or lymph node enlargement.

CT is almost invariably used to localise and characterise mediastinal abnormalities further, with diagnosis based on the location of the lesion, its shape, constituent tissues, and additional features such as its interaction with the surrounding structures.

Intrathoracic Lymph Nodes

Enlargement of intrathoracic lymph nodes is a manifestation of many diseases, and is frequently found in patients with bronchogenic carcinoma and other malignancies. Infections, particularly of mycobacterial and fungal origin, and non-infectious granulomatous diseases, such as sarcoidosis and pneumoconiosis, are other common causes.

Enlarged nodes can often be identified on plain chest radiographs, particularly when attention is focussed on the mediastinal interfaces as described above. Comparison with previous chest radiographs can be extremely useful in identifying subtle new disease.

CT is, however, the primary non-invasive technique for the diagnostic evaluation of thoracic lymph nodes, the location of which are described below.

Anterior Mediastinal Nodes

The internal mammary nodes lie with the internal mammary vessels close to the anterior chest wall. These nodes cannot be seen on a chest radiograph unless enlarged, and then only easily demonstrated on a lateral view. They receive lymph from the medial portion of the breast, the intercostal spaces, diaphragm, and the upper abdominal wall. Identification of these nodes is easy on CT, with the node being medial to the internal mammary vessel. Enlargement is often seen in lymphoma, pleural mesothelioma, and metastatic breast carcinoma.

Anterior diaphragmatic lymph nodes are located on the anterior aspect of the superior surface of the diaphragm and drain to the internal mammary nodes. They are more regularly seen at CT than on CXR. The paracardiac nodes are the more medial component of this group and again are most easily seen on CT. If visible they suggest abnormality.

Prevascular nodes are located anterior to the great vessels. The lowest of these nodes lies in the aortopulmonary window near the ligamentum arteriosum. Nodal enlargement may be identified by obscuration of the contour of the aortic knuckle on the frontal chest radiograph. As mentioned above, nodal enlargement in the AP window will produce a convex bulging of this region.

Middle Mediastinal Nodes

The right paratracheal nodal chain ascends along the anterolateral wall of the trachea, draining the right upper lobe and the middle and lower lobes indirectly via hilar and subcarinal nodes. The left lower lobe also drains to the right paratracheal nodes via the subcarinal nodes. The lowest node in this chain is the azygos node, lying near the azygos arch in the tracheobronchial angle. Nodal enlargement in this region is usually easily identified on a chest radiograph, with widening and lobulation of the right partracheal stripe and azygos vein area.

Left paratracheal nodes are smaller, generally fewer in number, and are rarely involved in isolation.

Subcarinal nodes lie below the carina and extend along the inferior margins of the main bronchi. They usually drain to the right paratracheal nodes. Enlarged subcarinal nodes are difficult to see on a chest radiograph as they lie in the centre of the chest, however, distortion of the azygo-oesphageal line is often a pointer to their presence.

Tracheobronchial nodes and bronchopulmonary nodes surround the mainstem bronchi and the pulmonary vessels medial to the mediastinal surface of the lung. They drain the lung and visceral pleura. Their enlargement produces a lobulated hilar contour and an increase in density, which is easier to appreciate if unilateral.

Posterior Mediastinal Lymph Nodes

These lie along the descending thoracic aorta and drain the posterior mediastinum (including diaphragm, oesophagus, and pericardium) to the thoracic duct. It is unusual to identify these nodes on a frontal chest radiograph even when markedly enlarged, but they may produce focal bulges in the paraspinous lines. This group of nodes is affected in lymphomas, and may be the site of metastases from lung and oesophageal carcinomas as well as tumours spreading from retrocrural and para-aortic abdominal nodes. Efferent lymphatics from this entire group drain to the thoracic duct, subcarinal, and intra-abdominal nodes.

The accurate identification of thoracic lymph node involvement is a crucial component of evaluation of a number of diseases, probably the most important of which is lung cancer staging. The most widely used criteria for predicting the presence or absence of disease in a lymph node is size. In general, the larger the node, the more likely it will be involved in the disease process. Unfortunately, no CT nodal size cut-off has proved entirely satisfactory.

The long transverse diameter on axial CT (long axis) is very dependent on the orientation of the typically sausage-shaped node to the scan plane. Nodal short axis (perpendicular to the measured long axis) has been shown on autopsy studies to be a more accurate predictor of nodal involvement. Most normal size nodes are less than 1 cm in short axis diameter.

Although the size of normal nodes may vary depending on their location, nodes in the paratracheal, aortopulmonary window, hilar, subcarinal, and paraoesophageal regions are considered abnormal if the nodal short axis is greater than 1 cm. Peridiaphragmatic and internal mammary nodes are considered abnormal if their short axis is greater than 0.5 cm. Nodes in the retrocrural and extrapleural regions are not normally visible on CT and should be considered abnormal when present. PET-CT and histological sampling are advised if the presence of disease in a node will affect therapy.

Lymph node maps have been used for at least 40 years and provide a method of precisely localising nodal involvement. They are required for accurately recording and communicating the presence of abnormal nodes. Lymph node locations have been traditionally divided into 14 stations based on surgical landmarks. Stations 1–9 correspond to mediastinal nodal groups. Stations 10–14 represent hilar and peribronchial nodal groups. Scalene and supraclavicular nodes are not represented, as they are extrapleural. The nodal map proposed by the International Association for the Study of Lung Cancer (IASLC) has been widely implemented since 2009.

The nodal stations are shown in Fig. 1.15:

1. Supraclavicular (low cervical, supraclavicular and sternal notch nodes)
2. Upper paratracheal 2R and 2L; right and left
3. Prevascular 3A right and left. Retrotracheal 3P.
4. Lower paratracheal 4R and 4L right and left.
5. Subaortic
6. Paraaortic
7. Subcarinal

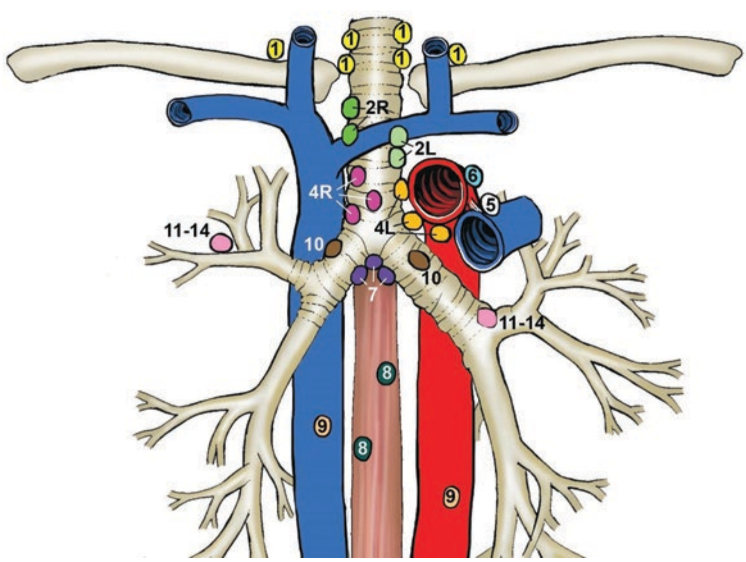

Fig. 1.15 IASLC mediastinal nodal map

8. Paraoesophageal (below carina)
9. Pulmonary ligament
10. Hilar
11. Interlobar
12. Lobar
13. Segmental
14. Subsegmental

Pulmonary Parenchyma

Beyond the segmental bronchi there are 20–25 generations of branches that end in terminal bronchioles. A terminal bronchiole gives rise to several generations of respiratory bronchioles, each providing 2–11 alveolar ducts and thence 5–6 alveolar sacs. The alveolus is the basic structural unit of gas exchange in the lung.

The secondary pulmonary lobule (Fig. 1.16) is the smallest unit of lung that can be seen on HRCT, and an understanding of its anatomy is a prerequisite for accurate HRCT diagnosis. This is because they have clearly defined anatomy, and many pathological abnormalities specifically affect components of the lobules and can be diagnosed on that basis.

Lobules contain 5–7 acini and are separated from the adjacent pulmonary lobule by an interlobular septum. They are typically irregularly polyhedral in shape and 1–2.5 cm in size. Each lobule is supplied by a lobular bronchiole and pulmonary artery which lie centrally. The draining veins are located in the septa. On HRCT normal interlobular septa are identified as straight lines 1–2.5 cm in length and slightly more than 0.1 mm in width (0.1 mm is typically the limit of HRCT resolution). The central largest lobular artery is normally visible as a dot-like or branching structure about 5 mm from the pleural surface. The largest lobular bronchiole can usually not be seen, as its walls are beyond the limit of resolution of the scan. The pulmonary parenchyma between the interlobular septa and the centrilobular core contains small vessels, airways, and alveoli which are below the resolution of CT. It is seen as a region of homogeneous attenuation slightly greater in attenuation than the air within the bronchi.

The lobules are usually easily defined in the supleural regions where the interlobular septa are well developed.

The components of the secondary pulmonary lobule become much more conspicuous when diseased, for example interlobular septa are easily identified when thickened by oedema fluid or tumour. Pathology related to small airways or arteries usually produces abnormality confined to the central portion of the lobule. Centrilobular emphysema, as expected by its name, is visualised as a small punched-out lucency in the central portion of the secondary pulmonary lobule surrounding the lobular artery. Infectious bronchiolitis will render the central lobular bronchioles visible by virtue of mucus plugging and peribronchiolar inflammation.

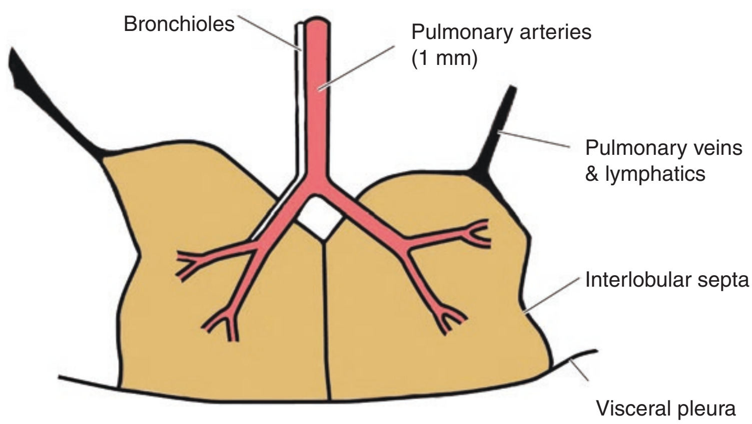

Fig. 1.16 Diagrammatic depiction of two normal adjacent secondary pulmonary lobules. The lobules are marginated by interlobular septa and in this instance the visceral pleura. An appreciation of lobular anatomy is prerequisite for diagnosis of pathology on high-resolution CT

The Diaphragm

The diaphragm is a musculotendinous sheet that separates the thoracic and abdominal cavities. It has both peripheral and central attachments. Its costal muscle fibres arise from the xiphoid process and the 7th–12th ribs. Posteriorly, tendinous fibres arise from the upper lumbar vertebrae forming crura. The right arises from L1–L3 and fibres from it surround the oesophageal hiatus, acting as a physiological sphincter limiting reflux of gastric contents. The left crus arises from L1 and L2.

Centrally the muscles of the diaphragm converge to form a central tendon which superiorly fuses with the fibrous pericardium. On a chest radiograph the upper surface of the dome-shaped diaphragm is visualised as it forms an interface with the air-filled lung. The soft tissues of the abdomen are indistinguishable from its inferior margin. The right hemidiaphragm is a few centimetres higher than the left in approximately 90% of adults. On a left lateral view of the chest the right hemidiaphragm is seen from front to back, whereas the anterior portion of the left is obscured by the overlying heart.

The diaphragm on CT is seen only where the upper surface interfaces with the lungs and the inferior surface abuts retroperitoneal or intraperitoneal fat. Its position can usually be inferred, as the lungs and pleura lie adjacent and peripheral to it and the abdominal viscera central to it. Multiplanar reconstructions can be very helpful in further evaluation of the diaphragm, particularly if a hernia or traumatic rupture is suspected.

The Chest Wall

Bones are the densest tissue seen on a normal plain radiograph. Those visualised on a chest radiograph include the ribs, clavicles, scapula, and vertebral bodies. A lateral radiograph is necessary to view the sternum and the vertebral bodies clearly.

Ribs are typically orientated obliquely, with their anterior portions angling downwards. The upper borders of the ribs are usually well defined, but the lower borders, particularly in the mid- and lower thoracic regions, are often difficult to see clearly. This is a consequence of the thinner bone of the subcostal groove in these regions accommodating the intercostal vessels and nerves.

Calcification of the costal cartilages is common, with the first costal cartilage calcifying shortly after the age of 20. The pattern of calcification differs between the two sexes. In men the upper and lower borders calcify first, whereas in women it is more central in location. Rib anomalies are not uncommon, and are usually not clinically relevant. It is worth checking for cervical ribs routinely as these occur in up to 1 in 150 individuals, arise from the seventh cervical vertebra, and may result in thoracic outlet syndrome.

The sternum is made up of the manubrium, the body, and the xiphoid process. The manubrium articulates with the clavicles. The sternum is most easily assessed on a lateral view or CT. The commonest congenital abnormality of the sternum is a pectus excavatum, when the sternum is depressed towards the thoracic vertebrae, narrowing the AP diameter of the chest. If severe, the heart is rotated and pushed to the left, and the right heart border appears indistinct on a PA chest radiograph. The anterior ribs appear more vertically orientated and the posterior ribs more horizontal than normal.

On a lateral view it is possible to see a retrosternal stripe of soft tissue interposed between the posterior border of the sternum and the lung. This is usually 1–3 mm thick with a characteristic lobulated contour with the lobulations at the levels of the ribs. A widening of this line or irregular lobulation may reflect internal mammary nodal involvement.

The bones of the thorax are seen in much greater detail with CT, as are the adjacent soft tissues of the chest wall. Multiplanar and volume-rendered 3D reformations can be invaluable for detecting subtle traumatic injuries and in planning chest wall reconstructive surgery.

Further Reading

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