

# Chapter 2

## Practical Reviews on the Anatomy of the Chest

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### 2.1 Normal Anatomy of the Lung

#### 2.1.1 Pulmonary Alveolus

The intrapulmonary bronchi divide and subdivide throughout the entire organ, constituting the bronchial trees. Each of the smallest subdivisions distally connects a pulmonary lobule (i.e., secondary pulmonary lobule), known as lobular bronchiole with a diameter of less than 1.0 mm. After entering the lobule, the lobular bronchiole continuously divides into respiratory bronchioles, about 0.5 mm in diameter, and finally reaches the terminals of the bronchial trees, composed of alveolar ducts and bulging sacs, and pulmonary alveoli.

Several alveoli converge into a single chamber, the alveolar sac. Each alveolus is surrounded by a blood capillary network, where gaseous exchanges take place, oxygen diffusing from the alveolar lumen into the capillary and carbon dioxide diffusing in the opposite direction crossing the alveolar walls. The pulmonary alveolus is a hollow cavity found in the lung parenchyma, as the terminal of 24-grade bronchial trees and the place of the external respiration. In adults, there are about 300–400 million alveoli. Their average diameter is 0.2  $\mu\text{m}$ , with a total surface area of nearly 100  $\text{m}^2$ , which is a few times larger than human skin surface area.

The alveoli arise from the walls of the sacs as diverticula. The alveoli alveolar epithelium comprises two major cell types and related supporting structures.

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### **2.1.1.1 Type I Alveolar Cells**

The majority of alveolar surface is lined by these cells, which are usually extremely thin (about 0.1  $\mu\text{m}$ ), tightly attached to the basement membrane, and lack proliferative capability. The type I cell is a complex branched cell with multiple cytoplasmic plates that are substantially attenuated and relatively devoid of organelles; these plates represent the gas exchange surface in the alveolus. Under electron microscopy, there is a basement membrane below the alveolar epithelium and outside the alveolar capillary endothelium. The air exchange between alveoli and capillaries occurs crossing through at least four layers of structures, i.e., the alveolar epithelium, the epithelial basement membrane, vascular endothelial basement membrane, and endothelial cells. Hence, type I alveolar cells are mainly involved in gas exchange. In interstitial pneumonia, edema and inflammatory cell infiltration may occur in alveolar septa and affect pulmonary ventilation.

### **2.1.1.2 Type II Alveolar Cells**

Type II alveolar cells are cubical or round and protruding into the alveolar cavity, with round nuclei and foamy cytoplasm, located among type I alveolar cells. These cells act as the “caretaker” of the alveolar compartment. They respond to damage of the vulnerable type I cells by dividing and acting as progenitor cells for both type I and type II cells. Alveolar type II cells form 63% of the epithelial lining cells but cover only 3% of the surface area. They have many features in common with highly metabolically active cells: abundant mitochondria, endoplasmic reticulum, polyribosomes, and Golgi apparatus. However, the most characteristic features are the microvilli around the apex and the rich osmiophilic lamellated inclusion bodies in the cytoplasm. These lamellar bodies are the site of storage of surfactant, the protein-lipid mixture that lines the alveolar compartment [1]. Type II cells synthesize, store, and release pulmonary surfactant into the alveolar cavities, where it acts to optimize conditions for gas exchange. The surfactant reduces surface tension at the gas-liquid interface and allows surface tension to vary directly with the radius of the alveolus, to maintain the consecutive gaseous exchange by inspiratory and expiratory movements. Deficiency or degeneration of surfactant caused pulmonary atelectasis. To identify cancer cells, deriving from the type I or II alveolar cells has no clinical significance.

### **2.1.1.3 Clara Cells**

In distal airways, Clara cells are present. These cells are nonciliated without mucus secretion. In human lungs, Clara cells comprise 15–20% of distal airway epithelial cells. Under light microscopy, cells are columnar and dome-like with shallow stained cytoplasm and the apical part protruding into the lumen. The electron microscope shows that there exist numerous secretory granules with low-electron density

in the cytoplasm at the top of cells. Clara cells have active proliferation, differentiation, and secretion function, which are involved in the repair process of bronchial epithelial damage. Clara cell secretory protein (CCSP) is the most important secretory product of Clara cells. It has many biological activities, including anti-inflammation, anti-fibrosis, and antitumor invasion which are closely related to various lung diseases. In addition, the CCSP also plays an important physiological role in organ protection, airway epithelial renewal, damage repair, biotransformation of exogenous chemicals, and distal airway fluid balance regulation.

#### **2.1.1.4 Alveolar Macrophage**

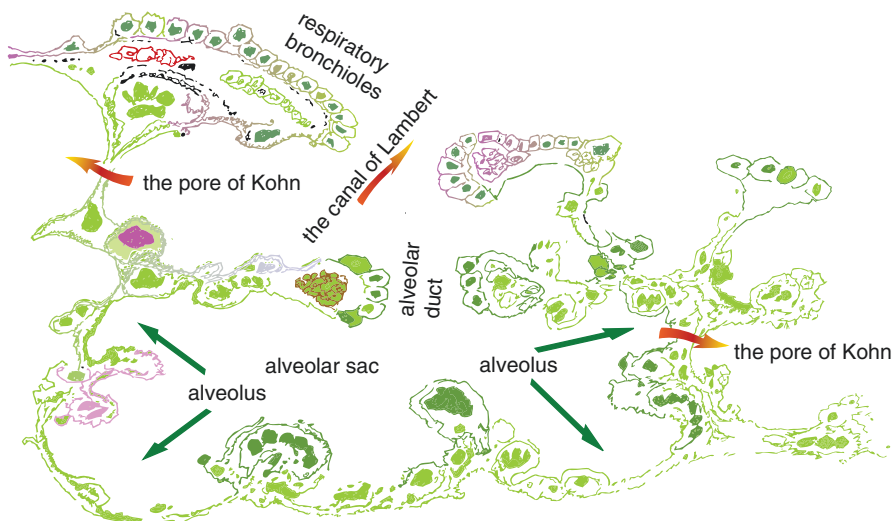
The alveolar macrophages are derived from blood monocytes and transformed to dust cells after engulfing dust particles. And heart failure cells are the alveolar macrophages containing hemosiderin, the decomposition products of hemoglobin, in patients with heart failure or chronic pulmonary edema.

#### **2.1.1.5 Alveolar Sac, Duct, and Pore**

The alveolar sac is a capsule composed of many pulmonary alveoli, connecting with the alveolar ducts, and each branch of alveolar ducts has two to three alveolar sacs. The pulmonary alveoli are communicated with each other by alveolar pores (also known as the pores of Kohn), and the pulmonary alveoli connect with the terminal bronchioles by the canals of Lambert (Fig. 2.1). Typically, one to six alveolar pores are seen in the alveolar wall. With the pulmonary alveoli expanding, these pores could be fully opened as the communication channels for air exchange in adjacent pulmonary alveoli. Moreover, collateral ventilation could be established through the alveolar pores to compensate limited gas exchange when a bronchus or its subdivisions are partly or completely blocked.

#### **2.1.1.6 Alveolar Septa**

The thin layer of connective tissues between the adjacent alveoli is known as alveolar septum, which contains abundant capillary networks, elastic fibers, reticular fibers, and collagenous fibers. The reticular fibers, elastic fibers, and a few collagenous fibers compose the framework of alveolar capillaries, and due to the presence of elastic fibers, the alveoli maintain good elasticity. In cases of chronic bronchitis or bronchial asthma, excessive expansion destructs the elastic fibers, and the involved pulmonary alveoli lose the elasticity, resulting in emphysema and impaired pulmonary function. Additionally, alveolar septa contain rich lymphatic vessels and nerve fibers. As the capillary permeability increases from various reasons, such as chemical toxins, plasma components will seep into the connective tissues, resulting in pulmonary interstitial edema.

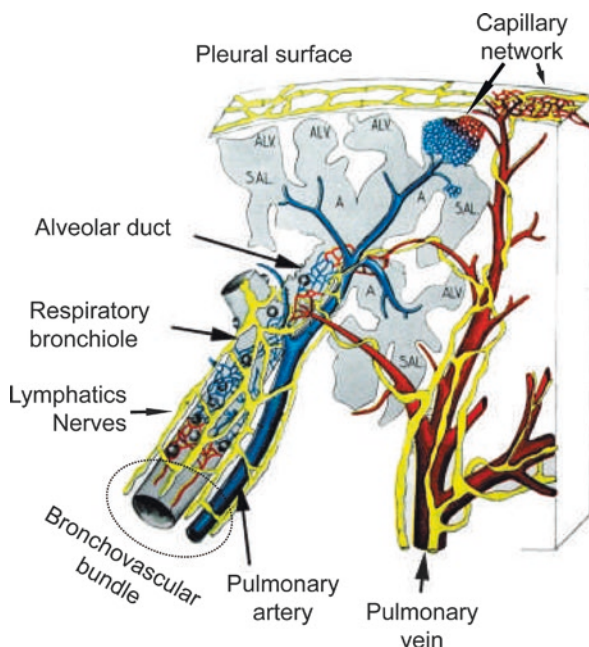


**Fig. 2.1** The pores of Kohn and the canals of Lambert

### 2.1.2 Pulmonary Vessels

The lungs have two functionally distinct vascular systems: pulmonary system and bronchial system. The former is the functional vascular system of the lung, while the latter from the systemic circulation provides nutrients to pulmonary structures.

Pulmonary arteries, originating from the base of pulmonary conus of the right ventricle, divide into branches which accompany the bronchial trees and end in a dense capillary network in the walls of the alveoli. The small pulmonary veins originate from the capillary network in alveolar walls and converge more and more widely in the process of concentric reflux, ultimately forming superior and inferior pulmonary veins into the left atrium. The branches of the pulmonary artery accompany closely the homonymous bronchi at a particular distribution pattern, i.e., in the front and outside of the bronchi. Unlike the pulmonary arteries, the pulmonary veins have fewer branches and weaker relationship with the bronchi. The distribution of its branches is not consistent with that of bronchi, but common in the back and inside of the homonymous bronchus. In the pulmonary segments, the distribution of segmental arteries is consistent with that of segmental bronchi, but the segmental veins can be divided into the inner-segment branch and the intersegment branch. The former is smaller and located within the pulmonary segments, collecting part of returning venous blood of corresponding lung segments. The latter is thicker and accepting the venous return from two adjacent lung segments, thus distributed between the adjacent lung segments and not accompanied by bronchi and arteries. It is clinically relevant and significant to recognize and distinguish pulmonary veins



**Fig. 2.2** The intersegmental and intrasegmental blood vessels in a primary pulmonary lobule. According to Miller, the primary pulmonary lobule is composed of alveolar ducts, atria (A), alveolar sacs (SAL), and alveoli (A) distal to the respiratory bronchiole, along with their associated blood vessels, nerves, and connective tissues (From Miller WS. *The lung*. Springfield, IL: Charles C Thomas; 1947:75)

and arteries since intersegmental veins can be used to acknowledge individual segments in imaging diagnosis and segmentectomy (Fig. 2.2).

Bronchial arteries are the nutrient vessels of the lung, supplying blood to the bronchus, lung parenchyma, pleura, and bronchial and intrapulmonary lymph nodes. Physiological anastomosis commonly exists between the terminal branches of pulmonary arteries and bronchial arteries to link the systemic circulation with the pulmonary circulation with co-distribution in the alveolar walls. It has been proved that the ligation of bronchial arteries below the lobe level would not cause the severe damage to distal bronchi and lung tissues.

Bronchial arteries vary in number and origin, usually only one in the right and two in the left, occasionally four to five on each side. They may be alone or in conjunction with intercostal artery arise from the descending aorta. Less frequently, they may come from the subclavian artery, the innominate artery, the internal thoracic artery, or even the intercostal artery. The left bronchial artery is about 1.1–1.5 mm in diameter, starting from the descending aorta at the level of fifth to sixth thoracic vertebra, while the right bronchial artery usually has a rectangular opening to the right wall of the descending aorta with a diameter of about 2 mm.

The bronchial arteries normally receive only about 1% of the total cardiac output and help maintain airway and lung function. They provide systemic blood supply to the trachea, bronchi, bronchial branches, esophagus, and visceral pleura. They also supply blood to the vasa vasorum of the thoracic aorta and pulmonary arteries as well as to the nerves, pulmonary veins, and lymph nodes in the thorax [2]. Besides, communications between bronchial arteries and pulmonary artery, intercostal artery, and Adamkiewicz artery are frequently observed (Fig. 2.3). Bronchial arteries create arterial plexus (i.e., the bronchial arterial plexus) in the bronchial wall adventitia. Some send out branches penetrating through the muscular layer into the submucosa and form a thin capillary plexus to supply nutrition for bronchial mucosa, the wall of pulmonary arteries, veins, and the visceral pleural membrane. About two-thirds of blood flows in the bronchial arteries are drained into bronchial veins, and the remaining one-third are collected into the azygos vein in the right and the hemizygos vein in the left and then to the superior vena cava.



**Fig. 2.3** The right bronchial artery (arrow) arises from the descending aorta and gives the Adamkiewicz artery (arrowhead)

The systemic circulation of the lungs mainly arises from the bronchial artery and bronchial vein and to a small extent from intercostal and inferior phrenic arteries. Although the bronchial circulation accounts for only a small proportion of the total blood flow in healthy people, it plays a vital role in maintaining the airway and lung function. Especially in many pathological conditions, bronchial circulation is more malleable in plasticity and plays a more important role. For example, in the development of lung cancer, bronchial circulation is considered as the major momentum. The hemodynamics of the blood supply system may change abnormally in the pathological state. CT perfusion imaging (CTPI) may be used to assess the hemodynamic changes in pulmonary microcirculation by analyzing the perfusion variations.

For a long time, there have been controversies on the relative proportion of the blood supply from pulmonary and bronchial circulatory systems in certain lung diseases. Early in the 1960s, autopsy-based reports revealed that lung cancers received blood supplies from both circulatory systems, confirmed in numerous subsequent studies. However, some researchers firmly believed that bronchial arterial system was the sole vascular supporting system for lung cancers. Hence, it is important to revisit and reemphasize the origin and amount of blood supply related to lung diseases for understanding the occurrence, development, and diagnosis, as well as decision making of treatment and the prognosis.

The bronchial arterial system is considered as the principal vascular system in the development and progression of lung cancers. In contrast, pulmonary arteries contribute a relatively small portion of blood supply of lung cancers, which is more evident in peripheral lung cancers, especially those located in the subpleural area. Occasionally, lung cancers may receive blood supply from bilateral bronchial arteries or other systemic arteries. The blood supply of lesions at the upper lobe tends to be from branches of the subclavian artery, and those lesions at lower lobes are usually supplied by the proper esophageal artery or phrenic artery. For centrally located lesions, blood supply may be from branches of systemic circulation in the mediastinum. Since both bronchial artery and pulmonary artery can participate in the blood supply to lung cancers, transbronchial arterial infusion chemotherapy alone may not be adequate for effective control of lung cancer in some cases.

In addition, intercommunication between two circulatory systems can be found in tuberculosis, similar to lung cancers. The underlying mechanism is the tuberculosis-induced damages to vascular bed. Due to the higher pressure in pulmonary artery system than that in the bronchial artery system, a bronchial-pulmonary arterial fistula would generate and account for the hemoptysis commonly seen in patients with tuberculosis and lung cancers. Imaging assessment of blood supply can also be used to evaluate the disease activity, a reliable approach for pretreatment prediction and posttreatment outcome evaluation.

On CT scan, the common manifestation of bronchial and pulmonary vessels is dependent on their size and path. Air-containing bronchi present as hollow tubular or circular structures, while blood vessels appear as high-density solid tubular or nodular opacities. Regarding density or morphological features, pulmonary arteries



and veins usually have no difference. According to their positional relationship with the corresponding bronchus mentioned above, it is possible to distinguish arteries from veins. Additionally, tracking the interested vascular structure in consecutive slices could be helpful to identify its origin or branches. Figure 2.4 shows the diagrammatic relative position of bronchioles, pulmonary and bronchial vessels, and alveoli in a pulmonary lobule.

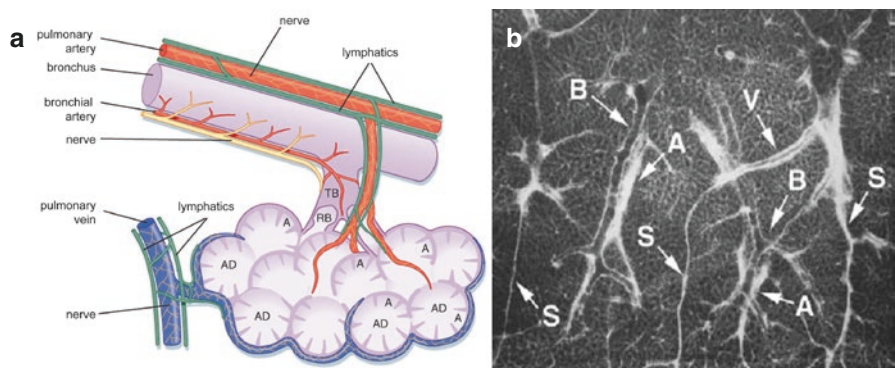
### ***2.1.3 Secondary Pulmonary Lobule***

The secondary pulmonary lobule is a fundamental unit of lung structure with irregularly polyhedral shape and varying size from 1 to 2.5 cm in diameter in most locations. Each of the lobes has about 50–80 pulmonary lobules. Each lobule is composed of a central bronchovascular bundle and dozens of peripheral pulmonary acinus and margined by connective tissue and the interlobular septa.

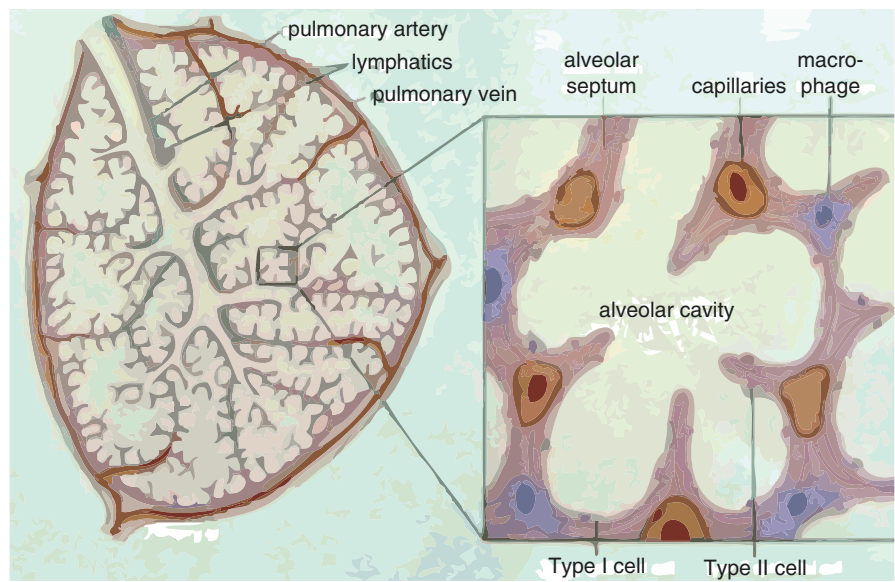
On thin-section CT, several of lobular components are usually visible, including the interlobular septa and septal structures, the centrilobular region and centrilobular structures, and the lobular parenchyma. Interlobular septa vary in amount and thickness, thickest and richest in peripheral lungs, such as the apical aspect of the upper lobes and the anterior and diaphragmatic surfaces of the lower lobes, and along the mediastinal pleural surfaces. In the subpleural area, septa could be up to 0.1 mm in thickness. Lobules are supplied by arteries and bronchioles measuring approximately 1 mm in diameter, while intralobular terminal bronchioles and arteries measure about 0.7 mm in diameter and acinar bronchioles and arteries range from 0.3 to 0.5 mm in diameter. On thin-section CT scans, a linear, branching, or dot-like opacity seen in the center of a lobule or within 1 cm of the pleural surface represents the intralobular artery branch or its divisions. The visibility of bronchioles in healthy subjects depends on the wall thickness of the bronchiole, rather than its diameter. For a 1-mm bronchiole supplying a secondary lobule, the wall thickness measures approximately 0.15 mm [3]. The central lobular structure, known as the bronchovascular bundle, is constituted by bronchioles (or terminal bronchioles), small arterioles, and some supportive connective tissues. The structure of pulmonary lobule and alveolus is shown in Figs. 2.4 and 2.5.

The recognition of lung abnormalities relative to the structures of the secondary lobule is fundamental to the interpretation of thin-section CT scans. How to distinguish vessels from pulmonary micronodules on CT imaging? The following principles may be helpful: (1) The cross section of a vessel is frequently escorted by a bronchus in similar size, generating a diamond-on-ring appearance. (2) In comparison with adjacent known vessels, a pulmonary nodule may have different features such as size or density from the vessels. (3) To observe the suspected nodule in consecutive images, a vessel would be visualized in multiple consecutive images with gradual size change, while a small nodule may be only seen in several images with the largest dimension measured in some middle





**Fig. 2.4** The relative position of bronchioles, vessels, and alveoli in a pulmonary lobule (a) Diagrammatic illustration. A alveolus, AD alveolar duct, RB respiratory bronchioles, TB terminal bronchiole (From Koeppen & Stanton: *Berne AND Levy Physiclogy*, 6th Edition. Reprinted with permission) (b) Radiograph of 1-mm lung slice taken from peripheral lower lobe. Two well-defined secondary pulmonary lobules are visible. Lobules are margined by thin interlobular septa (S)-containing pulmonary vein (V) branches. Bronchioles (B) and pulmonary arteries (A) are centrilobular (From Itoh H, et al. *Diffuse lung disease: pathologic basis for the high-resolution computed tomography findings*. *J Thorac maging* 1993;8:176–188. Reprinted with permission)



**Fig. 2.5** Diagram of the secondary pulmonary lobule and alveolus a secondary pulmonary lobule is composed of dozens of acini which comprise numerous alveoli. Alveolar septa are located between adjacent alveoli, containing abundant capillaries, reticular fibers, and elastic fibers (around the alveolus)

images. (4) The images of vessels are subject to patient's position on CT table, prone or supine or lateral, due to the gravity effect. However, pulmonary nodules are less likely subject to scanning position. (5) Image post-processing is helpful. In the multiplanar reformation images, a vessel could appear a tubular structure when reformation plane is parallel to its path and a dot-like opacity when perpendicular. However, for a pulmonary nodule, the reformation plane may have limited impacts on its appearance, and the largest dimension is typically found in the median images among reformatted images.

## **2.2 Cross-Sectional Imaging Anatomy of the Lung**

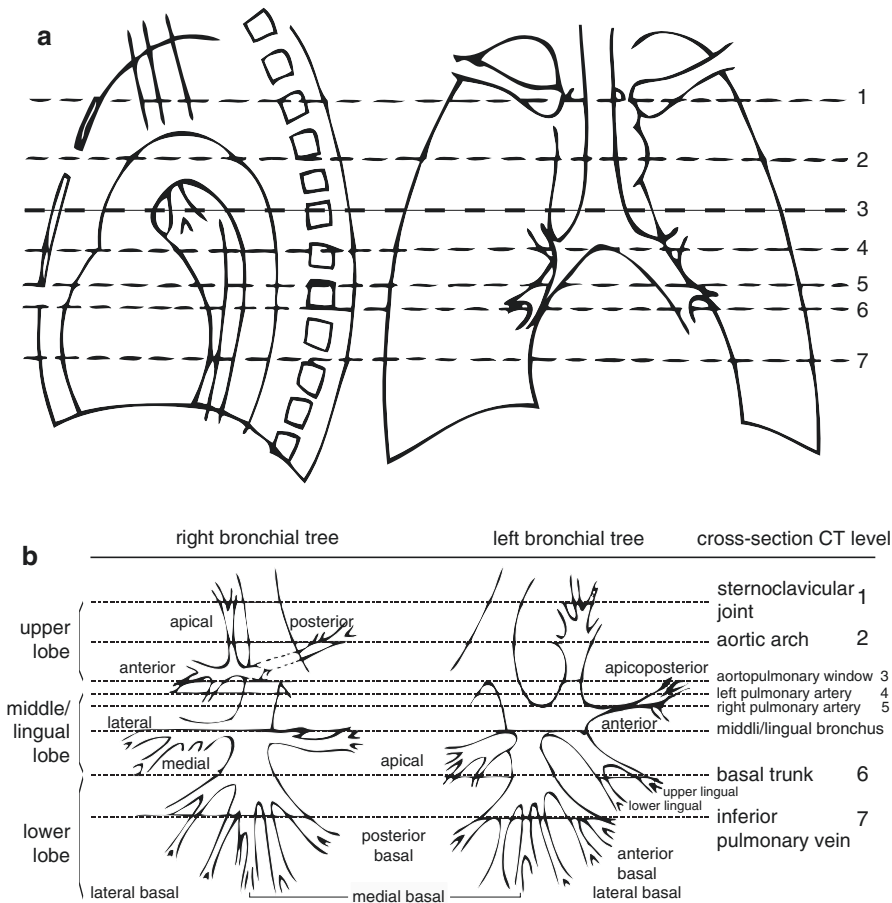
On CT imaging, recognition of pulmonary segments is based on segmental bronchi located in the center of the segments. Lobules and segments can be identified in consecutive slices through the upper, middle, and lower lobes of the lung. Figure 2.6 shows seven representative cross sections on CT imaging from the apex of the lung to the diaphragm. Figure 2.7 lists major structures within each section, including bronchi, segments, and mediastinal contents.

### ***2.2.1 The Level above Aortic Arch***

Several circular or comma-shaped opacities can be visualized in bilateral lung fields, representing bronchovascular bundles in apical segments of the upper lobes (Fig. 2.7a). Cupula of pleurae over the apex pulmonis, both extending into the root of the neck together, are also called cervical pleura. It could be 2 cm above the medial clavicle, probably with a manifestation of irregular patchy opacity due to thickening and adhesion, which should be distinguished from pulmonary lesions.

### ***2.2.2 The Level of Aortic Arch***

The apical bronchus is visible by the mediastinum accompanied by the apical artery inside and the apical vein outside. Within the upper lobe, the apical segment is an area bounded by the medial extremity of the high-density stripe demarcated between the anterior segment and the posterior segment, the intersegmental tributary of the apical segmental vein at the margin of the mediastinum, and the cross section of the posterior segmental vein (Fig. 2.7b). The major fissure in the left lung is located at a higher level than that in the right lung, so the upper segment (the posterior segment) of the left lower lobe is seen at this level. At this and following levels, serous pericardium reflexes along the roots of large vessels forming serous spaces. Those with larger sizes are named sinus, such as transverse sinus and oblique sinus, while

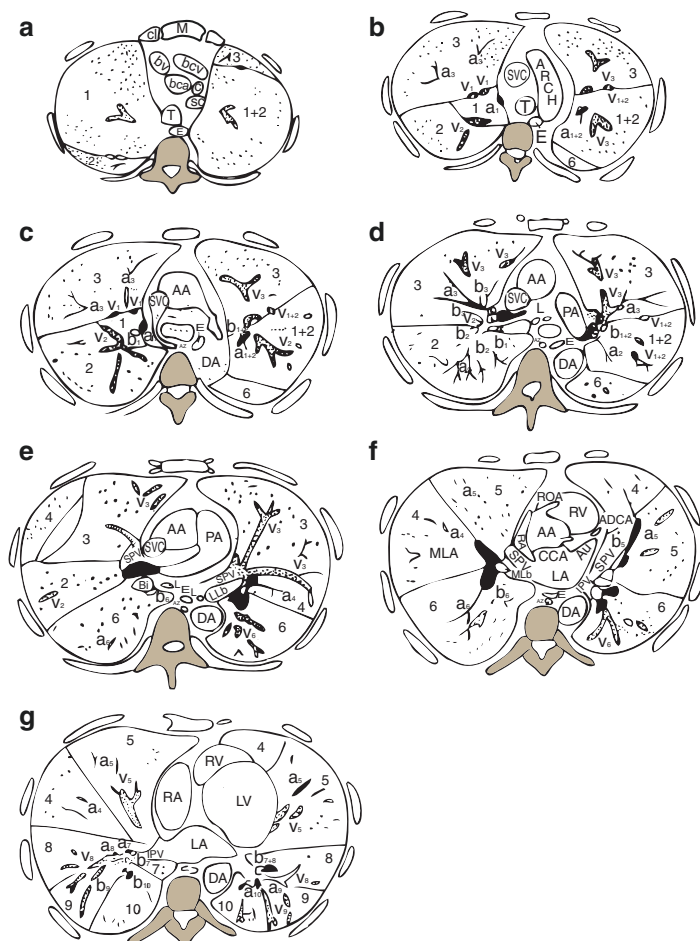


**Fig. 2.6** Diagrams of seven representative transverse cross sections of the lung. **(a)** The projection of distribution map of cross sections in the lung. **(b)** Major bronchial structures corresponding to each section

the smaller spaces are named recess, such as superior recess by heart and superior aortic recess (Fig. 2.7c). These recesses or sinuses could expand with appearance mimicking lymph nodes if excessive fluid accumulates in physiological or pathological conditions.

### 2.2.3 The Level of Left Pulmonary Artery

In this level, the right upper lobe bronchial trunk and the long axis of its anterior and posterior segmental bronchus can be visible in right lung field. The apical vein appears circular, located between anterior and posterior segmental bronchi; the



**Fig. 2.7** Major anatomical structures on sketched CT images from seven representative cross-sectional levels (a) Sternoclavicular joint level. (b) Aortic arch level. (c) Aortic window. When fluid accumulation occurs in the superior recess by the heart and transverse sinus, the recess may appear a circular (axial views) or elongated (coronal and sagittal views) low-density opacity, which should not be misdiagnosed as enlarged lymph nodes. (d) The left pulmonary artery window level. (e) The right pulmonary artery window level. (f) The level above the basal trunk. (g) Inferior pulmonary vein level. (These drawings were elaborately produced by the late professor Zongwen Shen from the former Shanghai Medical University, with reference to cross-sectional anatomy and CT scans of corpses) Abbreviations: A artery, AA ascending aorta, ADCA anterior descending coronary arteries, ARCH aorta arch, Au auricular appendix, Az azygos vein, B bronchi, b segmental bronchus, bca brachiocephalic artery, bv brachiocephalic vein, Bi bronchus intermedius, CA cephalic artery, RCA right coronary artery, Cl clavicle, DA descending aorta, E esophagus, IAR inferior aortic recess, ILA inferior lobar artery, ILB inferior lobar bronchus, IPV inferior pulmonary vein, IV innominate vein, IVC inferior vena cava, L lymph, LA left atrium, LCA left coronary artery, LLb lingular lobe bronchus, LPAR left pulmonary artery recess, LPVR left pulmonary vein recess, LSPV left superior pulmonary vein, LV left ventricle, M sternum, MLA middle lobar artery, MLb middle lobar bronchus, OS oblique sinus, PA pulmonary artery, PCR postcaval recess, RA right atrium, RCA right coronary artery, RIPV right inferior pulmonary vein RPA right pulmonary artery, RPAR right pulmonary artery recess, RSPV right superior pulmonary vein, RV right ventricle, RVOT right ventricular outflow tract SA subclavian artery, SAR superior aortic recess, SPV superior pulmonary vein, SVC superior vena cava, T trachea, TD thoracic duct, Th thymus, TS transverse sinus, V vein

posterior vein can be used to distinguish anterior and posterior segments in the right upper lobe.

A hypovascular zone in the left lung, representing the interlobar fissure, extends from the interlobar artery posterolaterally. Within the left upper lobe, an imaginary line dividing the anterior segment from the apical-posterior segment is drawn slightly anterior to the apical-posterior segmental bronchus. In the anterior segment, the anterior segmental bronchus runs anteriorly and horizontally (Fig. 2.7d). Located anteriorly to the anterior bronchus is the inferior branch of the anterior segmental artery. Close to the mediastinum, intrasegmental vein courses posteriorly to drain into the superior pulmonary vein. In the apical-posterior segment, there is a transverse apical-posterior segmental artery without escort by bronchus.

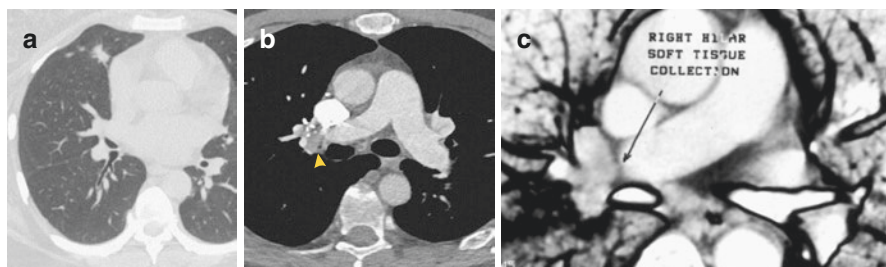
The boundary between mediastinum and lungs is evident in the right with a remarkable longitudinal linear opacity with lipid density, but not visible in the left. Hence, an imaginary line from the proximal of the first branch of the left pulmonary artery and the starting point of the left upper lobe bronchus is considered as the boundary line. The superior aortic recess can be seen in this section.

### ***2.2.4 The Level by Right Pulmonary Artery Trunk***

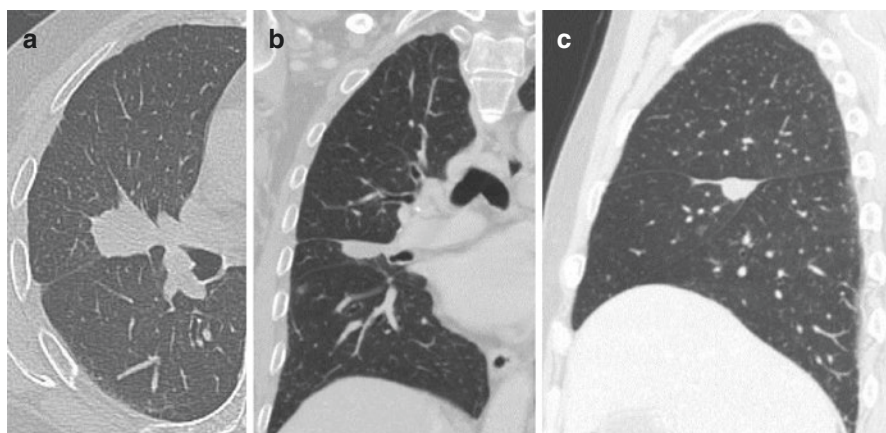
This section passes through the upper level of the intermediate bronchus. In the right lung, a hypovascular zone extending laterally between the interlobar artery and intermediate bronchus represents the right interlobar fissure, the horizontal fissure (transverse fissure, accessory interlobular fissure). An imaginary line is drawn from the upper division of the superior pulmonary vein dividing into the lateral and anterior areas. The lateral area is named as the lateral segment of the middle lobe, and the posterior triangular portion of the anterior area is an avascular plane of the para-interlobar fissure, and its anterior portion is the anterior segment of the upper lobe.

In the left lung, lingual lobe bronchus and vessels are visible. At this section, the major structures in the right lung include the anterior segment of the upper lobes, lateral segment of the middle lobe, and the upper segment of the lower lobe, while in the left the anterior segment and superior lingual segment of upper lobe and upper segment of the lower lobe (Fig. 2.7e).

In cases with pleural metastases, the horizontal fissure may be involved with imaging features of miliary distribution of bead-like nodular lesions, which should be distinguished from intrapulmonary metastases (Fig. 2.8a). Occasionally, prominent right hilar soft tissue collections are seen in or near the right hilum, superior to the right interlobar pulmonary artery and medial to the right superior pulmonary vein as illustrated in the anatomical section (Fig. 2.8b, c). These abnormalities are considered due to normal accumulations of hilar lymph nodes, fatty tissue, and connective tissues, measuring from 3 to 15 mm with more than one-half exceeding 10 mm. If there exists difficulty in differentiation with pulmonary diseases, such as pulmonary artery embolism or lymphadenopathy, contrast-enhancement thin-slice CT scan could be helpful. Additionally, encapsulated localized effusions in fissures are easily mistaken as pulmonary lesions, which could be differentiated with the assistance of image post-processing and contrast-enhancement scanning (Fig. 2.9).



**Fig. 2.8** Miliary metastases on the interlobar fissure and the right hilar soft tissue collections. (a) Miliary metastases on the right interlobar fissure. (b) Right hilar soft tissue collections (arrow-head). (c) Right hilar soft tissue collections and the low-density boundary line between the right lung and mediastinum (arrow)



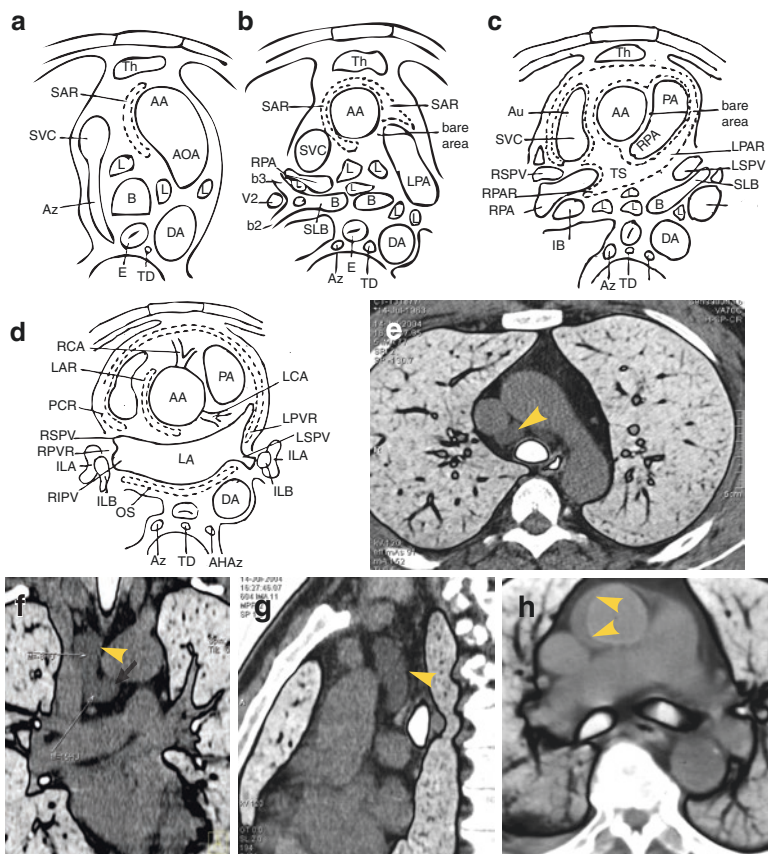
**Fig. 2.9** Encapsulated effusions in fissures. The effusions are easily misdiagnosed as intrapulmonary lesion in axial images. (a) In coronal (b) and sagittal (c) views, the effusions are clearly visualized between interlobular fissures

In this section, transverse sinus (TS), the superior aortic recess (SAR), and bilateral pulmonary artery recesses are observed (Fig. 2.10).

### 2.2.5 The Level of Interlobular Artery

This is a section passing through the basal trunk (Fig. 2.7). The bilateral hypovascular zones extending laterally from the lateral border of the lower lobe arteries represent the interlobar fissures. Within the middle lobe, an imaginary line drawn anterolaterally between the lateral and medial segmental bronchi arteries and veins demarcates the lateral segment and the medial segment. Within the left upper lobe,





**Fig. 2.10** Pericardial recesses and sinuses (**a–d**) The locations of pericardial recesses and sinuses in cross-sectional anatomy (dotted line) (**a**, aortic arch level; **b**, left pulmonary artery level; **c**, right pulmonary artery level; **d**, aortic root level) (**e–h**) Fluid accumulation is seen in the superior aortic recess (SAR), and pericardial recesses and sinuses (arrowhead) are variably dilated filled with components with liquid density of 8 HU. (**e**) Axial CT image at the level of aortic arch; (**f**) and (**g**) are coronal and sagittal views, respectively. (**h**) CT at the level of right pulmonary artery shows a recess wrapping around the ascending aorta *Abbreviations:* AA ascending aorta, DA descending aorta, L lymph node, LPR left lung recess, MPA main pulmonary artery, OS oblique sinus, RPA right pulmonary artery, SAR superior aortic recess, SVC superior vena cava, TS transverse sinus

an intersegmental tributary of the superior segmental vein courses posteromedially between the long stripe-shaped superior segmental bronchus and the round section of the inferior segmental bronchus. Finally, it drains into the lingular vein. It is a landmark that demarcates the superior segment and the inferior segment of the lingular lobe. The portion located anteromedially to the lingular lobe is still the anterior segment of the upper lobe.

In addition, at this level, the inferior aortic recess (IAR) and the oblique sinus (OS) can be visible. Left pulmonary artery recess (LPAR) is located between the left



atrial appendage and left superior pulmonary vein (LSPV). Right pulmonary artery recess is between right superior pulmonary vein (RSPV) and right inferior pulmonary vein (Fig. 2.10).

### ***2.2.6 The Level of Bilateral Inferior Pulmonary Veins***

This image is a section going through the inferior pulmonary veins (Fig. 2.7g). The bilateral hypovascular zones, located anterior to the inferior pulmonary vein at the margin of the mediastinum and extending laterally, represent the interlobar fissures. Within the right lower lobe, the medial basal segmental artery is situated laterally to the homonymous bronchus. The medial basal segment is located medially to medial basal artery and bronchus and adjacently to the proximal portion of the inferior pulmonary vein. After giving off the lateral basal segmental bronchus, the basal trunk continues inferiorly to the posterior basal segmental bronchus. The higher-level tributary of the anterior division of the inferior pulmonary vein which passes between anterior artery anteriorly and lateral bronchus posteriorly divides into the anterior and lateral basal segments. The higher-level tributary of the intermediate division separates the lateral basal segment from the posterior basal segment. Within the left lower lobe, the division of the segments is similar in appearance to that found on the right lower lobe.

The anterior parietal layer of the pericardium is visible about 2 mm in thickness. On the contrary, the visceral layer is too thin to be visualized in the physiological state. The thickness of pericardium adjacent to the right ventricle may be up to 7 mm and should not be considered as the pericardial thickening.

## **2.3 Updates on Regional Lymph Node Classification for Lung Cancer**

It is important to accurately group the regional lymph nodes associated with lung cancer for staging, treatment, and prognosis of the disease. Local and regional lymph nodes of lung cancer include pulmonary, hilar, mediastinal, supraclavicular, and infraclavicular lymph node zones. Up to 2009, there existed two grouping systems for the regional lymph nodes in lung cancer, that is, AJCC/Naruke system endorsed by the Japan Lung Cancer Society and the American Joint Committee on Cancer (AJCC) and MD-ATS system supported by American Thoracic Society (ATS).

The AJCC/Naruke system was initially proposed in 1978. In this system, lymph nodes are divided into superior and inferior mediastinal and intrapulmonary zones. Furthermore, the superior mediastinal zone includes (1) the most superior mediastinal, (2) upper paratracheal, (3) prevascular and retrotracheal, (4) lower paratracheal, (5) aortic window, and (6) para-aortic (ascending aorta, aortic arch, and phrenic). The inferior mediastinal zone includes (7) subcarinal, (8) paraesophageal, and (9)

pulmonary ligament (including the bilateral pulmonary vein). Intrapulmonary lymph node zone includes (10) hilar, (11) interlobar, (12) lobar, (13) segmental, and (14) intrapulmonary. In order to define intrathoracic lymph nodes more precisely from the anatomical perspective, ATS system was established based on the AJCC/Naruke system in 1983. Thirteen years later, the AJCC and Union for International Cancer Control (UICC) proposed MD-ATS system with the intention to integrate both ATS and AJCC/Naruke systems. However, this classification system was only accepted in North America. The rest of the world, including Europe, Japan, and China, continued using the AJCC/Naruke system. Multiple differences in the descriptors for mediastinal lymph nodes existed between the systems of AJCC and ATS, for example, level 1 lymph nodes in the AJCC system corresponding to levels 1 + 2 in the ATS system, and levels 2, 3, 4R, and 4 L in the AJCC system corresponded to levels 4R and 4 L in the ATS system. Perhaps the most significant discrepancy was that level 7 subcarinal lymph nodes in the ATS system were equivalent to levels 7 + 10 in the AJCC system. As a result, lung cancers with positive level 10 lymph nodes were staged N1 by ATS system but N2 by AJCC system.

To solve these discrepancies and facilitate worldwide communication, the International Association for the Study of Lung Cancer (IASLC) International Staging Committee were commissioned by AJCC and UICC to develop a revised lymph node classification system for the forthcoming UICC/AJCC 7th Edition for lung cancer TNM staging in 1998. After years of endeavors and dedications from numerous international experts, the IASLC lymph node classification was published in 2007 [4]. According to the IASLC system, the regional lymph nodes are divided into 7 zones and 14 stations, including supraclavicular zone (station 1); superior mediastinal zone (stations 2R, 2L, 3a, 3p, 4R, 4L); aortopulmonary AP zone (stations 5, 6); inferior mediastinal zone, including subcarinal zone (station 7) and the lower zone (station 8, 9); hilar/interlobar zone (stations 10, 11); and peripheral zone (stations 12, 13, 14). The detailed information regarding individual lymph node station is described in Table 2.1 and Fig. 2.11.

Compared with the previous classification systems of MD-ATS and AJCC/Naruke, IASLC map clarified preexisting confusions and redefined the scope and boundaries of each lymph node station to minimize the uncertainty and randomness in the clinical application of the system. The major revisions or updates include the following. (1) The supraclavicular and sternal notch lymph nodes, which were not previously identified as a lymph node station, are now clearly described as level 1 to facilitate differentiation from intrathoracic nodes. The sternal notch serves as the border between the levels 1 and 2. (2) The discrepancies between levels 2 and 4 have been resolved with more precise definitions. The left lateral wall of the trachea is set as the boundary between the right- and left-sided levels 2 and 4. The extent of level 5 is reduced, with its lower border adjusted to the upper rim of the left main pulmonary artery. At the same time, the upper limit of level 10L expands to the upper rim of the left main pulmonary artery, belonging to N2. (3) Considering that lymphatic system in the superior mediastinum predominantly collects the right paratracheal area with extension beyond the midline of the trachea, the boundary between the

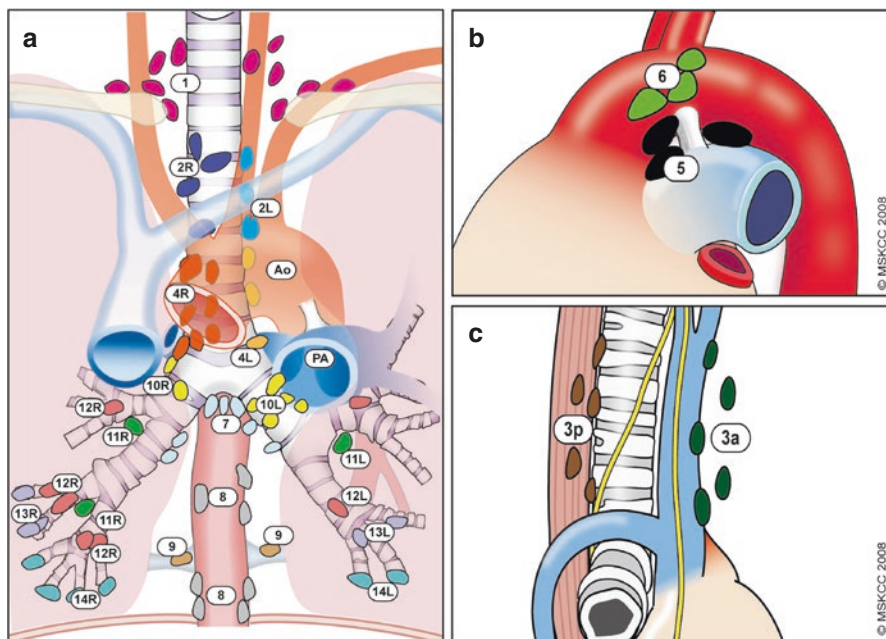
**Table 2.1** Regional nodal stations of lung cancer in IASLC classification system

| Zone                 | Nodal stations and anatomic boundaries                                                                         |
|----------------------|----------------------------------------------------------------------------------------------------------------|
| Supraclavicular zone | <b>#1 low cervical, supraclavicular and sterna notch lymph nodes</b>                                           |
|                      | Upper border: lower margin of cricoid cartilage                                                                |
|                      | Lower border: clavicles bilaterally and in the midline, the upper border of the manubrium                      |
|                      | 1R and 1L, respectively, represent the right and left side of the lymph node                                   |
| Superior mediastinal | The midline of the trachea serves as the border between 1R and 1L                                              |
|                      | <b>#2 Upper paratracheal lymph nodes</b>                                                                       |
|                      | 2R—Upper border: apex of right lung and, in the midline, the upper border of the manubrium                     |
|                      | Lower border: intersection of caudal margin of innominate vein with the trachea                                |
|                      | 2L—Upper border: apex of left lung and, in the midline, the upper border of the manubrium                      |
|                      | Lower border: superior border of the of aortic arch                                                            |
|                      | The left lateral border of the trachea (not the midline of the trachea) serves as the border between 2R and 2L |
|                      | <b>#3 Prevascular and retrotracheal lymph nodes</b>                                                            |
|                      | 3a: Prevascular lymph node                                                                                     |
|                      | Right side                                                                                                     |
|                      | Upper border: apex of lung                                                                                     |
|                      | Lower border: level of tracheal carina                                                                         |
|                      | Anterior border: posterior aspect of sternum                                                                   |
|                      | Posterior border: anterior border of superior vena cava                                                        |
|                      | Left side                                                                                                      |
|                      | Upper border: apex of lung                                                                                     |
|                      | Lower border: level of tracheal carina                                                                         |
|                      | Anterior border: posterior aspect of sternum                                                                   |
|                      | Posterior border: left common carotid artery                                                                   |
|                      | 3p: Retrotracheal lymph node                                                                                   |
|                      | Upper border: apex of lung                                                                                     |
|                      | Lower border: level of tracheal carina                                                                         |
|                      | <b>#4 Lower paratracheal lymph nodes</b>                                                                       |
|                      | 4R: Right paratracheal lymph nodes and pretracheal lymph nodes extending to the left lateral border of trachea |
|                      | Upper border: intersection of caudal margin of innominate vein with the trachea                                |
|                      | Lower border: lower edge of venae azygos                                                                       |
|                      | 4L: Nodes to the left of the left lateral border of the trachea, medial to the ligamentum arteriosum           |
|                      | Upper border: upper margin of aortic arch                                                                      |
|                      | Lower bound: upper rim of left main pulmonary artery                                                           |

**Table 2.1** (continued)

| Zone                         | Nodal stations and anatomic boundaries                                                                                                                            |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Aortopulmonary<br>AP zone    | <b>#5 Subaortic(aortopulmonary window)lymph nodes</b>                                                                                                             |
|                              | Upper border: lower margin of aortic arch                                                                                                                         |
|                              | Lower border: upper rim of left main pulmonary artery                                                                                                             |
|                              | Left border: ligamentum arteriosum                                                                                                                                |
|                              | <b>#6 Paraaortic lymph nodes</b>                                                                                                                                  |
|                              | Anterior and left lateral to the ascending aorta and aortic arch                                                                                                  |
| Inferior<br>mediastinal zone | Upper border: a line tangential to the upper border of the aortic arch                                                                                            |
|                              | Lower border: the lower border of the aortic arch                                                                                                                 |
|                              | <b>#7 Subcarinal lymph nodes</b>                                                                                                                                  |
|                              | Upper border: the tracheal carina                                                                                                                                 |
|                              | Lower border: the upper border of the lower lobe bronchus on the left; the lower border of the bronchus intermedius on the right                                  |
|                              | <b>#8: Subcarinal paraesophageal lymph nodes</b>                                                                                                                  |
|                              | The lymph nodes located below the subcarinal lymph nodes and along the esophagus                                                                                  |
|                              | Upper border: the upper border of the lower lobe bronchus on the left; the lower border of the bronchus intermedius on the right                                  |
|                              | Upper border: the diaphragm                                                                                                                                       |
|                              | <b>#9 Pulmonary ligament lymph nodes</b>                                                                                                                          |
| Hilar and<br>interlobar zone | Lymph nodes within the pulmonary ligament                                                                                                                         |
|                              | Upper border: the inferior pulmonary veins                                                                                                                        |
|                              | Lower: the diaphragm                                                                                                                                              |
|                              | <b>#10 Hilar lymph nodes</b>                                                                                                                                      |
|                              | Lymph nodes immediately adjacent to the mainstem bronchus and hilar vessels (including the proximal segment of the pulmonary veins and the main pulmonary artery) |
|                              | Upper border: the lower rim of the azygos vein on the right; upper rim of the pulmonary artery on the left                                                        |
|                              | Lower border: lobar bronchial opening bilateral                                                                                                                   |
|                              | <b>#11 Interlobar lymph nodes</b>                                                                                                                                 |
|                              | Between the origin of the lobar bronchi                                                                                                                           |
|                              | 11s: between the upper lobe bronchus and bronchus intermedius on the right                                                                                        |
| Peripheral zone              | 11i: between the middle and lower lobe bronchi on the right                                                                                                       |
|                              | <b>#12 Lobar nodes</b>                                                                                                                                            |
|                              | Adjacent to the lobar bronchus                                                                                                                                    |
|                              | <b>#13 Segmental lymph nodes</b>                                                                                                                                  |
|                              | Adjacent to the segmental bronchus                                                                                                                                |
|                              | <b>#14 Subsegmental lymph nodes</b>                                                                                                                               |
|                              | Adjacent to the subsegmental bronchus                                                                                                                             |

(From Rusch VW, et al. (2009) *The IASLC lung cancer staging project: a proposal for a new international lymph node map in the forthcoming seventh edition of the TNM classification for lung cancer. Journal of thoracic oncology: official publication of the International Association for the Study of Lung Cancer* 4 (5):568-577. Reprinted with permission)



**Fig. 2.11** Illustrations of the International Association for the Study of Lung Cancer (IASLC) lymph node map. (a) Distribution of lymph nodes by stations, except stations 3, 5, and 6. (b) The position of stations 5 and 6 lymph nodes. (c) The position of stations 3a and 3p lymph nodes. (From *AJCC/UICC 7th Edition TNM Stage*. Reprinted with permission)

right- and left-sided levels 2 and 4 has been moved leftward to the left lateral wall of the trachea. The midline lymph nodes of a left lung cancer should be designated N3 by current system instead of N2. In contrast, for a right lung cancer, the midline lymph nodes should be classified as N2 by current system instead of N3. (4) The arbitrary designation of the anterior tracheal lymph nodes in the previous AJCC system has been eliminated because these nodes are not reliably distinguishable from levels 2 and 4 and are generally removed en bloc with level 4 during a mediastinal component of systematic nodal dissection from the right. The designation of prevascular and retrotracheal nodes as 3a and 3p has been retained and clarified [5]. (5) The entire subcarinal group of lymph nodes, previously designated as level 7 in the ATS map but levels 7 and 10 in the AJCC map, are now defined as level 7, with clarified anatomic borders. (6) As an anatomical landmark with more imaging and surgical recognition, the lower margin of the azygos vein on the right and the upper rim of the pulmonary artery replaced the pleural fold and became the border between the levels 4 and 10. (7) Similarly, more precise definitions have been made for the designation of level 10 and 11. As a result, levels 10R and 10L are now classified as N2 instead of N1. (8) Certain lymph node stations with similar outcome data are grouped into a zone. The zone concept is valuable for oncologists and radiologists when dealing with large nodal masses that involve multiple nodal stations [5].

Despite that IASLC system has improved the recognition of the scope of involved lymph nodes, uncertainties are not completely eliminated, and some gray areas still remain. In fact, some definitions or pitfalls in current classification system limit the clinical performance, for example, in the context of radiation therapy, as stated below [6]. (1) The relative location variation in lung apex and clavicle probably causes difficulties in determination of levels 1, 2, or 3, resulting in an uncertainty of an N2 or N3 disease; (2) The boundaries between levels 10R and 4R, and 10L and 4L, are ambiguous, likely leading to mistakenly staging N1 or N2 stages, especially when lymph nodes are located in the front of the tracheal bifurcation; (3) The arterial ligament, serving as the boundary of lymph nodes between levels 4L and 5, is not easily visualized on CT images; (4) The extent of level 7 is expanded in both anterior and posterior directions, which requires more practice in accurate recognition; (5) Level 10 extends further medially toward the carina. The implication of this change is that N1 regions extend further than previously. CT-based separation of levels 10 and 11 can be challenging.

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## Suggested Readings

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