Chapter 1

Anatomical Considerations

A firm knowledge and understanding of airways anatomy is mandatory to understand the virtual bronchoscopic features of tracheobronchial diseases as it permits a better understanding of the features of the disease (appearance pattern), and the specific distribution of the disease (distribution pattern).

Anatomic Organization of the Tracheobronchial Tree

The tracheobronchial tree is a branched distribution system that carries air from the trachea down to the acini, the functioning unit of gas exchange. The trachea divides into main bronchi that divide into lobar bronchi. The lobar bronchi divide into segmental bronchi that in turn divide into subsegmental bronchi which divide into several generations of smaller bronchi until finally the terminal bronchi are reached. These terminal bronchi divide into bronchioles that differ from the bronchi in lacking cartilage and glands in their walls; whereas the bronchi contain \( (Verschakelen\ and\ De\ Wever\ 2007)\).

- **Trachea and Main stem Bronchi**

  The trachea is a cartilaginous and membranous tube which is continuous with the larynx at the level of the cricoid cartilage (Figure.1). Its uppermost portion is located at the level of the sixth or seventh cervical vertebrae in the neck, while its lower end lies at the level of the fourth or fifth thoracic vertebrae in the chest. \( (Drevet\ et\ al.,\ 2016)\).
The trachea is located in the midline position, but can be deviated to the right at the level of the aortic arch, with a greater degree of displacement in case of atherosclerotic aorta, advanced age or in the presence of severe chronic obstruction pulmonary disease (Minnich and Mathisen 2007).

The normal adult tracheal length ranges from 10–13 cm (longer in men than in women) with approximately 5 cm lying superior to the suprasternal notch (Drevet et al., 2016).

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**Fig. 1. Principal features of the larynx and trachea. Anterior view. LMB, left main bronchus; RMB, right main bronchus. (Minnich and Mathisen 2007)**
The trachea is divided into extrathoracic and intrathoracic portions; the intrathoracic trachea starts at the point at which trachea passes posterior to the manubrium sterni. The extrathoracic trachea measured 2 to 4 cm in length, whereas the intrathoracic trachea measured 6 to 9 cm in length (Naidich et al., 2007).

Trachea is composed of 16 to 22 C-shaped cartilaginous rings that form the anterior and lateral walls and incomplete posteriorly that help to support the tracheal wall and to maintain an adequate tracheal lumen during forced expiration. The posterior portion of the tracheal wall, lying between the two open ends of the tracheal cartilages, is a thin fibromuscular membrane termed the posterior tracheal membrane. (Zwischenberger and Sankar 1995 & Minnich and Mathisen 2007).

The cross-sectional appearance of the tracheal lumen may appear rounded, oval, or horseshoe shaped. The posterior tracheal membrane may appear convex posteriorly, flat, or convex anteriorly (Figure 2) (Finkelstein et al. 2003). In children, the tracheal lumen is nearly circular; with growth, the adult configuration with an ovoid shape emerges. The circular lumen may persist as a normal variant (Minnich and Mathisen 2007).

The diameter of the trachea vary widely in anatomically normal persons. The external diameters of the trachea measure approximately 23 mm coronally and 18 mm sagitally in men. In women, tracheal diameter is slightly less, averaging 20 mm in the coronal plane and 14 mm in the sagittal plane. The tracheal wall is about 3 mm in thickness (Bretnach et al., 1984 & Minnich and Mathisen 2007).
The tracheal luminal diameter changes dynamically with changes in intraluminal pressure, from cough, respiration, or ventilation. The trachealis muscle of the posterior wall pulls the edges of the cartilaginous rings toward each other during coughing. With aging or chronic obstructive pulmonary disease, the lateral diameter of the trachea may decrease with an increase in the anteroposterior diameter, a condition known as saber sheath trachea. Chronic obstructive pulmonary disease may also result in softening of the tracheal rings with a decrease in the anteroposterior diameter of the trachea (*Minnich and Mathisen 2007*).

The trachea bifurcates at the carina into the right and left mainstem bronchus at the level of the sternal angle anteriorly and the 5th thoracic vertebra posteriorly (Figure 3). The tracheal lumen narrows slightly as it progresses towards the carina. The right mainstem bronchus lies in a more vertical orientation relative to the trachea, whereas the left mainstem bronchus lies in a more horizontal plane (*Campos 2009*).
The right main bronchus is relatively short, usually about 1.1 cm, compared with 5 cm for the left main bronchus (Olivier et al., 2006).

The angle of the tracheal bifurcation, the carinal angle, can vary widely even in normal individuals. The carinal angle may be wider in individuals with large left atrium, in females, in obese patients, and in people were the carina located closer to the spine (Karabulut 2005).

Fig. 3: Virtual bronchoscopy. Three-dimensional volume-rendered endoscopic view from submillimeter collimation CT axial acquisition. The white arrows inside the inset coronal images indicate orientation of field of view, and is reflected by the white dot. (A) At the carina the dot points into the bronchus intermedius; black arrowheads at the RUL bronchus origin; and the black arrows within the left main stem. (B) The dot is at the RUL segmental division. In this orientation, long white arrows outline the apical bronchus, small white arrows at the posterior bronchus, and small white arrowheads at the anterior segmental bronchus (Ugalde et al., 2007).
● Lobar and Segmental Bronchi

The bronchi are composed of both cartilaginous and fibromuscular elements, similar to the trachea, but the distinction between those parts of the bronchial lumen that are supported by cartilage and those that are not is less clear cut than in the trachea. For a short distance, the main bronchi contain horseshoe-shaped cartilage plates, as does the trachea, but the cartilage plates become less regularly shaped at more peripheral levels (Naidich et al., 2007).

There is considerable anatomic variation in the pattern of bronchial branching, especially in the subsegmental airways. Variations also involve the lobar and segmental airways to a lesser degree. Despite these anatomic variations, the anatomic location of the bronchopulmonary segments is relatively consistent (Parker 2012).

Each bronchopulmonary segment takes its name from the segmental bronchus supplying it (Figure 4). There are ten segmental bronchi on the right side and eight on the left. The left lung has two segments fewer than the right because the apical and posterior bronchi have a common stem and the medial basal bronchus is usually lacking (Minnich and Mathisen 2007).
Fig. 4: Diagram of normal airway anatomy, frontal view. The basilar segmental bronchi are oriented from lateral to medial. The anterior basilar segmental bronchus is most lateral, and the posterior basilar segmental bronchus is medial, just lateral to the right medial basilar segmental bronchus. Climbing the diaphragm from lateral to medial can be thought of as climbing the ALPs (Anterior, Lateral, and Posterior basilar segmental bronchi), as a way to remember this orientation. RUL, right upper lobe; RML, right medial lobe; RLL, right lower lobe; LUL, left upper lobe, LLL, left lower lobe (Collins and Stern 2008).
● **Right-Sided Bronchial Anatomy**  
(Adapted from Parker 2012 & Savithri et al., 2015)

**Right principal bronchus**
Right principal bronchus arises from the trachea and give rise to right superior lobar bronchus and bronchus intermedius which gives rise to both right middle lobar bronchus and right inferior lobar bronchus.

**Right upper lobe bronchus**
The right upper lobe bronchus arises from the lateral wall of the right main bronchus about two centimeters below the carina, then it divides into three segmental branches, the anterior, posterior, and apical divisions after one centimeter from its origin. The upper lobe bronchus or one of its segmental divisions may originate directly from the lateral wall of the trachea, forming an anatomic variant that called the “tracheal bronchus”.

**Bronchus intermedius**
The bronchus intermedius extends 3–4 cm distally from the right upper lobe bronchus origin, and then bifurcates to supply both the middle and right lower lobes.

**Right middle lobar bronchus**
The middle lobe bronchus extends 1–2 cm before bifurcating into lateral and medial segmental divisions.

**Right lower lobar bronchus**
The right lower lobe has five segmental branches. The superior segment is the first branch that arises from the posterior wall of the lower lobe bronchus just beyond its origin, then the four basal branches sequentially arise, lateral to medial in the following order: anterior, lateral, posterior, and medial.
Left-Sided Bronchial Anatomy
(Adapted from Parker 2012 & Savithri et al., 2015)

Left principal bronchus

The left principal bronchus arises from the trachea and divides into superior lobar and inferior lobar bronchus.

Left superior lobar bronchus

The left upper lobe bronchus arises from the anterolateral wall of the left main bronchus and then either bifurcates or, less frequently, trifurcates to supply the upper lobe and lingula. In the bifurcation pattern, the upper division immediately divides into anterior and apical posterior segments. The lower division (lingular bronchus) then bifurcating into superior and inferior segmental branches.

In case of trifurcation pattern, the apical posterior, anterior, and lingular bronchi originate simultaneously from the upper lobe bronchus to supply their respective segments.

Left inferior lobar bronchus

The left lower lobe has four segmental divisions. These divisions are similar in name and anatomic distribution as the segmental divisions of the right lower lobe (superior, lateral and posterior), the only difference is the absence of a separate medial basal bronchus, as the anterior and medial portions of the left lower lobe are supplied by a single, combined anteromedial basal segmental bronchus.
Anatomical Variants

Tracheobronchial variations can be discovered during routine bronchoscopy or computed tomography with estimated incidence of 1–12%; these variations are often asymptomatic. Symptomatic patients present typically with cough and lower respiratory tract infection. Knowledge and understanding of tracheobronchial variations have important implications for diagnosis of symptomatic patients and performing certain procedures, including bronchoscopy (*Wooten et al., 2014*).

● Tracheal bronchus

Tracheal bronchus (Figure 5) is a collection of bronchial variations originating from either the trachea or a main bronchus that are directed to the upper lobe of the lung with a prevalence of 0.1–2% (*Berrocal et al., 2004*).

Tracheal bronchi are classified into four groups based on their morphologic pattern: displaced (Figure 6), rudimentary, supernumerary, and anomalous right upper lobe bronchus (*Shepard and Weber, 2004*).
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True tracheal bronchus (Figure 7) which is commonly referred to as “Bronchus suis” or “pig bronchus”, due to its frequent occurrence in several animal species, occurred when the entire right upper lobe bronchus is displaced onto the trachea (Kairamkonda et al., 2003).

Tracheal bronchus may be associated with other congenital abnormalities of the tracheobronchial tree such as: tracheoesophageal fistula, tracheal stenosis, and bronchostenosis. It is also often associated with cardiac congenital anomalies such as tetralogy of Fallot or ventricular septal defects (Ming and Lin 2007).
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- **Accessory cardiac bronchus**

The accessory cardiac bronchus (Figure 8) may originate from the right main bronchus, but the majority originate from the intermediate bronchus with incidence ranges from 0.09 to 0.5% in the general population and up to 16% when associated with other major bronchial variations (Yildiz et al., 2006).

![Virtual bronchoscopy view of accessory cardiac bronchus in 54-year-old man](image)

**Fig. 8: Virtual bronchoscopy view of accessory cardiac bronchus in 54-year-old man (Kivrak et al., 2013)**

The term “cardiac” bronchus stems from the fact that the bronchus points toward the mediastinum and progresses parallel to the intermediate bronchus toward the pericardium. Accessory cardiac bronchi may be short or long with terminal sprigs (Figure 9) (Wooten et al., 2014).
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Fig 9: Accessory Cardiac Bronchus types  The short type is a blind-ending diverticulum that takes the form of a simple bronchial stump devoid of alveolar tissue. The long type is a branching structure that occasionally contains alveolar tissue (Wooten et al., 2014).

- Tracheal diverticulum

The tracheal diverticulum (Figure.10,11) is a benign entity characterized by single or multiple outpouchings of the tracheal wall, that can be either congenital or acquired, with an overall prevalence about 1% (Sato et al., 2010 & Soto-Hurtado et al., 2006).

Typically, the congenital tracheal diverticulum is small and located approximately 4–5 cm below the vocal cords or a few centimeters above the carina on the right lateral surface of the trachea (Desir and Ghaye, 2009).

In contrast, acquired tracheal diverticula appear laterally between the cartilaginous rings or posterolaterally through the trachealis muscle (Restrepo et al., 2004).
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Fig 10: 65-year old male patient with right-sided tracheal diverticulum. (a) Diverticulum opening in posterolateral tracheal wall, virtual bronchoscopic view, *main carina. (b) axial and (c) coronal section of thorax CT. Arrow: the hole in the postero-lateral wall of trachea (Elicora et al., 2012)

Fig. 11: Congenital and acquired tracheal diverticulum (Wooten et al., 2014).
Bridging bronchus

The bridging bronchus (Figure 12, 13) is an airway malformation where the right middle and lower lobes are supplied by an aberrant bronchus originating in the left main-stem bronchus and crossing over the mediastinum (Baden et al., 2008).

Two subtypes of the bridging bronchus have been defined. The first one has a normal trachea bifurcating into the right main bronchus and left main bronchus at the fourth and fifth thoracic vertebrae, then the bridging bronchus originates at the sixth and seventh thoracic vertebrae on the left main bronchus and supplies the right middle and right lower lobes (Wooten et al., 2014).

In the second subtype, the right main bronchus is either absent or seen as a short tracheal diverticulum, but similar to the first subtype, the second subtype has the bridging bronchus originating between the sixth and seventh vertebrae. Patients with the second subtype usually have hypoplastic lungs (Baden et al., 2008).

Fig. 12: virtual bronchoscopic view from the distal trachea showing the bifurcation (BF), right upper lobe (RL) and left main bronchus. The pseudocarina (PC) is at the bottom of the left MB with originating bridging bronchus (BB) (Baden et al., 2008).
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Fig. 13: Bridging Bronchus. Subtype 1: Normal trachea bifurcating into the right main bronchus and left main bronchus at the fourth and fifth thoracic vertebrae, the bridging bronchus arises at the sixth and seventh thoracic vertebrae on the left main bronchus and supplies the right middle and right lower lobes. Subtype 2: The right main bronchus may be absent or seen as a short tracheal diverticulum, the bridging bronchus originates between the sixth and seventh vertebrae, patients with that subtype usually have hypoplastic lungs (Wooten et al., 2014).

- **Bronchial isomerism**

  Isomerism is a disorder of laterality (Figure 13, 14), right bronchial isomerism is defined by two trilobed lungs with two short main bronchi, whereas a left bronchial isomerism is defined by two bilobed lungs with two long main bronchi (Bush, 1999).
Fig. 14: Right bronchial isomerism in a 4-month-old female infant with double outlet ventricle. (a) On a contrast material–enhanced three-dimensional (3D) reconstructed CT image of the tracheobronchial tree, the left bronchial tree has the same morphologic features as the right bronchial tree, with the early rise of the ULB at a distance from the MLB. LLB = lower lobe bronchus, RLLB = right lower lobe bronchus, RULB = right ULB. (b) On a 3D reconstructed CT image of the tracheobronchial tree and pulmonary arteries, both ULBs are eparterial, since they originate behind the ipsilateral pulmonary arteries. These findings are consistent with right bronchial isomerism. (Chassagnon et al., 2016).

Fig. 15: Left bronchial isomerism in an asymptomatic 61-year-old man. LULB = left ULB. (a) Contrast-enhanced 3D reconstructed CT image of the tracheobronchial tree shows that, similar to the left ULB, B4 and B5 on the right side arise with the ULB. (b) Superimposed 3D reconstructed CT images of the tracheobronchial tree and pulmonary arteries show that both ULBs are hyparterial, since they arise below the crossing of the ipsilateral pulmonary artery and main bronchi. These findings are consistent with left bronchial isomerism. (Chassagnon et al., 2016).