Lower Airway Anatomy

4

Colin Wallis

Introduction

A detailed and intimate knowledge of the normal anatomy of the paediatric airway is essential for any bronchoscopist undertaking studies in children. There are important anatomical differences that occur with growth and normal variants need to be recognized.

In the previous section the upper airways (from the nasal entrance to the subglottic area) were described. Here we review the paediatric airway below the cricoid bone.

Familiarity of this anatomy comes from repeated examinations of the airway, preferably adopting the same "route" on each evaluation, and recognizing landmark configurations for orientation. The trachea and carina are the most obvious example. Return to these recognizable points when lost or confused. In this way, recognition of the normal anatomy becomes intuitive and with this comfortable familiarity comes the ready recognition of normal variants and pathological changes.

In this chapter's description of the lower airway anatomy, it is anticipated that the bronchoscopist is standing at the child's head and facing down the bronchial tree with the patient's right side on the right of the bronchoscopist. The lower airways are then traditionally divided into the extrathoracic trachea, the intrathoracic trachea and carina, the main right and left bronchi, the lobar bronchi and their subsequent divisions. A competent paediatric bronchoscopists should have a ready recognition of this normal anatomy down to these lobar subdivisions.

The Normal Trachea and Carina

The normal trachea is instantly recognizable by the anterior cartilaginous rings with an absent section posteriorly that is bridged by a softer pars membrana (membranous trachea) consisting of the trachealis muscle. In the newborn child and infant the rings can have a wider gap across their posterior section. With growth the rings adopt a more C-shaped appearance and in the older child the arc will extend to nearly 320 degrees. Adolescent females tend to preserve a round configuration, while males tend to have some sagittal widening and transverse narrowing.

The ends of the tracheal cartilage "rings" should not meet. Completely fused rings or nearly fused rings are not a normal variant.

The normal tracheal lumen is unobstructed and viewed bronchoscopically as straight without branches. Pulsation of the large vessels and right atrium which normally abut on the trachea and main bronchi may cause pulsatile deflections through the wall around the level of the

C. Wallis (✉)
Great Ormond Street Hospital for Children and The Institute of Child Health, UCL, London, UK
e-mail: colin.wallis@gosh.nhs.uk

carina but the lumen should not obstruct or permanently distort in the normal subject. The airway should maintain its integrity during quiet breathing with some narrowing of the cross-sectional area due to inward bulging of the membranous trachea. With coughing, especially in the younger child, there can be significant inward bulging of the trachealis and sometimes some loss of integrity of the cartilaginous component. Arbitrarily, a loss of internal shape to approximately 50% is considered within the normal range. Abnormal malacia may be masked by rigid instrumentation, positive pressure ventilation or heavy sedation and anaesthesia.

The normal trachea has sparse secretions that are clear, light and frothy and are easily suctioned away. Careful observation of these bubbles can reveal movement of the bubbles toward the larynx, indicating normal ciliary functioning. The mucosa is smooth throughout. The trachea consists of between 18 and 22 rings and enlarges in length and width with somatic growth. Like the larynx, the trachea is situated higher in infants with the upper extrathoracic section at the level of the fourth cervical vertebra. In adults the upper level descends to C6–C7.

Contrary to the numerous variations of lobar or segmental bronchial subdivisions, abnormal bronchi arising from the trachea or main bronchi are rare. A true tracheal bronchus is any bronchus originating from the trachea, usually within 2–6 cm of the carina. The finding of a tracheal bronchus supplying, most commonly, the right upper lobe is a common association with distal complete rings or abnormal pulmonary artery slings and thus not considered a normal variant. When the entire right upper lobe bronchus is displaced onto the tracheal bronchus, it is also called a "pig bronchus" and has a reported frequency of 0.2%. A prevalence of 0.1–2% for a right tracheal bronchus and 0.3–1% for a left tracheal bronchus has been found in bronchographic and bronchoscopic studies.

The tracheal carina is a key landmark on the bronchoscopist's journey through the paediatric airway and should be instantly recognizable and a point of reference at times of disorientation. It is a keel-shaped structure with a characteristic cartilaginous ring arrangement. (Fig. 4.1a). The angle of the carina is more obtuse in infancy and early childhood. In the first two years of life the carina is situated on the right of the mid line and successively becomes more medial. The carina adopts a more acute angle in adolescence and adulthood. This blunted appearance of the main carina in paediatric bronchoscopy examinations is true of many of the other airway bifurcations.

The Bronchial Tree

The carina is a valuable anatomical landmark and the point of division into the left and right-sided bronchial tree. Subsequent branching of the primary bronchial tree is remarkably consistent in humans although normal variants do occur at the subsegmental level, especially in the lower lobes.

A full examination of the bronchial tree should be completed in all procedures if possible and should preferably follow a systematic route. A suggested examination is described next.

The right lung bronchial anatomy

(i) On reaching the carina, the aperture of the right main bronchus (RMB) comes into clear view on the right and the scope should naturally enter. In newborns the right main stem bronchus is four times shorter than the left; at three years of age it is one-third and in adolescents it is half the length of the left main bronchus.

(ii) Shortly after entering the RMB the bronchus intermedius will be visible (Fig. 4.1b) and a turn of the bronchoscope tip towards the right side will bring the right upper lobe (RUL) orifice into clarity with its trifurcation into an apical, posterior and anterior divisions. These orifices should be widely patent. If the tip of the scope has remained in the correct orientation, the corresponding lobes should be arranged as per the image in Fig. 4.1c.

(iii) Withdrawing the scope, you enter the right bronchus intermedius. Two orifices will be noted. They are the right middle lobe (RML) anteriorly, and the right lower lobe
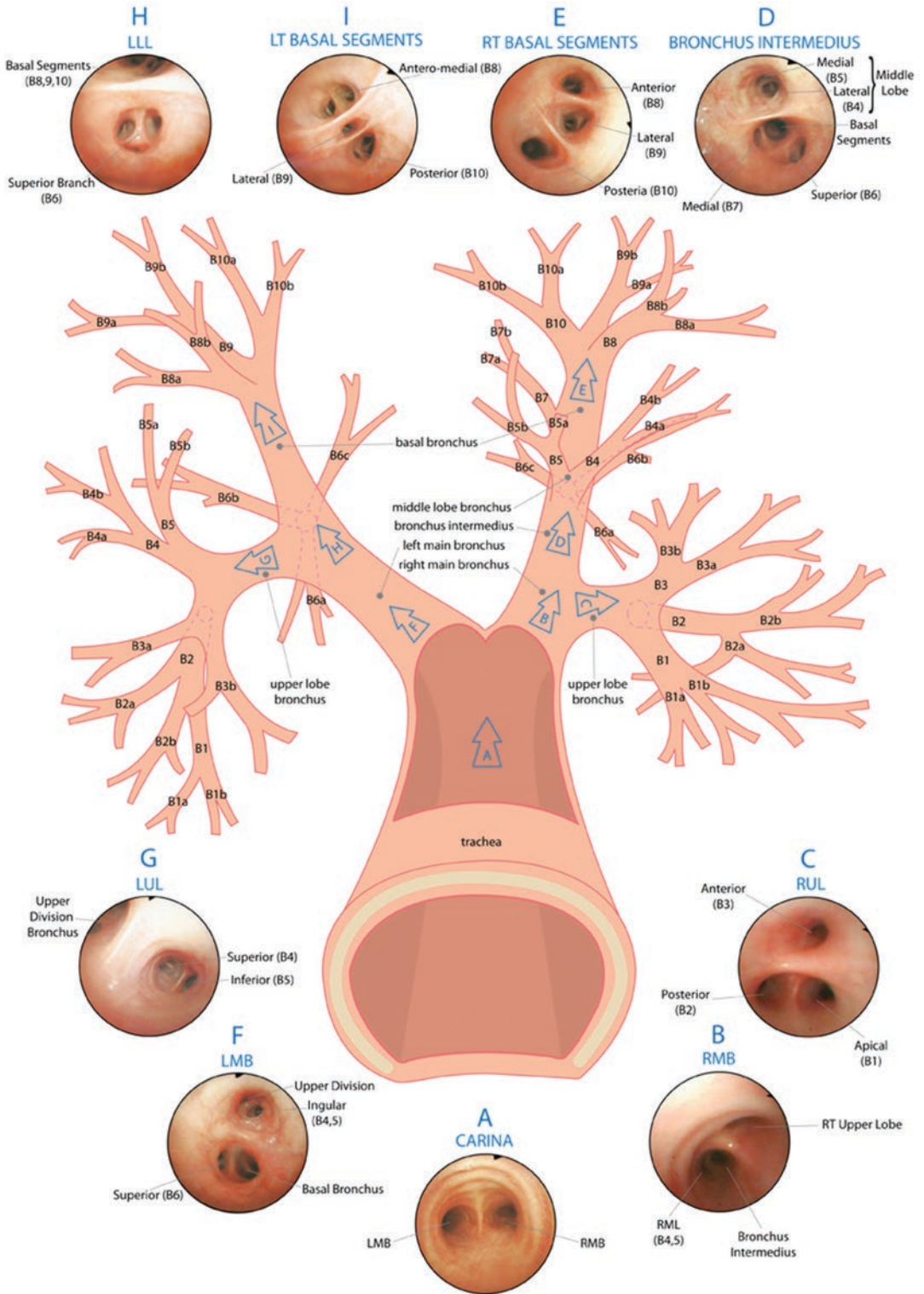
Fig. 4.1 The normal bronchial tree from the bronchoscopist's perspective. (Reproduced with permission from Wallis C. Paediatric Bronchoscopy. S. Karger AG, Basel 2010)

beneath the carinal division with observation of its early subdivisions (see v).

(iv) The RML is now entered to reveal its bifurcation into the medial and lateral segments each with their bifurcations.

(v) Withdraw the scope again and advance towards the RLL. The medial basal segment will branch off first along the medial side and the superior segment of the right lower lobe will appear on the opposite wall (Fig. 4.1d). Both these bronchi should be inspected at this stage.

(vi) At the distal end of the right bronchial tree you will see the anterior, lateral and posterior basal segments clustered together with a characteristic carinal pattern and known by this author as "the three musketeers" (Fig. 4.1e). Recognition of this cluster of bronchi is another useful anatomical landmark.

(vii) Return to the carina. If you did not evaluate the superior segment bronchus at step v, take the opportunity as you withdraw to do so now.

Left lung bronchial anatomy

(viii) From a position just above the carina, the opening of the left main bronchus (LMB) appears slightly smaller than the right and may not be seen "end on". The left main bronchus is longer than the right and, importantly, the upper division branching off to the left has a less acute angle (Fig. 4.1f) than you found for the RUL.

(ix) The upper division of the LUL commonly bifurcates into an apicoposterior and anterior segmental bronchus. Trifurcation at this point can be a normal variant.

(x) Withdraw the scope and enter the lingular segment of the LUL with its division into a superior and inferior branches. Practice will help distinguish the characteristic anatomy of the lingula segment from its neighbouring LUL (Fig. 4.1g).

(xi) Withdraw the scope and direct the tip towards the left lower lobe (LLL) bronchus. The superior segment of the LLL branches off postero-laterally and can be missed if proceeding too quickly (Fig. 4.1f). Distal to the opening of the superior segment, the three basal segments of the left lower lobe will be noted: the antero-medial, lateral, and posterior – in order and as illustrated in Fig. 4.1i. Individual bronchial openings for the antero-medial basal segment rather than a joint origin is a common normal variant.

(xii) Careful withdrawal of the bronchoscope back to the cricoid provides the opportunity to observe the dynamics of the airway if the patient is free breathing, and completes the inspection of the normal anatomy of the lower airways.

Normal Variants

There are a number of uncommon branching patterns that are considered normal variants. The principle of what constitutes a normal branching variant is that the bronchus should provide unobstructed airflow in inspiration and expiration to and from a normal lung structure distally and with congruous blood supply and free mucociliary clearance of secretions into the proximal airway. A normal variant will always be asymptomatic and discovered incidentally. Anatomical variations are most commonly seen in the left upper lobe and in the arrangements of the basal bronchi in the lower lobes. Examples are listed in Table 4.1.

One variant that may not necessarily be normal as per the definition above but is occasionally reported is the accessory cardiac bronchus. An accessory cardiac bronchus is a supernumerary bronchus from the inner wall of the right main bronchus or intermediate bronchus that progresses toward the pericardium (frequency 0.08%). Most accessory cardiac bronchi have a blind extremity, but imaging and anatomical studies have demonstrated that some develop into a series of small bronchioles, which may end in vestigial or rudimentary parenchymal tissue or even a ventilated lobule.

Table 4.1 Bronchial nomenclature

Anatomical nomenclature	Numbering system	Further subdivision	Common variations
Right upper lobe			
Apical	B^1	a and b	May be absent or arise from B2 or B3
Posterior	B^2	a and b	Numbering swapped around in Boyden system
Anterior	B^3	a and b	
Right middle lobe			
Lateral	B^4	a and b	May have a superior/inferior division similar to the lingula
Medial	B^5	a and b	
Right lower lobe			
Superior (apical)	B^6	a, b and c	
Medial basal	B^7	a and b	Occasionally there is an additional accessory cardiac branch
Anterior basal	B^8	a and b	The basal bronchi are the most variable divisions of the right lung
Lateral basal	B^9	a and b	
Posterior basal	B^{10}	a, b and c	
Left upper lobe			
Apicoposterior	B^{1+2}	a, b and c	May have a separate carina B^1, B^2
Anterior	B^3	a, b and c	
Superior lingular	B^4	a and b	
Inferior lingular	B^5	a and b	
Left lower lobe			
Superior (apical)	B^6	a, b and c	
Antero-medial basal	B^8	a and b	May have an additional medial bronchus B^7 with a separate anterior branch B^8
Lateral basal	B^9	a and b	
Posterior basal	B^{10}	a and b	May trifurcate into a, b, and c

Note: the Boyden surgical anatomical focus refers to the anterior and posterior segments of the upper lobe as B2 and B3. This nomenclature is not used by many bronchoscopists who prefer the Japanese system of Yamashita using anterior as B3 and posterior as B2

Bronchial Nomenclature

Standardisation of bronchial nomenclature has always been contentious. The lobar and segmental labelling used in this chapter, adopts the recommendations of a consensus meeting at a congress of anatomists in the 1950's. Inevitably it was not universally accepted and led to vigorous debate and correspondence. Although the descriptive terms I use above in describing the normal anatomy are widely used by paediatric bronchoscopists, alternative nomenclature still occurs. The term "apical" is often used interchangeably for the superior segment of the lower lobes. Similarly the term "dorsal" may be substituted for "posterior". Occasionally the lower lobe will be referenced as the inferior lobe.

In addition to the descriptive terms above, anatomists and radiologists have also devised a numbering system for the bronchial tree. This allows for detailed isolation of specific subdivisions beyond the primary nomenclature. Rather redundantly and perhaps confusingly, the letter B is used on each occasion. For example the apical segment of the upper lobe is labeled B1 and subsequent bifurcations are then given the label B1a and B1b with the facility for still further subdivision. Trifurcations, such as commonly occur in the antero-medial branch of the LLL or the posterior basal branches, are labeled a, b, and c. Clearly this has advantage in disciplines such as adult oncology, where there is a need for precise small tumour localisation in the lung. In practice, the majority of paediatric bronchoscopy procedures rarely need identifi-
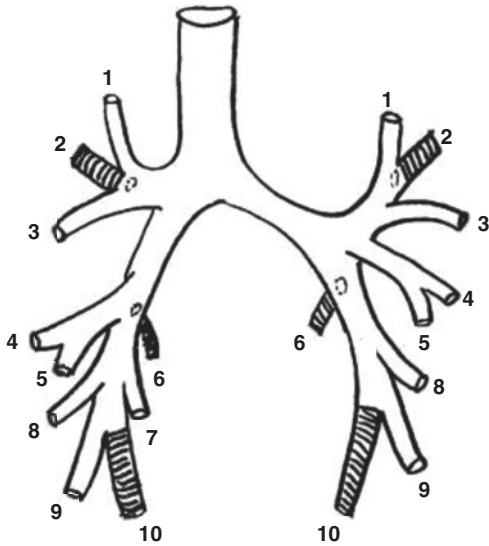
	RIGHT		LEFT
1	Apical	1	apicoposterior
2	Posterior	2	
3	Anterior	3	Anterior
4	Lateral	4	Superior lingula
5	Medial	5	Inferior lingula
6	Superior	6	Superior
7	Medial basal	7	Generally absent
8	Anterior basal	8	Anterio-medial basal
9	Lateral basal	9	Lateral basal
10	Posterior basal	10	Posterior basal

Fig. 4.2 A schematic traditional diagram of bronchial anatomy indicating the numbering and nomenclature. The illustrated shaded bronchi travel in a posterior (dorsal) direction

cation beyond the anatomical descriptive nomenclature. For clarification, both systems are presented in Table 4.1 and in Fig. 4.2.

Bibliography

1. Ghaye B, Szapiro D, Fanchamps J-M, Dondelinger RF. Congenital bronchial abnormalities revisited. Radiographics. 2001;21:105–19.
2. Boyden EA, Clark SL, Danforth CH, Greulich WW, Corner GW. Science. 1942;96(2483):116.
3. Boyden EA. Segmental anatomy of the lungs. New York/Toronto/London: Graw-Hill; 1955.
4. Jackson CL, Huber JF. Correlated anatomy of the bronchial tree and lungs with a system of nomenclature. Dis Chest. 1943;9(4):319–26.
5. Jafek BW, Carter DR. Endoscopic nomenclature for bronchopulmonary anatomy. Otolaryngol Head Neck Surg. 1979;87(6):815–7.
6. Yamashita H. Roentgenologic anatomy of the lung 1st ed. 1978 Igaku-Shoin. Tokyo, Japan [Stuttgart, Germany]: Thieme; 1978.