

Lung anatomy

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Lung anatomy¹

THE thoracic anaesthetists' interest in anatomy relates mainly to thoracic epidurals, bronchoscopy and tube positioning. While epidural anatomy is well catered for (see Section ??), copies of the primary texts on the relevant lung anatomy (Brock 1942–1944, Brock 1954, Boyden 1955, Hollinger and Johnston 1957, Kavuru and Mehta 2004) are difficult to find.² I am pleased, therefore, to be able to include (with permission) some diagrams and plates from Brock³ (1942–1944, 1954), which contain quite the best lung anatomy diagrams for thoracic anaesthetists that I have found so far, not withstanding the excellent diagrams in Kavuru and Mehta (2004). See also references to the anatomy of the epidural space (Section ??), radial artery (Section ??), central veins (Section ??), and bronchoscopic anatomy (Chapter ??). Other useful texts are Burwell and Jones (1996), Ellis *et al.* (2004), Itoh *et al.* (2004), Minnich and Mathisen (2007), Deslauriers (2007).

4.1 Anatomical terms⁴

Alveolus (Gk): Diminutive of *alveus* (cavity) → *alveolus* (small cavity).

Azygos (Gk): *a* (without) + *zugon* (yoke) → *azygos* (not yoked), i.e., not a paired structure. A non-paired body part, especially a vein.

Azygos vein: A vein of the right superior thorax draining into the superior vena cava.

Azygos lobe: A lung zone separated by an indentation (typically from above down) formed by an azygos vein and its superior mesentery ('meso-azygos'). The so-called 'azygos lobe' is not a true lobe (it does not have a constant bronchus and vessels). First described by HA

¹<http://www.nickalls.org/dick/papers/thoracic/hand-anatomy.pdf>

²Copies are available in the British Library, London.

³Lord RC Brock; thoracic surgeon at Guy's Hospital, London.

⁴Modified from: *The New Sh. Oxf. Eng. Dict.* (1993); Jaeger EC and Page IH (1953), *A source-book of medical terms* (CC Thomas, Springfield, Illinois, USA); Field EJ and Harrison RJ (1968), *Anatomical terms: their origin and derivation*, 3rd ed. (W Heffer & Sons, Cambridge, UK.)

Wrisberg (1737–1808) in 1778—hence the ‘lobule of Wrisberg’ (Brock 1954, p. 216).

Bougie (Fr): *bougie* (candle).

Bronchus (Gk): *brogkhos, bronchos* (windpipe).

Bulla (L): *bulla* (bubble-like).

Carina (L): *carina* (keel of a boat); *carinatus* (keel-like). The last ring of the trachea has a keel-like inferior projection carried back in the fork between the major bronchi.

Chyle (Gk): *chyl* (juice).

Clavicle (Gk): *kleis* (a key). (L): *clavis*; dim. *clavicular* (a bar for closing a window). Some suggest it is named from the Greek owing to its fancied resemblance to a key. However, it is most likely derived from the Latin because it resembles a curved window fastener, and joins or “locks the shoulder girdle to the body.” The Roman *clavis* was also an S-shaped metal bar used to strike bells.

Costal (L): *costa* (rib).

Cricoid (Gk): *krikos* (a ring). The shape of the cricoid cartilage is like a signet-ring.

Diaphragm (Gk): *dia* (through, across) + *phragma* (fence).

Effusion (L): *effundere* (pour out); *effusus* is past participle of *effundere*.

Empyema (Gk): *empyesis* (suppuration), *empyematos* (abscess).

Fissure (L): *fissus* (split, cloven).

Hiatus (L): *hiatus* (a gap).

Hilum (L): *hilum* (a trifle, a small thing). Point of attachment; point where an organ is attached by vessels & nerves.

Lingula (L): *lingere* (to lick); *lingula* (tongue-like). Part of the left upper lobe (equivalent to the right middle lobe), consisting of superior and inferior segments supplied via the lingula bronchus. It is occasionally separated by a partial fissure from the rest of the upper lobe. The following is from Brock (1954, p. 82).

The term “lingula” really refers to the tip or tongue-like projection of the lowest and most anterior part of the left upper lobe, but it is justifiable to make use of the name to describe the whole portion of which the lingula is really but a part. . . . Its chief practical importance lies in the frequency of which it is involved by bronchiectasis in common with the left lower lobe.

Lung (Anglo-Saxon): *lungen* (light). The lungs were originally known as ‘lights’ because they were so light in weight.

Manubrium (L): *manubrium* (a handle). The *manubrium sterni* is shaped like the handle of a sword.

Mediastinum (L): Probably from *per medium tensum* (that which is tight down the middle); hence between the two lungs.

Oesophagus (L): *-phagos* (eating) → *ysophagus*. From the Greek *oisophagos* (gullet).

Pharynx, pharyngeal (Gk): *pharyngos* (throat).

Phrenic (Gk): *phren* (the mind). Taken to mean the seat of emotion around the heart, hence associated with the diaphragm.

Pleura (Gk): *pleura* (side, rib).

Sternum (Gk): *sternon* (the male breast).

Stomach (Fr): *estomac, stomaque*; (L) *stomachus*; (Gk) *stomakhos*.

Thorax (Gk): *thorax, thorakos* (the chest).

Thymus (Gk): *thymos* (thyme; an aromatic herb). The thymus gland is so named owing to a resemblance to a bunch of thyme.

Throid (Gk): *thyra* (a door) → *thyreos* (shield with a notch for the chin). Apparently the name ‘thyroid’ was introduced in 1646 by Thomas Wharton (1616–1673), English anatomist and physician at St. Thomas’ Hospital, London.

Trachea (L): *trachia* (rough). (Gk): *trachys*. Also: *Aspera arteria* (air conduit).

Vertebra (L): *vertebra* (a joint). From *verto* (I turn).

4.2 History of lung anatomy⁵

Lung anatomy was initially investigated using the process of injecting coloured wax into the bronchi and vessels—a technique largely developed by Jan Swammerdam⁶ (1637–1680). Two types of wax models were developed: the so-called ‘wax corrosion’ cast, and the later wax-injected dried dissections; details of these techniques were often included in early anatomy books.⁷ A fine example of an early wax corrosion cast in a glass bell-jar is shown in the portrait of William Hunter (1718–1783) at the Royal College of Surgeons, London (Tompsett, 1965).

The process of establishing the true basic anatomy of the lung was very slow, the first serious attempt to describe the anatomy in any useful detail being that by the famous Swiss anatomist Christoph Theodor Aeby (1835–1885). However, the models he worked from were poor and he made significant errors—based on comparative anatomy—which were perpetuated through his writings (Aeby 1880). Fortunately, these errors were soon revealed⁸ by the pathologist William Ewart, whose careful work led to the modern concept of the bronchopulmonary segment.

4.2.1 Bronchopulmonary segment

William Ewart (1848–1929) was a pathologist at the Brompton Hospital, London, and is generally regarded as the ‘father of segmental anatomy’ (Tompsett, 1965). Ewart was uneasy about the somewhat casual approach to lung anatomy, as he tells us in his treatise (Ewart 1889):

Moreover, a suspicion had arisen in my mind that the present deficiencies in our anatomical knowledge . . . might perhaps be held responsible for the halting . . . in the development of Pulmonary Surgery, contrasting with the steady progress made in the surgery of other organs.
Ewart 1889 (from Tompsett 1965)

⁵For overviews see Tompsett (1965), Boyden (1955), Sealy *et al.* (1993), Fell and Pearson (2007).

⁶Tompsett (1965).

⁷Pole (1790) was one of the first to include details of the injection process for making anatomical models.

⁸This is highlighted in the title of Ewart’s book (Ewart, 1889) in which he includes the following: ‘. . . with a criticism of Professor Aeby’s views on the bronchial tree . . .’

Ewart's magnificent achievement was the realisation that the lung consists of a number of functionally and anatomically separate components, which he termed 'respiratory units'. He summarises his key findings regarding the bronchi as follows:

(3) **The bronchial tubes do not anastomose.** Each lobe therefore receives from the main bronchus a distinct air-supply. The same principle of separate supply extends, within the lobe, as far as the infundibula. This absence of anastomosis is physiologically of great moment. . . .

Respiratory districts — At the *root* of the lung the conditions are very different, since the primary, secondary, and tertiary branches from the main bronchus radiate towards the periphery for considerable distances, without bearing any lobules. Within each lobe, large groups of lobules being served by separate bronchi are thus kept in practical isolation from each other as regards their air-supply. Each of these sublobar groups may be considered as forming a *separate respiratory district*, within which the tidal air, or the bronchial contents in general, may, perhaps, be capable of interchange from lobule to lobule. . . .

A knowledge of the situation, within each lobe of the respiratory districts of which it is composed, is likely to be valuable to the clinical physician. But an attempt to define their anatomical boundaries would with advantage be postponed until a full description of the bronchial tree had supplied a sound basis for the subdivision of each lobe into its lobular groups.

Ewart 1889, p. 65–66.

Ewart died⁹ in 1929, only a few years before the surgical significance of his 'respiratory districts' became widely appreciated. Just three years later Kramer and Glass (1932) extended Ewart's concept, viewing his respiratory districts as 'pathological units'. Glass (1933) then coined the term *bronchopulmonary segment*, and soon after Churchill and Belsey (1939) demonstrated the surgical resectability of bronchopulmonary segments—establishing that they were effectively also 'surgical' units. A new era of thoracic surgery was being ushered in by developments in anatomy, as Boyden (1955) describes:

The modern period begins with the suggestive studies of Kramer and Glass (1932), the one a bronchoscopist,¹⁰ the other a surgical resident at the Mount Sinai Hospital in New York. Pressed by surgical colleagues for a better localization of lung abscesses, including a knowledge of where to enter the chest for drainage, Glass proposed "to establish a smaller and more accurate unit of localization than the lobe." Unaware of Ewart's pioneer work, he named the *bronchopulmonary segment* and stated that it represented "not only an anatomic but a pathologic unit:" this, by virtue of the fact that its orifice occupies a prominent position in the lobar bronchus and therefore is vulnerable to aspiration of infected material. Besides giving us the now generally accepted name for this unit, Glass injected the main divisions of each lobar bronchus with different "colored fluid dyes," thereby providing the first diagrams of surface distribution. Relationship to the thoracic cage was determined from bronchograms of

⁹Obituary of Ewart W. (1848–1929). *Lancet*; 217, 408–409 [from Boyden 1955]

¹⁰Dr Rudolph Kramer: see also Kirschner (2003).

the lung. Altogether, eleven segments were recognized. In general these corresponded to Ewart's districts, except that the two subsegments of the pectoral district and two subdivisions of the middle lobe were given the status of segments.

Boyden 1955, p. 14

These were important and exciting times for thoracic surgery. Kirschner (2003) puts these great achievements in context as follows:

... Recognized today as a momentous advance in the surgical anatomy of the lung, this laid the groundwork for the localization and precise drainage of lung abscess, and the anatomical basis for precise pulmonary resection.

Kirschner (2003), p. 329.

4.3 Lung development & embryology

The recent advent of molecular biology and gene expression promises a seriously detailed understanding of the development of the lung, as indicated by a recent paper by Metzger *et al.* (2008). Using a mouse model they reveal that—to use a computer programming analogy—lung development appears to be largely under the control of a molecular master branching-program coordinating three slaves (branching-subroutines).

The development of lung branching is therefore perceived as proceeding according to a relatively fixed sequence of repeating functional molecular branching-instructions, controlled by a relatively small number of genes operating at branch tips. The editorial relating to this paper summarises the interest in this area, as follows:

Whether a master branch generator controlling a select few slave subroutines represents a general developmental strategy that has been reused over evolutionary time in different branched organs, remains an intriguing possibility. Also, solving the specific problem of gas diffusion as a limit on size, and discovering how simplified, genetically controlled branching routines interact with physical and biological factors to direct complex yet reproducible patterns of development, will be matters of great interest. To quote Charles Darwin as interpreted by biologist Sean Carroll,¹¹ they will aid our understanding of how “endless forms most beautiful”¹² have evolved from a relatively simple tool-box of genetic modules.

Warburton (2008).

¹¹SB Carroll (2007). *Endless forms most beautiful: the new science of Evo Devo and the making of the animal kingdom*, (Norton, New York) ISBN 987-0393060164.

¹²This is a quote from the last paragraph of Darwin's *The origin of species* (1859): ‘There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved’ (Nickalls, 2009).

4.4 Nomenclature

In May 1949 the nomenclature of the bronchi and segments was standardised by the Thoracic Society (BTS, 1950). For discussion see Boyden (1953).

4.4.1 Right lung

The bronchus to the right upper lobe should no longer be called the ‘eparterial’ bronchus—use ‘upper lobe bronchus’ instead. The part of the bronchus between the upper lobe bronchus and the middle lobe bronchus should be called the ‘upper part of the right main bronchus’, and the lower part should be called the ‘lower part of the right main bronchus’.

Upper lobe

1. Apical bronchus and segment
2. Posterior bronchus and segment
3. Anterior bronchus and segment

Middle lobe

4. Lateral bronchus and segment
5. Medial bronchus and segment

Lower lobe

6. Apical bronchus and segment
7. Medial basal (cardiac) bronchus and segment
8. Anterior basal bronchus and segment
9. Lateral basal bronchus and segment
10. Posterior basal bronchus and segment

4.4.2 Left lung

- (a) No segment 7, (b) the upper lobe has an upper division and a lower (lingula) division, (c) use the term ‘lingula’ in preference to ‘lower division’

Upper lobe

— upper division bronchus

1. Apical bronchus and segment
2. Posterior bronchus and segment
3. Anterior bronchus and segment

— lingula (lower division) bronchus

4. Superior bronchus and segment
5. Inferior bronchus and segment

Lower lobe

6. Apical bronchus and segment
8. Anterior basal bronchus and segment
9. Lateral basal bronchus and segment
10. Posterior basal bronchus and segment

4.5 Carina

The safe positioning of an endotracheal tube relies not only on an understanding of the applied anatomy and an awareness of the likely position of the carina, but also on an appreciation of those factors which can move the carina relative to the end of the tube. In particular, the distance of the tip of a tube from the teeth is a very useful guide for recognising when a tube is likely to be close to the carina, or even beyond it. The surface marking of the carina in a supine patient is the manubrio-sternal angle (Burwell and Jones 1996, Ellis *et al.* 2004, Minnich and Mathisen 2007).

Table 4.1:
Approximate distances in an average supine adult male.

Teeth → vocal cords	15 cm
Trachea	10 cm
Carina → left-subcarina	5 cm
Carina → right-upper lobe orifice	2.5 cm
Teeth → carina	25 cm
Teeth → left-subcarina	30 cm

4.5.1 Factors moving the carina

The distance of the carina from the teeth varies quite markedly with (a) neck position (± 2 cm with flexion/extension), (b) body position (supine, lateral, lithotomy, Trendelenberg) particularly in obese patients or those with a large or distended abdomen, and (c) body height/weight. The length of the trachea (and hence position of the carina) is greatly influenced by the position of the diaphragm.¹³

While the carina is typically about 24 cms from the teeth in a lean supine adult male of normal height, it can be as little as 18 cms in an equivalent obese patient in lithotomy. The recent letter by Greenland (2004) gives some useful references regarding anatomy and how to position an endotracheal tube safely.

With a single-lumen tube it is not uncommon for the tip to be inadvertently positioned at or below the carina in short and/or obese patients; the risk increasing further when such patients are head-down and/or in lithotomy. The risk is even more significant if there is also raised intra-abdominal pressure, as in laparoscopy (Nishikawa *et al.* 2004). Furthermore, in short patients the larynx-intubation guide-marks on standard endotracheal tubes may locate the tip of the tube too close to the carina (Chong *et al.* 2006; Cherng *et al.* 2002).

Appreciating the factors which influence the position of the carina is especially important when positioning double-lumen tubes, since in this setting even small movements of the carina may not only jeopardise the adequacy of lung isolation and ventilation (see

¹³Hence: 'what moves the diaphragm also moves the carina' (see Section ??).

Section ??), but can equally well lead to obstruction and lobar collapse. The TEPID database (see Section ??) is a good predictor of the distance to the carina in supine patients, and has proved to be a useful practical guide in this regard. It is important to have a low threshold for using a fiberoptic bronchoscope to check the tube position following any change in the patient's position.

Note that tube/carina problems are particularly likely to arise in the ITU, owing to the fact that patients ventilated in the ITU are subject to the combination of (a) PEEP, and (b) being nursed in a 45 deg semi-sitting position. This combination of factors typically results in the carina being significantly further away from its usual supine location. For example, when trainees bronchoscope such patients they often express surprise at how far away the carina is. One must take care to avoid inadvertently positioning the ETT close to the carina if the patient is in a semi-sitting position, since later, when the patient is supine (for nursing or other reasons), the carina may rise too close to the end of the tube. The expected number of cms from the teeth is usually the best initial guide to ETT position in this setting.

4.6 Right-upper lobe orifice

Typically the right-upper lobe (RUL) orifice is 2–2.5 cm below the carina, and is often positioned very slightly antero-lateral (i.e., a right-sided endo-bronchial tube often needs to be rotated slightly anticlockwise in order to align the side hole with the RUL orifice).

The location of the RUL orifice relative to the carina is somewhat variable, and can even originate from the trachea directly (see below).

4.7 Aberrant bronchus

Supernumerary bronchus: A bronchus supplying a (supernumerary) segment which is additional to the usual bronchus (supplying its usual lung zone or segments). It is most frequently associated with the right upper lobe, and typically arises laterally from the right side of the trachea, about 2 cm above the normal right upper-lobe bronchus (Brock 1954, p. 201). For clinical implications see Section ??.

Displaced bronchus: A bronchus which is otherwise normal (i.e., supplies its usual lung zone or segment), but is displaced (up or down) from its usual location. Displaced bronchi are much more common than supernumerary bronchi. The commonest displaced bronchus is an upward displacement of the apical bronchus of the right upper lobe. On the left side, a not uncommon displaced bronchus is that of the medial basal ('cardiac') bronchus, arising medially from the left lower-lobe bronchus above the origin of the anterior basal bronchus—exactly analogous to the 'cardiac' bronchus of the right lower lobe (Brock 1954, p. 207). For clinical implications see Section ??.

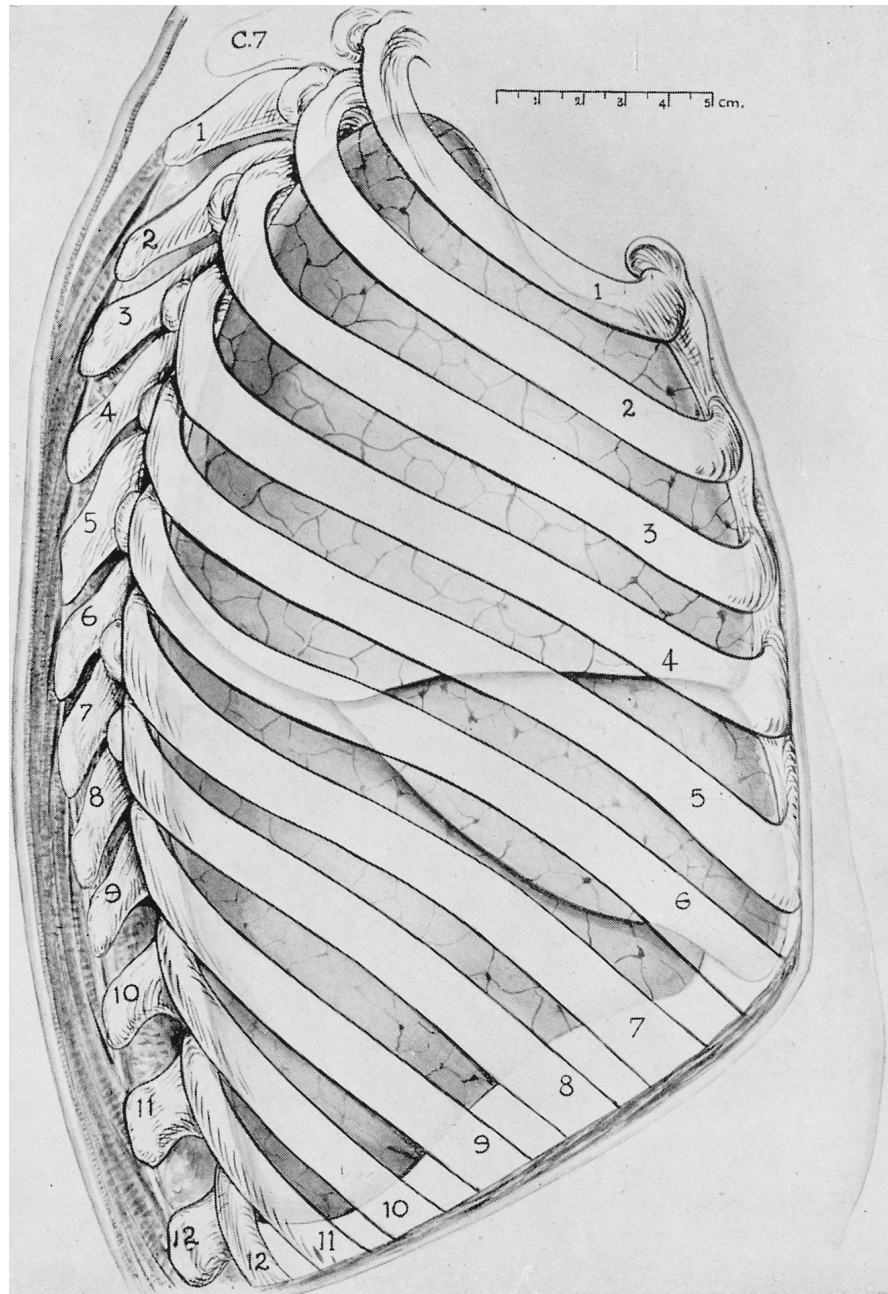


Figure 4.1:

Drawing of a dissection to show the relation of the fissures of the right lung, and to demonstrate the depth from the skin surface of the termination of the fissure (From Brock (1942–1944), with permission)

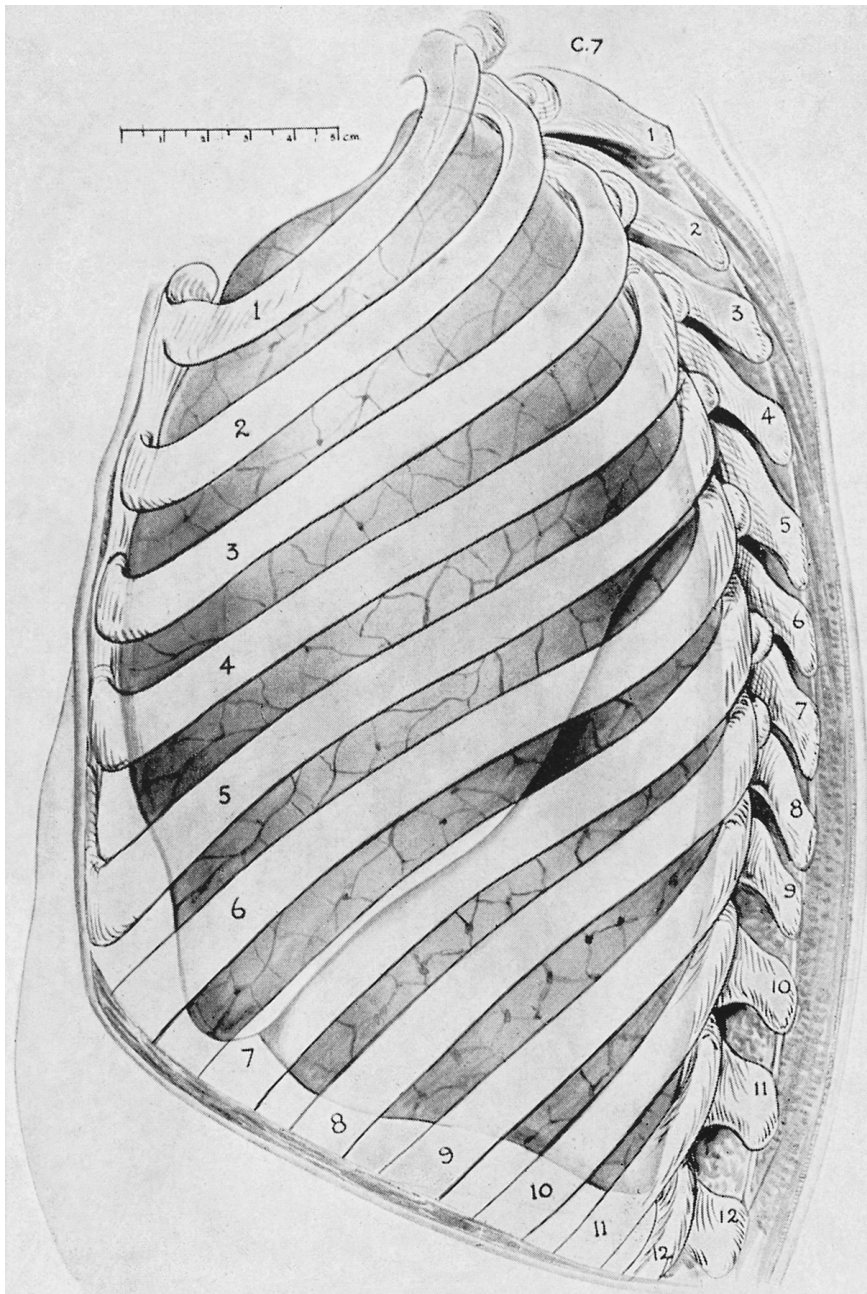


Figure 4.2:
Similar drawing of the left lung to show the fissure (*From Brock (1942–1944), with permission*)

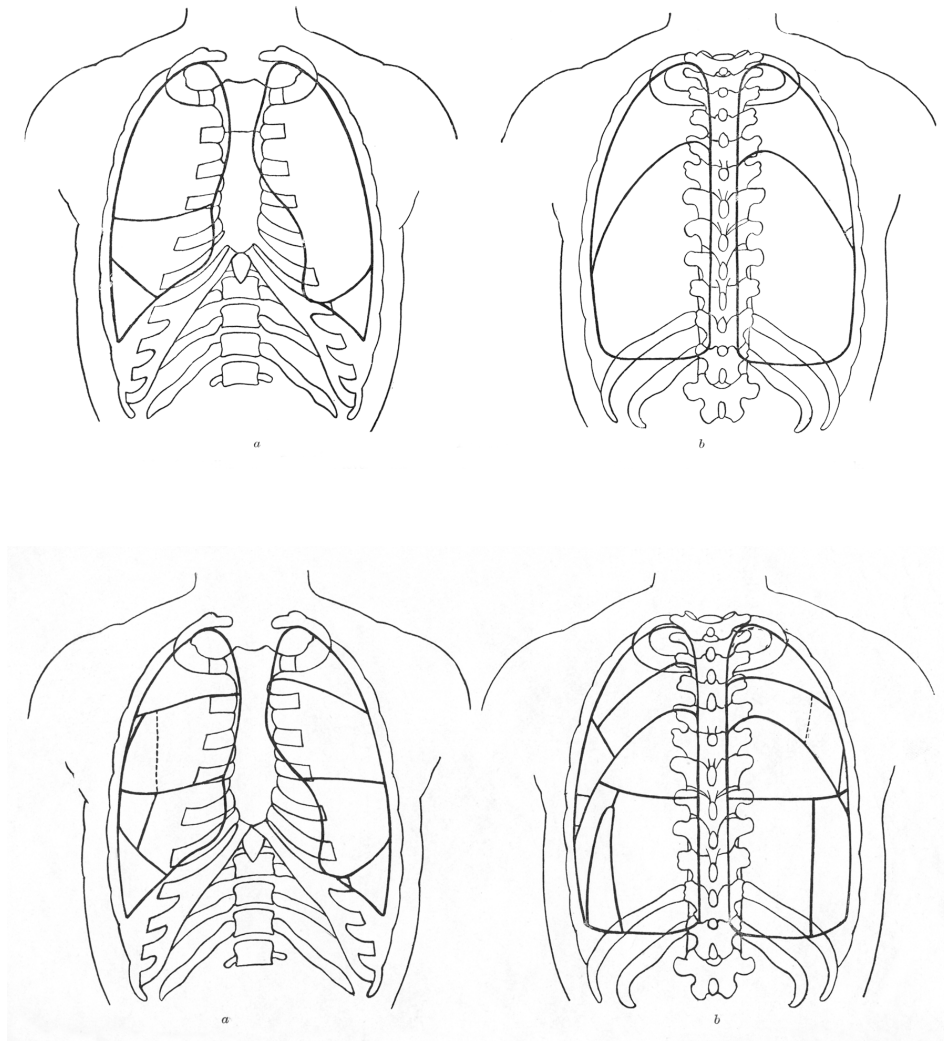


Figure 4.3:

Top: Chest diagrams to show the level of the lobes and interlobar fissures of the lungs as seen from the front and back.

Bottom: Similar diagrams to show the bronchopulmonary segments.

The lateral subsegments of the right upper lobe are indicated by broken lines
(From Brock (1942–1944), with permission)

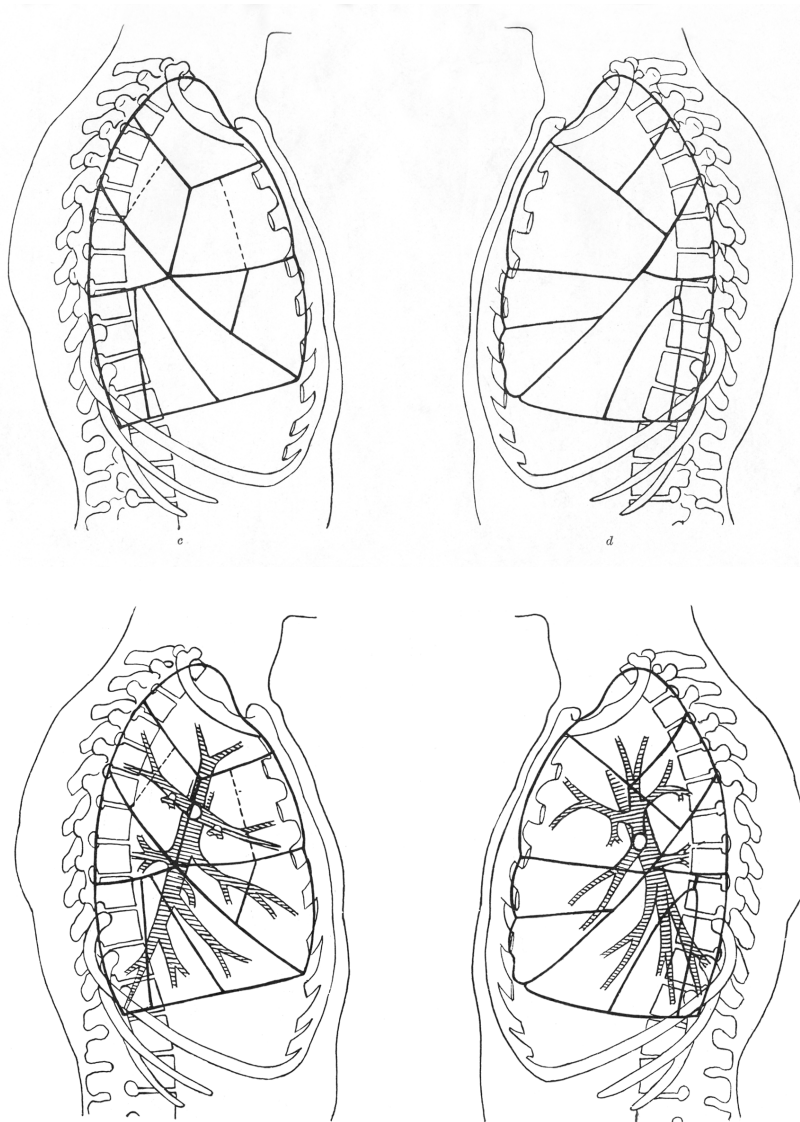


Figure 4.4:

Top: Chest diagrams to show the bronchopulmonary segments as seen in the lateral view. The lateral subsegments of the right upper lobe are indicated by broken lines.

Bottom: Similar diagrams to show the bronchi supplying the bronchopulmonary segments (*From Brock (1942–1944), with permission*)

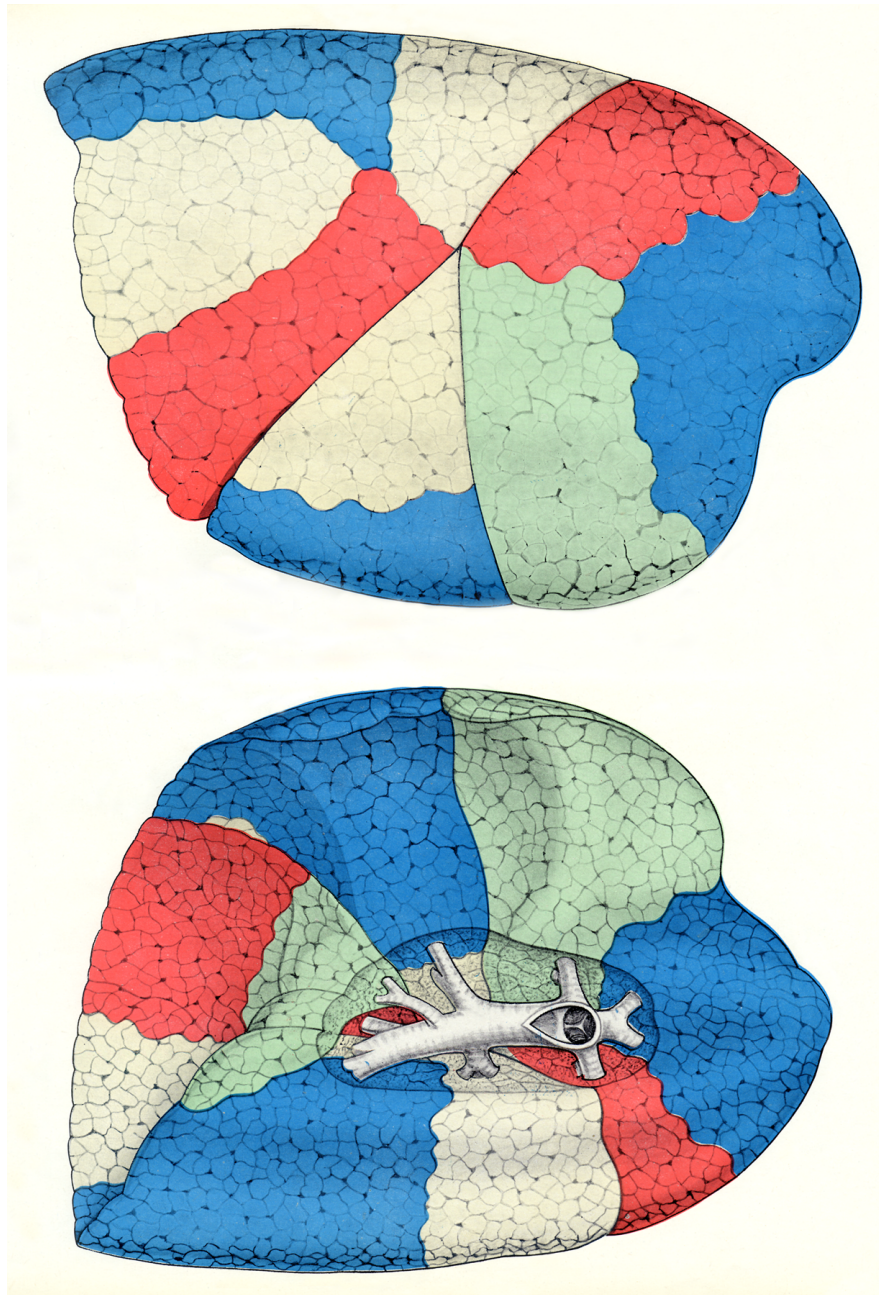


Figure 4.5: **Right lung:** Lateral and medial views in which the individual segments have been injected with coloured gelatin. (*From Brock (1942–1944), with permission*)

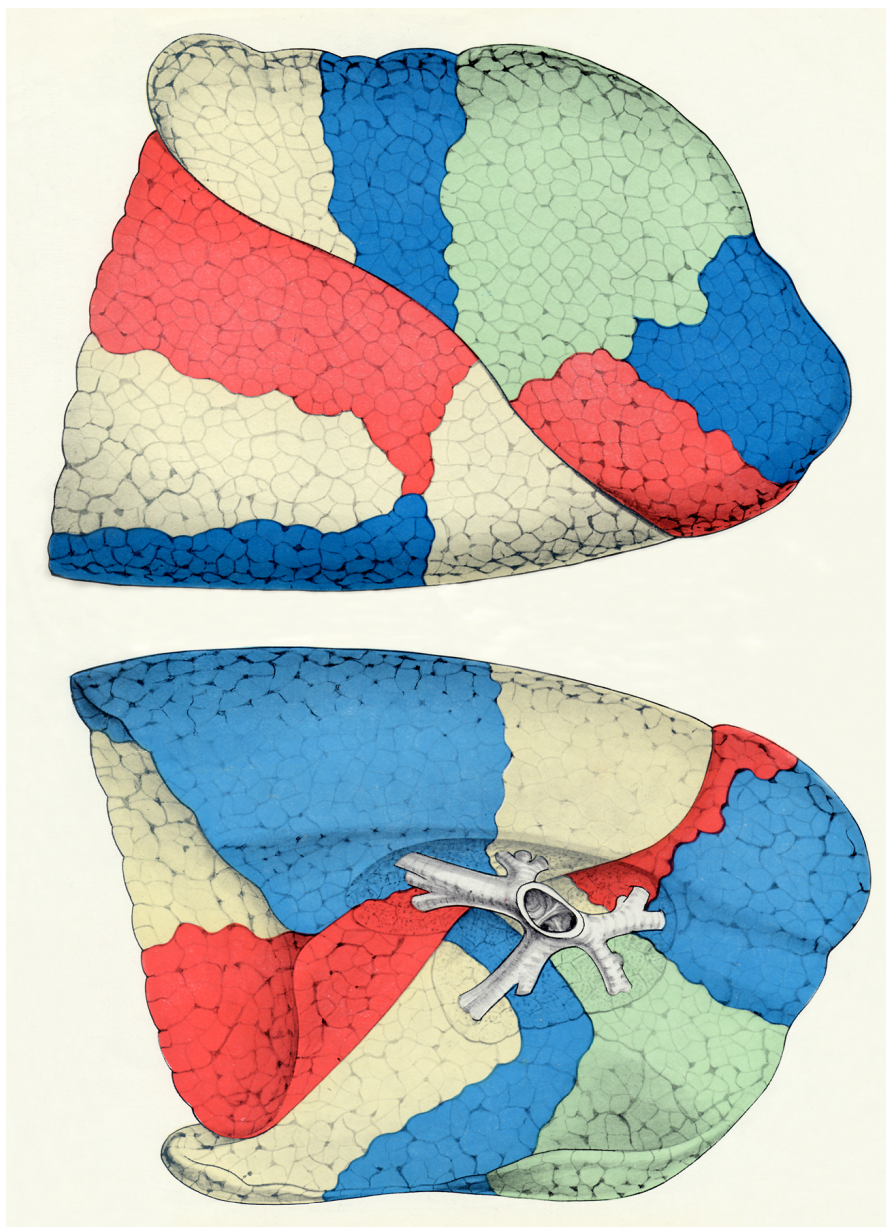


Figure 4.6: **Left lung:** Lateral and medial views in which the individual segments have been injected with coloured gelatin. (From Brock (1942–1944), with permission)

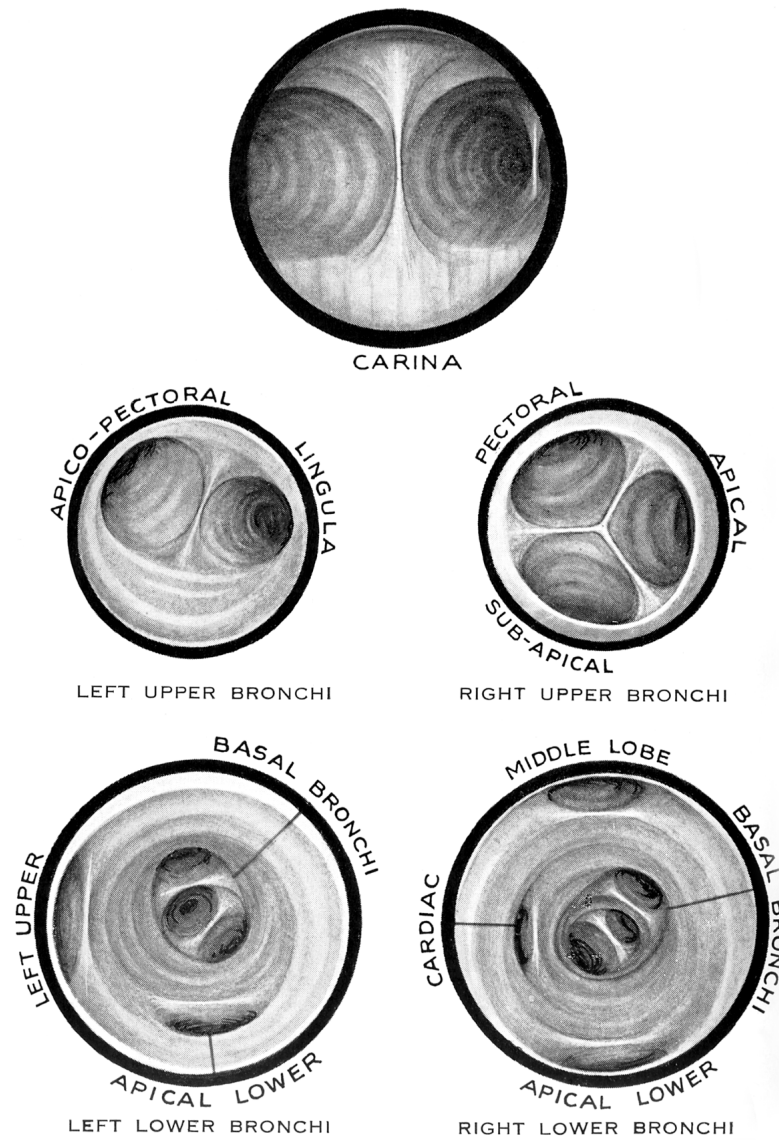


Figure 4.7:

Drawings of normal bronchi as seen at bronchoscopy in a supine patient. However, in my experience the *left upper* bronchial orifice in the *left lower bronchi* drawing is generally seen much closer to the 10–11 o'clock position—compare with Figures ?? and ?. See Section 4.4 for the more modern nomenclature. (From Brock (1942–1944), with permission).

4.8 References

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[chapters: Historical perspectives of thoracic anatomy / Surface anatomy and surface landmarks for thoracic surgery / Muscles of the chest wall / The anatomy of the ribs and the sternum and their relationship to chest wall structure and function / The intercostal space / The costovertebral angle / Anatomy of the thoracic outlet / Correlative anatomy for the sternum and ribs, costovertebral angle, chest wall muscles and intercostal spaces, thoracic outlet / Anatomy of the neck and cervicothoracic junction / The glottis and subglottis: an otolaryngologist's perspective / Glottis and subglottis: a thoracic surgeon's perspective / Anatomy of the trachea, carina, and bronchi / Lobes, fissures, and bronchopulmonary segments / Pulmonary vascular system and pulmonary hilum / Bronchial arteries and lymphatics of the lung / Correlative anatomy for thoracic inlet; glottis and subglottis; trachea, carina, and main bronchi; lobes, fissures, and segments; hilum and pulmonary vascular system; bronchial arteries and lymphatics]
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