THE SURGICAL ANATOMY OF THE PULMONARY VESSELS

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Surgical resections of the lung have in recent years become common and relatively safe procedures. Depending upon the extent and nature of the disease process, the whole lung, one or two lobes, or one or more bronchopulmonary segments may require excision. Modern pulmonary resection depends to a very large extent upon the precise identification of the primary, secondary, and tertiary hilar bronchovascular structures, and it has thus become essential to have a detailed knowledge of the anatomy of these structures at the different hilar levels.

The aim of this paper is to describe and to illustrate this anatomy. It is based upon a study of 42 complete casts of the bronchovascular tree and the hilar anatomical findings displayed during the course of 92 partial and 30 whole lung resections performed by some members of the Thoracic Surgical Unit, Johannesburg, during the past year. The pulmonary vessels and the bronchi are illustrated chiefly from such approaches as are used by the surgeon when dissecting the different primary, secondary, and tertiary hila.

Each lung, anatomically, is composed of 10 bronchovascular or bronchopulmonary segments. These segments are miniature lobes differing from lobes only in their size and in the usual absence of fissures at their anatomical boundaries.

A lobar bronchus branches from a main bronchus at a relatively constant site, and subdivides in a more or less standard fashion into its segmental bronchi. The pulmonary artery, however, has not this same lobar distribution, and although the segmental pulmonary arteries follow the segmental bronchi somewhat closely, they tend to have a variable and independent origin from the pulmonary artery.

The segmental artery, like the segmental bronchus, occupies a central position within the bronchopulmonary segment. The blood carried to the segment by such a centrally situated artery is collected by perisegmental pulmonary veins; as such, they are either placed superficially, imme-

PULMONARY ARTERY

The main pulmonary artery divides in front of the left main bronchus into a left and a right pulmonary artery (Fig. I).

RIGHT PULMONARY ARTERY.—The right pulmonary artery has to cross the midline to reach the root of the right lung. This it does by passing transversely to the right, behind the ascending aorta and the superior vena cava respectively, in front of the oesophagus and immediately above the left atrium and right superior pulmonary vein under cover of the arch of the azygos vein.

Behind the superior vena cava the right pulmonary artery divides into an upper and a lower trunk (Fig. I). Of these the superior pulmonary trunk supplies the anterior and apical bronchopulmonary segments of the right upper lobe by dividing, as it enters the lung substance in front of the right upper lobe bronchus, into the apical (A1) and anterior (A3) segmental arteries (Fig. II). Emerging from behind the superior vena cava, it is, but for the covering given it by the pleura on the root of the lung, completely exposed.

The inferior pulmonary trunk proceeds from behind the superior vena cava to become subpleural, but only to disappear almost immediately by passing behind the superior pulmonary vein (Fig. IV). It is the counterpart of the left pulmonary artery. Passing laterally and slightly downwards, under cover of the superior pulmonary vein (Fig. IV), it crosses the anterior sur-
face of the right bronchus, between the origins of the upper and middle lobe bronchi (Figs. II and III). Then curving downwards, it runs subpleurally in the depths of the oblique fissure (Fig. III), on the antero-lateral aspect of the basal bronchus.

The inferior pulmonary trunk supplies the middle and lower lobes as also, in the majority of cases, the posterior bronchopulmonary segment of the upper lobe via the posterior ascending segmental artery (A2, Fig. III) and frequently also the anterior bronchopulmonary segment, via the anterior ascending segmental artery (A3, Fig. III). In such instances the anterior ascending segmental artery is usually accessory to the anterior segmental artery (A3, Fig. II), but in a small percentage of these cases it is solely responsible for supplying the anterior bronchopulmonary segment. Occasionally, however, the anterior ascending segmental artery may derive its origin from the middle lobe artery (A3, Fig. IIIb).

The acute angle formed between the oblique and transverse fissures forms the point of an arrow which guides one to that area of the subpleural pulmonary artery, in the depths of the oblique fissure, from which the pulmonary arterial supply to the middle and lower lobes and part of the upper lobe is derived (Fig. III).

Arising from the postero-lateral surface of the inferior pulmonary trunk, in this area, one finds the lower lobe apical segmental artery (A6, Fig. III). It descends slightly in a backward direction, lying superior and, as the surgeon sees it, lateral to its corresponding bronchus. To the anatomist, however, the artery is superior and anterior to the bronchus. The reason for this difference is that the surgeon, in opening the slit-like oblique fissure, displaces the apex of the lower lobe medially. Similarly also, the middle lobe artery (Figs. III, IIIa, and IIIb) appears to be superior and lateral to its corresponding bronchus instead of superior and posterior.

The lower lobe apical segmental artery is usually single (A6, Fig. III), but at times the apical segment of the lower lobe summons the aid of a second segmental artery (A6 i, A6 ii, Fig. IIIa).

Arising more or less opposite the lower lobe apical segmental artery, from the anterior surface of the pulmonary artery, is the middle lobe artery. It may be single, when it divides into two branches, one each for the medial and lateral segments of the middle lobe (A4 5, Fig. IIIa). As frequently two separate middle lobe segmental arteries are present (A4, A5, Fig. III).

Arising from the inferior pulmonary trunk, slightly above the lower lobe apical segmental artery, is the artery to the posterior segment of the upper lobe. It passes backwards and upwards and is termed the posterior ascending artery (A2, Figs. III, IIIa, and IVd). Whereas the posterior segmental artery of the right upper lobe in the majority of cases arises from the pulmonary artery in this situation, it frequently, however, arises from the superior pulmonary trunk itself during the latter's subpleural course, from either of its two terminal branches, namely, the apical (A1) or anterior (A3) segmental arteries (Figs. IIa and IIb), from the lower lobe apical segmental artery (A2, Fig. IIIb), or even from the middle lobe artery.

The inferior pulmonary trunk breaks up into the four basal segmental arteries, either just within the oblique fissure or just inside the lung parenchyma. Each basal segmental artery follows its respective bronchus very closely, keeping to its antero-lateral side. These take off from the inferior pulmonary trunk either singly or via an anterior and a posterior trunk, the former dividing into the medial (A7) and anterior (A8) basal segmental arteries, whereas the latter provides the lateral (A9) and posterior (A10) basal segmental arteries (Fig. III).

**Left Pulmonary Artery.**—The left pulmonary artery, arising in front of the left main bronchus, ascends slightly in a posterior and lateral direction, arches over the left main bronchus, and then hooks round the left upper lobe bronchus, following a subpleural course throughout (Figs. V, VI, and VII). It more fully establishes its superiority over the left superior pulmonary vein (Fig. VIII) than does its right counterpart, the inferior pulmonary trunk, which lies directly behind the right superior pulmonary vein (Fig. IV).

Owing to the different courses taken by the left and right pulmonary arteries, the antero-posterior and infero-superior relations in the hilum of the left lung are vein, bronchus, and artery, whereas the same relations in the hilum of the right lung are vein, artery, and bronchus.

As the left pulmonary artery is about to arch over the left main bronchus it gives off the first of a series of segmental arteries for the supply of the left upper lobe. This segmental artery (A3, Fig. V), arising from the antero-superior surface of the pulmonary artery, passes in front of the upper division of the left upper lobe bronchus to the anterior bronchopulmonary segment, crossing behind the apical-posterior tributary (V1, V2, Fig. VIII) of the superior pulmonary vein.
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RIGHT
1. Apex Upper Lobe
2. Posterior
3. Anterior
4. Lateral Middle
5. Medial Middle
6. Apex Lower Lobe
7. Medial Basal
8. Anterior Basal
9. Lateral Basal
10. Posterior Basal
+ Inferior Vein

LEFT
1. Apex Upper Lobe
2. Posterior
3. Anterior
4. Superior Lingular
5. Inferior Lingular
6. Apex Lower Lobe
7. Medial Basal
8. Anterior Basal
9. Lateral Basal
10. Posterior Basal
+ Inter-Antero-Lingular Vein
From the postero-superior surface of the left pulmonary artery the short, sessile, bifurcating apical-posterior segmental artery (A1, A2, Fig. VI) is derived. The apical-posterior artery may, however, be a clearly defined single trunk, dividing into its two constituent segmental arteries (Fig. VIb). On the other hand, the apical segment may be supplied by two separate segmental arteries (A1, A1, Fig. VIIa). Similarly, the posterior segment may have a dual segmental arterial supply (A2, A2, Fig. VIIc).

Arching around the back of the upper lobe bronchus, the left pulmonary artery enters the oblique fissure, and, running immediately beneath the pleura, it comes to lie on the side of the lower lobe bronchus. From this position, near the upper end of the oblique fissure, the artery sends from its anterior aspect a single arterial stem to the lingular bronchopulmonary segments. The lingular artery is posterior to its corresponding bronchus (but lateral to it as the surgeon sees it) and at a somewhat lower level, and divides into the superior and inferior lingular segmental arteries (A4+5, Fig. VII). Commonly the lingular segmental arteries arise independently from the anterior surface of the pulmonary artery (A4, A5, Fig. VII i).

Arising from the postero-lateral surface of the pulmonary artery, more or less opposite the lingular artery, although usually at a somewhat higher level, is the lower lobe apical segmental artery (A6, Fig. VII). As on the right side, here too there may be two separate lower lobe apical segmental arteries (A6 i, A6 ii, Fig. VII ii).

The level of origin of the lower lobe apical segmental artery in relation to that of the lingular artery is of particular importance (Fig. VII). In lower lobectomy this segmental artery (A6) requires to be ligated separately from the rest of the lower lobe artery, as mass ligation of the pulmonary artery immediately above the origin of the first segmental artery to the lower lobe (A6) would include the segmental arterial supply to the lingula.

The anterior segmental artery (A3) commonly arises from the anterior surface of the pulmonary artery in the oblique fissure in relation to the lingular artery. It may form with the lingular artery (A4, A5) a common antero-lingular trunk (Fig. VIIia), or it may be associated with only the upper of two separate lingular segmental arteries (Fig. VIIia iii). On the other hand, the anterior segmental artery may arise independently of and cranial to a bifurcating lingular artery (Fig. VIIia i) or two separate lingular segmental arteries (Fig. VIIia ii).

The lingular artery, on the other hand, may form with the anterior segmental artery a common antero-lingular trunk on the antero-superior surface of the pulmonary artery immediately before it loops over the upper surface of the left main bronchus (Fig. Vb), leaving the anterior surface of the pulmonary artery in the lingular region of the oblique fissure conspicuously bare (Fig. VIIib). Alternatively, only the superior lingular segmental artery (A4) may be associated with the anterior segmental artery (Fig. Vc), leaving its partner (A5) in charge of the oblique fissure (Fig. VIIic).

The apical segmental artery (A1) also occasionally arises with the anterior segmental artery (A3) from the antero-superior surface of the left pulmonary artery (Fig. Vd).

To ascertain the whereabouts of these segmental vessels it is advisable to display the segmental arterial anatomy in the lingular region of the oblique fissure, should this fissure be fully developed. Depending on whether there are three, two, one, or no segmental arteries in the lingular area, there will arise no, one, two, or three segmental arteries from the antero-superior surface of the pulmonary artery (Figs. VII, VIIa, VIIb, VIIc, and Figs. V, Va, Vb, and Vc). The remaining arterial stems arising from the postero-superior or posterior surface of the arching pulmonary artery belong to the apical-posterior bronchopulmonary segment.

The four basal segmental arteries follow their respective bronchus closely, and, like their fellows on the right side, cling to the antero-lateral sides of these bronchi (Fig. VII). Here also the pulmonary artery may terminate within the oblique fissure, but usually the dissection has to be extended into the lung substance to see that the medial (A7) and anterior (A8) basal segmental arteries, like their corresponding bronchi, usually arise from a common anterior trunk, and that the lateral (A9) and posterior (A10) basal segmental arteries either leave singly or via a common posterior trunk (Fig. VII).

PULMONARY VEINS

Right Superior Pulmonary Vein.—The right superior pulmonary vein drains the right upper and middle lobes. On entering the pericardium, this vein lies immediately below the right pulmonary artery. In the hilum of the lung, however, it overlaps the inferior pulmonary trunk, and its uppermost tributary, the apical-anterior vein (V1, V3, Fig. IV), descends across the anterior segmental artery. This subpleural vein drains the
upper and middle lobes via three to five trunks. The uppermost trunk is the apical-anterior vein, which receives a subpleural segmental vein from each of the apical and anterior bronchopulmonary segments (V1, V3, Fig. IV).

Entering the superior pulmonary vein immediately below the apical-anterior trunk is the inferior vein (+, Fig. IV), so called because it courses subpleurally on the inferior surface of the upper lobe (anterior segment) in the transverse fissure.

Next, the tributaries from the lateral and medial bronchopulmonary segments of the middle lobe enter the superior pulmonary vein, either as a common trunk or independently (V4, V5, Fig. IV).

One more vein completes the quintet. This is the posterior segmental vein. But for the course of this vein the superior pulmonary vein would have been a channel shaped like a hand, all the digits meeting the palm subpleurally. This posterior vein (V2, Fig. IV), however, comes from the very depths of the upper lobe to enter inconspicuously the deep surface of either the pulmonary vein itself, or, more commonly, its inferior tributary, having first catered for the posterior and intersegmental regions of the upper lobe (V2, Fig. IVd). This vein is unique in that, of all the segmental veins, it is the only one which at no stage runs a subpleural course.

One or both middle lobe veins may at times become detached from the superior pulmonary vein to drain into the inferior pulmonary vein (Figs. IVb and IVc). Similarly, one or both of these middle lobe segmental veins may drain directly into the left atrium.

**Right Inferior Pulmonary Vein.**—The right inferior pulmonary vein, in the root of the lung, courses below the right superior pulmonary vein; but here it occupies a somewhat more posterior plane. Its tributaries leave the lung by passing behind their respective bronchi. For this reason, and also because the inferior pulmonary vein is to some extent hidden by the lower lobe and by the upward extending anterior layer of the pulmonary ligament, the vein and its tributaries are more readily dissected from the posterior aspect (Figs. IV and IVa).

The inferior pulmonary vein receives all five segmental veins which drain the lower lobe, and occasionally, as mentioned above, one or both middle lobe segmental veins. If the superior pulmonary vein may be compared with a hand, then the inferior pulmonary vein can most certainly be said to resemble a shrub (Boyden, 1945), the branches of which radiate somewhat irregularly from a short stem (Figs. IV and IVa). Its lowermost tributary is the medial basal segmental vein (V7), which lies immediately above a constantly present lymph gland at the upper end of the pulmonary ligament.

The uppermost, and most easily discernible, tributary is the lower lobe apical segmental vein, which, descending from the apex of the lower lobe, crosses behind the basal bronchus, below the origin of its corresponding bronchus, to end at the upper angle of the receiving vein somewhat posteriorly (V6, Figs. IV and IVa).

The remaining three tributaries, namely, the anterior (V8), lateral (V9), and posterior basal (V10) segmental veins, leave their respective intersegmental regions (Fig. IV) by crossing behind their corresponding bronchi to enter the inferior pulmonary vein in no fixed manner between the lower lobe apical segmental vein above and the medial basal segmental vein below.

**Left Superior Pulmonary Vein.**—The left superior pulmonary vein is formed by three venous trunks which, to the surgeon, are all anterio-inferiorly related to their corresponding bronchi, and which, anteriorly, are all covered by the pleura on the root of the lung. It receives all the left upper lobe segmental veins (Fig. VIII).

The uppermost tributary is the apical-posterior trunk, which drains the apical-posterior bronchopulmonary segment. This apical-posterior trunk (V1, V2, Fig. VIII) overlies the anterior artery or the antero-lingual trunk when these arteries arise from the antero-superior surface of the pulmonary artery.

Joining the superior pulmonary vein laterally and immediately below the apical-posterior vein is the tributary from the anterior segment (V3, Fig. VIII). Before reaching the superior pulmonary vein the anterior segmental vein is joined by the inter-antero-lingual vein (+, Fig. VIII) which drains along the intersegmental plane described by its name, thus corresponding somewhat to the inferior vein draining into the right superior pulmonary vein.

The lowermost member of the left superior pulmonary vein is that which drains the superior and inferior lingual bronchopulmonary segments (V4, V5, Fig. VIII). These two segmental veins may, however, join the superior pulmonary vein separately. One or both lingual veins may, like the middle lobe veins, empty into the inferior pulmonary vein or directly into the left atrium.
The apical-anterior-posterior segmental venous pattern of the left upper lobe may at times resemble that of the right upper lobe and vice versa.

**LEFT INFERIOR PULMONARY VEIN.**—The left inferior pulmonary vein runs, like the right inferior pulmonary vein, below the superior pulmonary vein and at a somewhat more posterior level. Similarly, its five tributaries, crossing behind their respective bronchi, can be dissected more readily from behind. Here too the lower lobe apical segmental vein (V7) and the medial basal segmental vein (V8) are the uppermost and lowermost tributaries respectively (Fig. VIII).

An inferior pulmonary vein frequently resembles not a shrub but a branch of a tree (Boyden, 1945), the thick end of the branch representing the inferior pulmonary vein, which, tapering down, becomes the posterior segmental vein (V10). The branch has three lateral branches, namely the lower lobe apical segmental vein (V6), the anterior basal vein (V8), and the lateral basal vein (V9) respectively, and one medial branch, the medial basal vein (V7, Fig. VIII).

Very occasionally a lung is drained by one pulmonary vein only.

**DISCUSSION**

Several plates of the pulmonary vessels are presented showing their relations to each other and to the bronchi at the different primary, secondary, and tertiary hila.

Although, functionally, a lung is composed of "bronchopulmonary" segments, the term "bronchovascular" is sometimes employed, as the structures met with during hilar dissections are of prime importance to the surgeon, and the latter term emphasizes the existence of multiple bronchovascular hila.

The usual anatomy as well as different varieties of the less usual anatomy, as indicated by big and small Roman numerals respectively, are illustrated. By indicating the views from which the anatomy is shown, the models, placed immediately above the illustrations, allow one to become readily orientated, and explanatory descriptions are thereby considerably reduced.

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Of the bronchovascular casts mentioned above, 32 were prepared by Dr. F. Frodl, late of the Department of Pathology, Utrecht, Holland. His paper on the detailed anatomy of the pulmonary vessels is now in the press. I am deeply indebted to Professor P. Nieuwenhuijse, head of that department, and to Dr. F. Frodl, now of the Department of Radiology, Utrecht, for so generously having granted me access to these casts.

Mr. P. Marchand, of the Thoracic Surgical Unit, Johannesburg, made 10 similar casts, and to him I wish to extend my sincerest thanks for having permitted me to include them in this series.

Contributions by Mr. L. Fatti and Mr. G. R. Crawshaw made possible the publication of drawings in colour.

**REFERENCE**