Rom J Morphol Embryol 2011, 52(2):563–568

ORIGINAL PAPER

RJME Romanian Journal of Morphology & Embryology http://www.rjme.ro/

Pulmonary venous compartment of the airways circulation

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Abstract

Bronchial circulation has three components: a systemic arterial component represented by the bronchial arteries; a pulmonary venous component represented by the pulmonary veins; and a systemic venous component represented by the bronchial veins. We have used vascular casting, microscope dissection coupled with tracers and light microscopy to define the detailed anatomy of the pulmonary venous compartment of the bronchial circulation. We have found that the extrapulmonary drainage territory of the pulmonary veins correlate with the forming pattern of the right superior pulmonary vein. In the case of a large apical venous trunk, pulmonary veins drain the venous blood of the main bronchia, terminal portion of the trachea and of the tracheobronchial lymph nodes. In the case of the systemic venous drainage of the extrapulmonary airways, we constantly found a pulmonary component which drains the venous blood from the subcarinal lymph nodes and the medial side of the main bronchia.

Keywords: bronchial circulation, pulmonary veins, tracheobronchial lymph nodes.

Introduction

Bronchial circulation plays an important role in both the normal function of the lung and in many pathologic conditions of the airways including the effort asthma, bronchiectasis, hemoptysis or lung abscesses [1–5]. Bronchial circulation forms a dense vascular plexus in the airway wall. It has been assumed that bronchial circulation has three main components: an arterial component represented by the bronchial arteries originating from the systemic arterial circulation; a venous systemic component represented by the bronchial veins; and a pulmonary venous component represented by branches of the pulmonary veins.

Most studies on the bronchial circulation were focused especially on the arterial component; the bronchial arteries being already described in 1721 by Ruyisch [1, 6–9]. The bronchial arterial blood drains into the pulmonary circulation and the azygos venous system. At present, the azygos venous system is considered to drain the blood from the levels of the lobar and the main bronchi [9], while the rest of the intrapulmonary airways have a venous circulation totally tributary to the pulmonary veins [10].

Many clinical observations indicated a correlation between the increase of the right upper pulmonary vein diameter, the appearance of the traheobronchial lymphadenopathy and the decrease of the cardiac ejection fraction in the patients with left cardiac congestive failure [11–13]. Also, the volumes of those lymph nodes decrease with the beginning of the heart supportive treatment [13].

It is already known from experimental studies that the pulmonary lymphatic flow shows a more specific increase in case of increasing pressure in the pulmonary venous system [14, 15]. Those clinical and experimental observations suggested that the lung veins involvement might provide venous drainage to the extrapulmonary lymph nodes, especially to the tracheobronchial lymph nodes.

In the present work, we have used vascular casting, microscope dissection coupled with tracers and light microscopy to study the distribution territory and the morphologic features of the pulmonary venous compartment of the bronchial circulation.

Materials and Methods

Our study was performed on a number of 11 cardio-pulmonary blocks collected during necropsy of sudden death cases (accidents, suicides) from the necropsy service of the Emergency County Hospital of Craiova. None of these cases involved any life threatening respiratory diseases. We have used the microscopic dissection coupled with colored gelatin injection and vascular casting to define the detailed anatomy of the pulmonary venous compartment of the bronchial circulation [16–19].

After being removed, trachea was canulated and the lungs were cleaned with distilled water by filling them under pressure (40 cm H_2O) and by forcing out the fluids with a mild compression of the lung parenchyma. We used the method of colored gelatin injection to reveal the branches of the pulmonary veins. Briefly, the method involves the following steps: cutting open the posterior wall of the left atrium and pulmonary veins canulation; warming the whole lung at 50^{0}C in a water basin; slowly injection of the pulmonary veins with 30% gelatin (mixed with 2% China ink tracer and 15% barium sulphate) until the pulmonary parenchyma was uniformly colored; cooling and fixation of the lung by immersion in 10% buffered formalin (at 4^{0}C).

Corrosion preparations were performed on two cardiopulmonary blocks. After washing the lungs, the heart was removed and a polyacrylic resin (65% solution of Duracryl® Spofa–Dental) was injected in the pulmonary venous system and airways. Pulmonary parenchyma was removed by digestion in a 25% potassium hydroxide solution for 5–7 days, to reveal the vascular casting. After the pulmonary parenchyma digestion, the vascular casting was cleaned in 5% formic acid and then washed in tap water.

The study of the preparation was performed under a surgical microscope on which a microscope digital camera (DCM 510) was mounted. The lungs have been horizontally sliced at 3 cm distance for the microscopic dissection point of the intrapulmonary airways. From those sections, blocks were removed and lung samples were processed for wax embedding, then 10 μm thick serial sections were cut and routinely stained with Hematoxylin–Eosin.

Results

Pulmonary venous compartment of the bronchial circulation – intrapulmonary component

Studying under the surgical microscope the large bronchi vascularisation (lobar, segmental, subsegmental) on corrosion pieces revealed the presence of venous branches tributary to the pulmonary veins, which are formed at the level of the adventitial bronchial plexus and usually leave the bronchial wall at the branching angle level (Figure 1, A–C).

These branches open directly into the large trunks of the pulmonary veins, they do not drain the neighboring alveolar capillary and they have bronchia and its daughter branches as a distribution territory.

At the peripheral bronchi levels, the rule of the venous collector placed at the branching angle level is not respected anymore. The venous collectors from the bronchial adventitial plexus open into the pulmonary venous trunks at the point of crossing the peripheral bronchi. Those venous trunks drain the bronchial wall but they also get collectors from the alveolar capillary of the neighboring lung parenchyma (Figure 1, D–F).

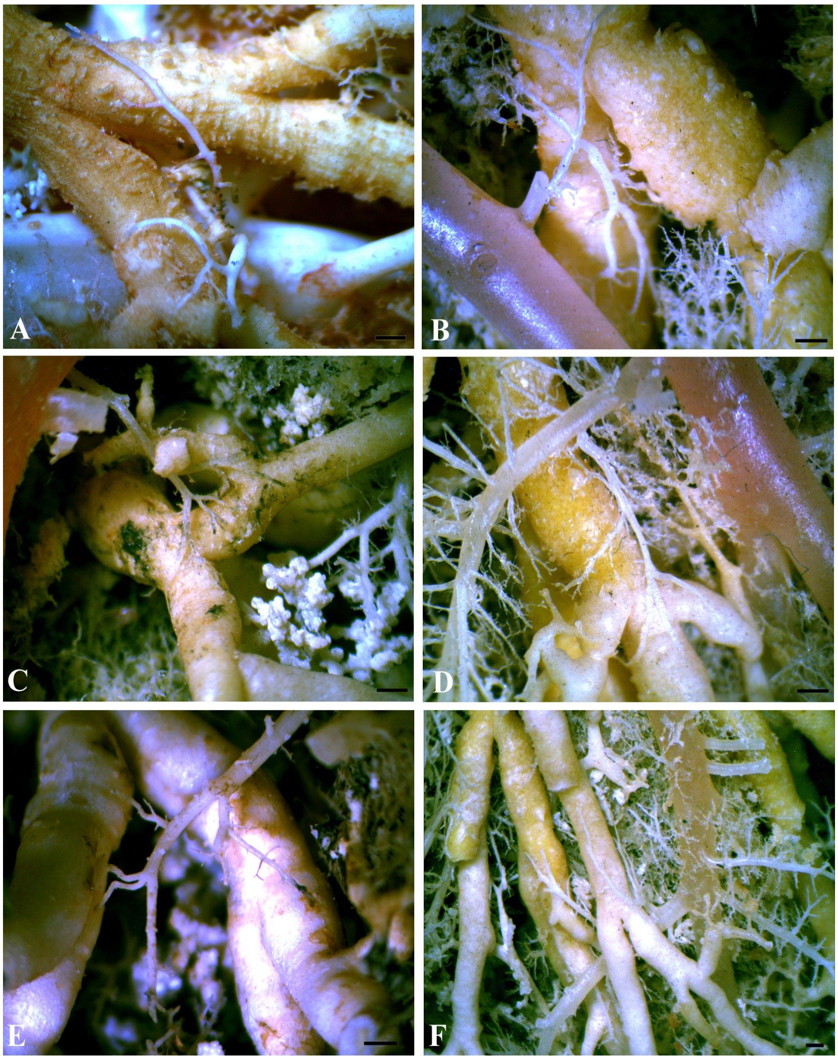

Figure 1 – ***Pulmonary venous component of the intrapulmonary bronchial circulation. Pulmonary veins and airways casts of child (A) and adult (B–F) lungs. Segmentary bronchi and the first generations of subsegmentary bronchi are drained for their own venous collectors opening into venous trunks of large size; those ones leave the bronchial wall, usually at the level of the bifurcation angle (A, B, C). Peripheral bronchi are drained towards the venous collectors tributary to the pulmonary veins at their crossing point with the bronchi (D, E, F). A peripheral venous trunk can sectorially collect the blood from the level of more peripheral bronchi both of same or different orders (E, F). Bar = 1 mm.***

Dissection under the surgical microscope the colored gelatin injected pieces showed that the pulmonary venous branches form adventitial venous plexus of the bronchial wall. Those veins drain the blood from the bronchial wall structures, intrapulmonary lymph nodules and pulmonary arteries walls and are richly anastomosed with the homologous venous branches of the upper and lower order bronchi, respectively (Figure 2, B and C).

Those venous branches receive deep branches connecting them to the submucous venous plexus (Figure 2, A–C). The deep branches sectorially connected the submucous plexus to the adventitial plexus (Figure 2, C and F).

Both the surgical microscope dissection and the histological sections analysis showed that there was no clear difference between the adventitial and submucous venous plexus, at the level of the small size bronchia (Figure 2A).

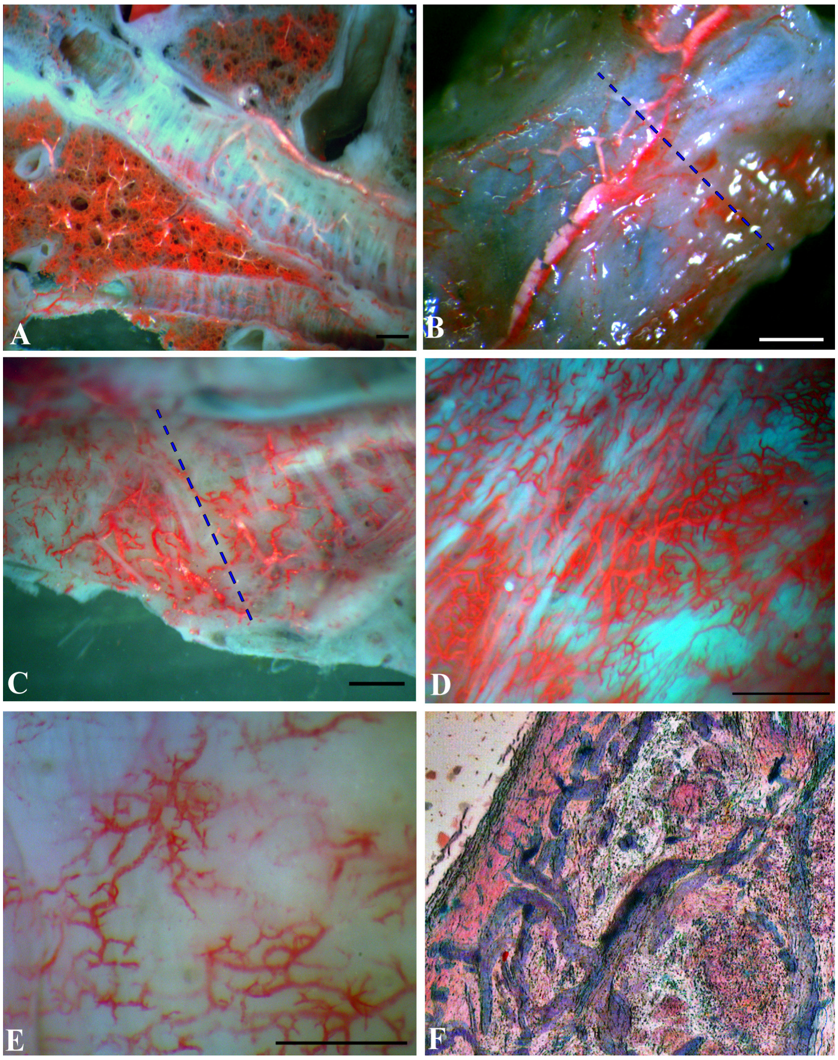

Figure 2 – ***Mezoscopic aspects of the submucous venous plexus (A, C, D, E) and adventitial venous plexus (B) at the subsegmentary bronchia (A), segmentary bronchia (B, C), main bronchia (D) levels and supracarinal region of the trachea (E). Interrupted lines trace the anastomotic areas between the territories drained for two neighboring venous branches, in the same segmentary bronchia. F: planar projection of the venous plexus of lobar bronchia (10 transversal seriate sections, HE stained, ob. ×10). Pieces injected with colored gelatin in the pulmonary veins. Bar = 1 mm.***

Pulmonary venous compartment of the bronchial circulation – extrapulmonary component

We constantly observed a venous branch of the right inferior pulmonary vein (RIPV) originating from both the adventitial plexus of the anterior face of carina and the right branch of the main bronchia, on all the dissected pieces. That venous branch had a descending pathway on the medial side of the right main bronchia and the intermediary bronchia and it opened into the RIPV. We also constantly identified a venous branch originating from the adventitial plexus of the anterior face of the left main bronchia. It followed a descending trajectory to open into the left inferior pulmonary vein (LIPV).

After dissecting the venous plexus of the right main bronchia, we identified three variants of the venous collector distributions.

Variant I

In four of the studied cases, we identified the presence of a venous branch, which was formed at the right tracheobronchial angle level and had a descending trajectory on the lateral side of the right main bronchia to drain to the superior venous trunk of the right superior pulmonary vein (RSPV). That variant of the venous drainage of the extrapulmonary airways can be met in case of the presence of large superior venous trunk of the RSPV (Figure 3D).

In this case, venous drainage of the superior and inferior tracheobronchial lymph nodes follows the next pathways (Figure 3, A and E):

- inferior tracheobronchial (carinal) lymph nodes: RIPV, RSPV and to a lesser extent, in LIPV;
- right superior tracheobronchial lymph nodes: RSPV and to a lesser extent, towards the RIPV and systemic veins tributary to the azygos venous system (AVS);
- left superior tracheobronchial lymph nodes: systemic veins tributary to AVS and partly, the RIPV.

Variant II

In two dissected cases, we identified a small size of the superior venous trunk of the RSPV. In this case, venous drainage of the superior and inferior tracheobronchial lymph nodes follows the points (Figure 3, B and F):

▪ carinal lymph nodes: RIPV, systemic veins tributary to AVS and, less frequently, towards the LIPV;

▪ right superior tracheobronchial lymph nodes: systemic veins tributary to AVS and less frequently, towards the RSPV;

▪ left superior tracheobronchial lymph nodes: systemic veins tributary to AVS.

Variant III

In three dissected cases, we found a superior venous trunk of the RSPV of a very small size, or with a retro-bronchial trajectory; in this last case being tributary to the RIPV and having a modified pathway.

In this variant, we did not identify any branches of the RSPV draining the extrapulmonary part of the right main bronchia. Under those circumstances, the venous drainage of the superior tracheobronchial and carinal lymph nodes follows the next ways (Figure 3, C and G):

▪ carinal lymph nodes: RIPV, systemic veins tributary to AVS and to a lesser extent to the LIPV;

▪ right and left superior tracheobronchial lymph nodes: to systemic veins tributary to AVS.

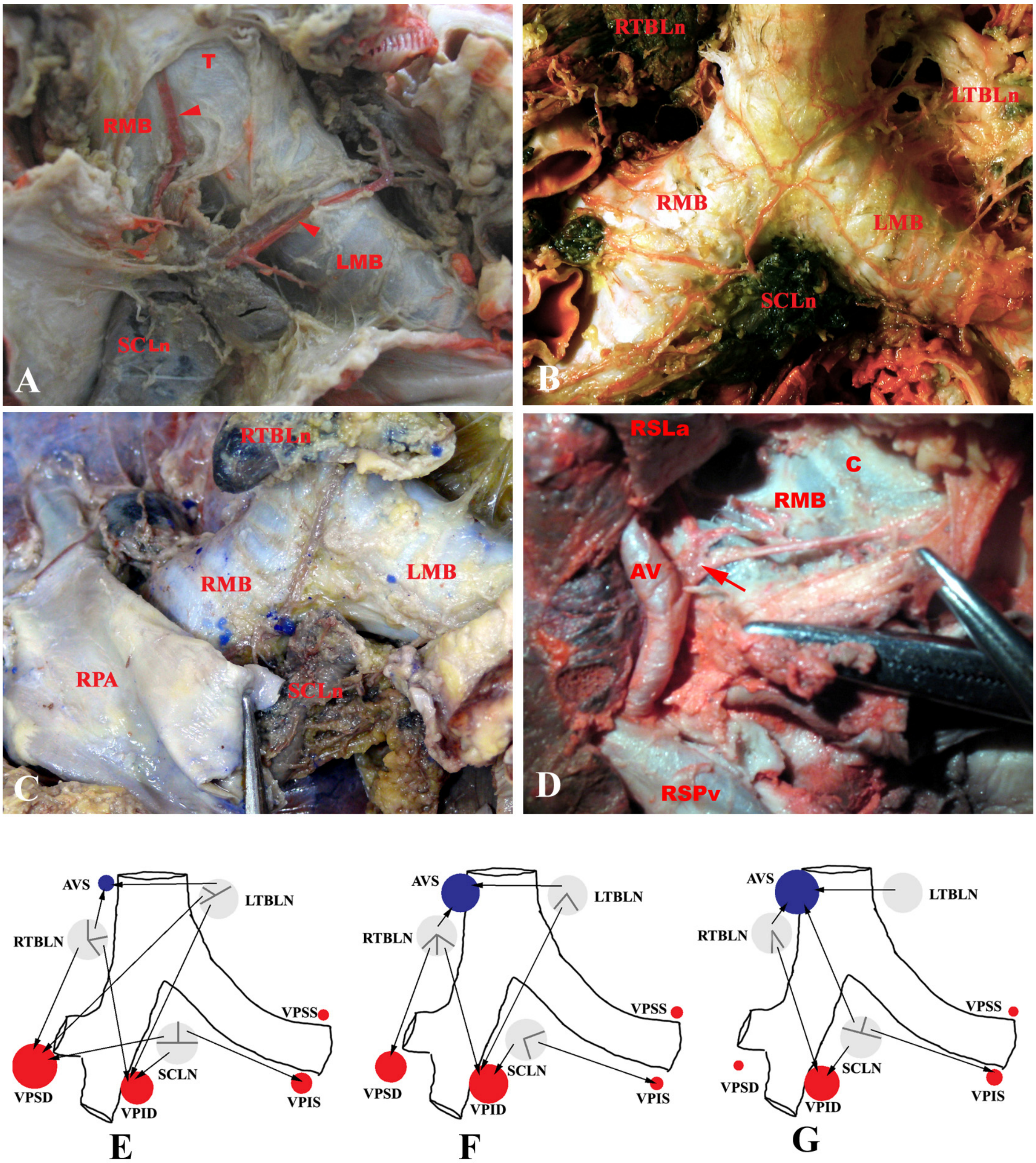

Figure 3 – ***Variants of pulmonary venous branches distribution at the levels of the main bronchia, carena and tracheobronchial lymph nodes. In variant I (A, E), a large venous network tributary to the right pulmonary veins can be noted. In variant II (B, F), a fine venous network tributary to the right pulmonary veins and left inferior pulmonary vein can be noted. In variant III (C, G), the venous network from the carena and the main bronchi origin levels is tributary to the azygos system vein. In variant I, a large apical venous trunk collecting the venous blood from the main bronchia, carena and left main bronchia origin can be noted (D).***

Discussion

It has been assumed that the venous drainage of the first two airway generations follow the same trajectory to that of the bronchial arteries, blood being collected by azygos venous system [4]. In sheep, under normal conditions, between 13% and 15% of bronchial blood flow turns into the right heart [20, 21]. Bronchial arteries of the intrapulmonary airways connect with the pulmonary circulation by bronchopulmonary anastomoses predominantly at a postcapillary level [22]. Bronchial circulation forms two vascular plexus in the bronchial wall: peribronchial plexus, localized into the adventitia; and submucous plexus, placed beneath the epithelial layer [23]. Submucous vascular plexus receives between 60% and 85% of the total blood flow of the bronchial arteries [24, 25].

Colored gelatin injection in the vascular system, followed by dissection under the surgical microscope is a time-consuming and a laborious method. When correctly applied, this method allows the accurately differentiation of the pulmonary or systemic venous components at the bronchial circulation level.

Retrograde injection of the pulmonary venous system with colored gelatin allowed us to reveal under excellent condition the distribution of the venous braches to the intra- and extrapulmonary airways walls. By utilizing this method, we revealed both the submucous and adventitial vascular plexus. Histological sections through the large bronchia showed that the pulmonary vein injection filled all the veins from the bronchial wall. We did not identify any venous branches unfilled by colored gelatin at the level of the intrapulmonary bronchial circulation that would be tributary to the bronchial veins.

We did not identify a proper adventitial venous plexus in the subsegmental bronchia. Pulmonary veins branches have a variable trajectory into the bronchial axis; collaterals arising at this level penetrate the muscular layer and compose a sectorial submucous plexus. That distribution could be explained by the airways and bronchial circulation development mechanism. The lung buds seem to branch into the mesenchyma at the levels where the pulmonary veins are already differentiated [26].

At the extrapulmonary level, we identified pulmonary venous branches distributed to the main bronchia, inferior trachea, tracheobronchial lymph nodes, pericardium and esophagus. Pulmonary veins anastomoses with bronchial veins at the level of the extrapulmonary airways wall. Those anastomoses have a variable pattern and thus we can describe a venous circulation predominantly pulmonary or predominantly systemic at the extrapulmonary airways wall and the tracheobronchial lymph nodes. Predominant pulmonary venous drainage of the extrapulmonary airways associates the presence of a large apical venous trunk of the RSPV. In that case, we found a venous drainage of the tracheobronchial lymph nodes provided by the pulmonary venous system. Those data could explain the appearance of the tracheobronchial lymphadenopaty associated to the significantly larger diameter of the RSPV in congestive heart failure. Also, pulmonary venous drainage of the extrapulmonary airways can explain the healing failure of a bronchial stump and bronchopleural fistula after anatomic lung resection. Bronchopleural fistula is more common after right than left pneumonectomy [27].

Conclusions

Pulmonary venous compartment of the bronchial circulation ensures at the intrapulmonary level the venous drainage of the all the structures contained by the bronchovascular sheath. Extrapulmonary component of the venous complex depends on the forming variants of the right superior pulmonary vein. In the case of large apical venous trunk of the RSPV, pulmonary veins drain the blood from the tracheobronchial lymph nodes, main bronchia and lower trachea. In the case of absence or a small apical venous trunk of RSPV, the pulmonary veins drain the venous blood from the level of the carinal lymph nodes and terminal portions of the main bronchia.

Acknowledgements

This study was supported by a CNCSIS grant IDEI No. 2943/2008.

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Received: January 25th, 2011

Accepted: April 20th, 2011