DOI: 10.5114/kitp.2013.38098

Anatomic variations of pulmonary vessels relevant with regard to lung tissue resections – literature review and personal experiences

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Kardiochirurgia i Torakochirurgia Polska 2013; 10 (3): 232–238

Abstract

The less invasive methods of lung tissue resection are becoming a clinical standard. This obligates surgeons to be well trained in the field of anatomy. Thus, we decided to create a comprehensive description of normal anatomy as well as anatomical variations of pulmonary vessels for the purpose of thoracic surgery procedures. We also retrospectively analyzed a database of 642 patients with lung cancer who underwent lung tissue resection at the Department of Surgery of the National Tuberculosis and Lung Diseases Research Institute in Warsaw (Poland), searching for descriptions of the anatomic variations observed during the surgical procedures. The results were subsequently compared to existing literature data. Variations of the arterial system were found in 8.72% of cases. Variations of the venous system were described in 3.12%. The frequency of variations in our database is lower than previously suspected based on the literature data. Nevertheless, several rare and potentially dangerous variations were described.

Key words: pulmonary arteries, pulmonary veins, variations.

Streszczenie

Małoinwazyjne metody anatomicznych resekcji miąższu płucnego stają się klinicznym standardem. Wymagają one od chirurga świetnej znajomości anatomii operowanego obszaru. Stworzono kompleksowy opis anatomii prawidłowej oraz znanych z piśmiennictwa zmienności naczyń płucnych na użytek torakochirurgii. Przeanalizowano również 642 przypadki zabiegów resekcji miąższu płucnego u pacjentów z rakiem niedrobnokomórkowym płuca operowanych w Klinice Chirurgii Instytutu Gruźlicy i Chorób Płuc w Warszawie, poszukując wzmianek o zmiennościach anatomicznych dostrzeżonych w trakcie zabiegu. Wyniki tej analizy zostały porównane z danymi z piśmiennictwa. Zmienność w obrębie układu tętniczego opisano w 8,72% przypadków, a układu żylnego w 3,12% przypadków. Częstość ta jest niższa, niż zakładana na postawie danych dostępnych w piśmiennictwie. Opisano natomiast kilka bardzo rzadkich, ale potencjalnie niebezpiecznych odmian.

Słowa kluczowe: tętnice płucne, żyły płucne, zmienność.

Introduction

The epidemiological problem posed by the still increasing incidence of lung tumors, non-small-cell cancer in particular, contributes to the rising number of performed thoracic surgery procedures, which constitute the primary method of treating this type of neoplasm in its early stages. The efforts aimed at reducing the number of perioperative complications and the invasiveness of the employed procedures resulted in the popularization of the anterolateral approach in thoracotomy and the introduction of minimally invasive methods, such as video-assisted thoracoscopic surgery (VATS), into everyday practice. These methods are more challenging for surgeons, as they require better understanding of anatomy in the ever smaller operating field. During pulmonary resections, they are also burdened with the risk of potential vessel collisions, a dangerous complication of such procedures.

The aim of this study is to present a detailed description of the normal anatomy of pulmonary veins and arteries, provide an overview of the literature in order to highlight the potentially dangerous and rare vascular variations that should be considered by the operator, and retrospectively analyze our own material from pulmonary resections performed at the Department of Surgery of the National Tuberculosis and Lung Diseases Research Institute in Warsaw (Poland) in order to estimate the clinical significance of this problem.

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Normal anatomy

As noted in the introduction, the understanding of normal anatomy constitutes the foundation of surgical knowledge. Hence, the description presented below will be based on reports deemed to be the most frequent in the literature. Pulmonary vessel anatomy was undoubtedly overlooked for many years, and classic guidebooks devote little space to the subject [1]. However, the rapid development of thoracic surgery, cardiology, and cardiac surgery attracted more attention to this topic.

The right pulmonary artery (Fig. 1) is anterior and inferior to the main bronchus, posterior and superior to the right pulmonary vein. The upper trunk branches off from the superolateral vessel circuit in the vicinity of the lung hilum and gives off vessels supplying most of the superior lobe (segments 1R, 3R, and, partially, 2R). The interlobar part of the artery (running along the oblique fissure) crosses the intermediate bronchi anteriorly. At this point, a posterior branch diverges from the artery to supply part of the 2R segment. The level of this branch also sets the level for the divergence of the branch running from the anteromedial vessel circuit to the middle lobe (segments 4R and 5R), most often forming a single trunk which quickly divides into vessels supplying the said segments. At the level of the two aforementioned branches or, more frequently, slightly distally to them, another artery branch leaves the posterior circuit of the interlobar segment of the right pulmonary artery and runs to the 6R segment. After this division, the trunk of the pulmonary artery leaves the interlobar fissure and becomes the common basal trunk (or root). It then gives off branches, most often arborescent in structure, running to the basal segments of the inferior lobe [2].

In the hilum of the lung, the left pulmonary artery (Fig. 2) lies superiorly to the superior lobe bronchus. It then crosses the diverging bronchi from above and enters the oblique fissure. At the hilum, the left pulmonary artery gives off branches to the superior lobe; although the most prevalent number of these branches is 4, it may vary significantly. For the sake of comparing the right and left side, the vascularization of the 1L, 2L, and 3L segments is considered separately from the vascularization of the lingula. The superior part of the superior lobe is most typically supplied by 2-3 branches diverging from the posterolateral vessel circuit. These are, respectively: a common trunk for segments 1L and 3L, a separate, more distal branch running to the 2L segment, and, sometimes, a separately diverging anterior descending branch for part of the 3L segment. A common trunk for segments 1L and 2L and a separate branch for the 3L segment constitute a norm that can be observed with similar frequency. At its interlobar segment, the left pulmonary artery gives off a typically singular branch running to the superior (apical) segment of the inferior lobe (segment 6L). The arteries supplying the lingula, forming a singular arterial trunk (for segments 4L and 5L), diverge from the lower circuit of the trunk in the interlobar fissure; this bifurcation is typically distal from the previous A6R branch and the distance between them may amount to 16 mm [2]. Further on, as on the right side, terminal branches leave the common basal trunk in an arborescent fashion; it is worth noting that the branch running to the posterior basal segment (10L) usually diverges at the highest point. Also of note is the fact that the majority of the population have no bronchi for the 7L segment; as a result, the arterial branch, which developmentally belongs to this segment, must be classified as the second branch supplying the widened 8L segment (left anteromedial basal).

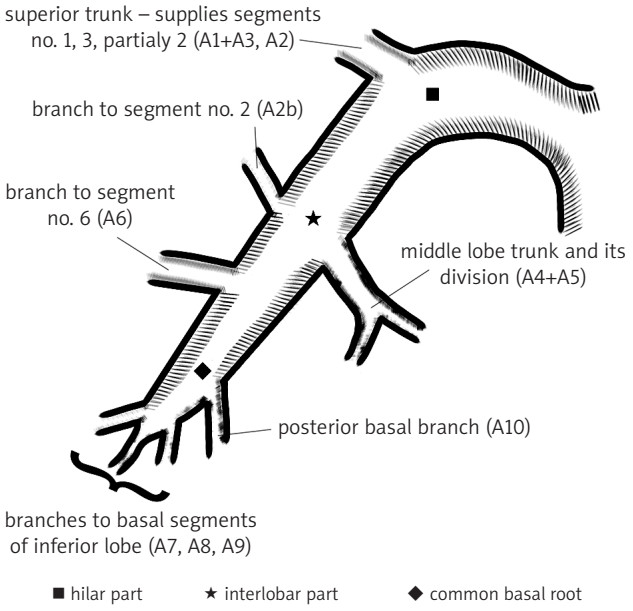

Fig. 1. Right pulmonary artery and its branches; number of branches and their order of origin is considered

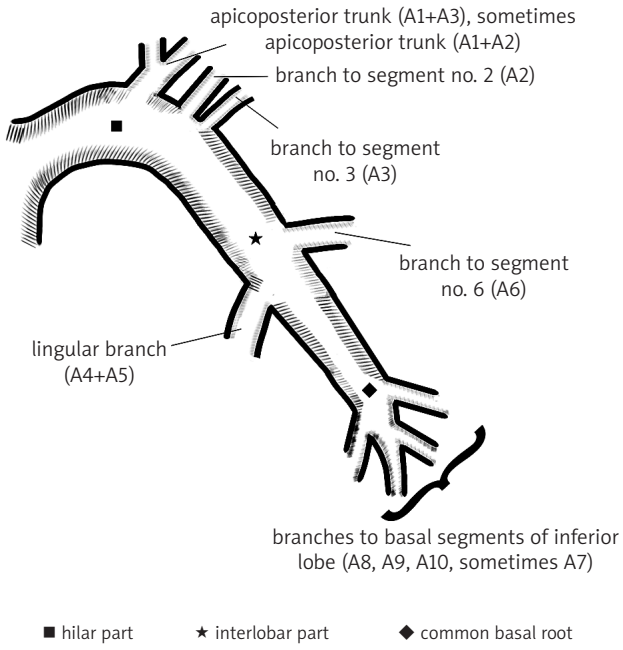

Fig. 2. Left pulmonary artery and its branches; number of branches and theirorder of origin is considered

Anatomically, two veins emptying into the left atrium can be observed on the right side and two more on the left side. The drainage area of each of these veins and the distance between the anastomosis and the orifice in the atrium and pericardium are of unquestionable importance. However, this topic is still insufficiently described in the literature.

On the right side, two veins emptying into the left atrium (LA) are to be expected: the superior pulmonary vein drains the superior lobe and, through a single venous trunk running from segments 4R and 5R, the middle lobe; the level at which the superior pulmonary vein is ultimately formed is usually the level of the distal end of the intermediate bronchus. In turn, the right inferior pulmonary vein drains the inferior lobe segments; the branch which joins it most proximally is the branch draining the 6R segment. The proximal anastomoses of the right inferior pulmonary vein branches are located less than 1 cm, on average, from their orifice [3].

On the left side, two veins can be observed that drain the area of the superior lobe (including the lingular segments) and the inferior lobe, respectively. The left inferior pulmonary vein is formed by the joining of the superior and inferior basal veins; it is then additionally joined by the drainage from segment 6L. The two left pulmonary veins enter the left atrium independently, but the distance between them is so small that the septum separating their orifices is not visible from the direction of the left atrial lumen.

The relatively short distance (5.4 mm, SD = 3.3) before the first bifurcation of the left inferior pulmonary vein (drainage from segment 6L – see above) is noteworthy, as it may result in incomplete drainage ligation during left lower lobectomy [3].

It should also be noted that although the dominant type of pulmonary vein connection structure is arborescent, its variations described as "brush-like" and "intermediate" are becoming increasingly frequent [2].

Own material

Descriptions of 642 randomly selected thoracic surgery procedures, performed at the Department of Surgery of the National Tuberculosis and Lung Diseases Research Institute in Warsaw (Poland) between January 1st 2005 and November 30th 2012, were used for the purpose of analyzing the discussed topic. All procedures were conducted due to oncological indications, as a method of treating non-small-cell lung cancer. 50 patients underwent pneumonectomy, while in the remaining 592 cases lobectomy was performed. In 5 cases, the procedure involved the use of VATS; in the remaining cases, the classic anterolateral thoracotomy approach was employed.

A retrospective analysis was conducted, aimed at finding reports describing the anatomy observed during the procedures. Only clear indications concerning the observed types and variations were included. After being collected, the data underwent basic analysis.

Results

Among the 642 analyzed descriptions of procedures, 76 contained anatomical descriptions that were not in accordance with the one included in the introduction to this article. Variations of the arterial system, particularly of its right side, were more frequent (56/642 cases, 8.72%). 17 descriptions pertained to a double branch leading to the 2R segment, while another 8 concerned doubling of the branch running to the middle lobe. Table I presents a detailed list of the arterial variations and their frequency.

Venous systems different from the norm described above were observed during 20 procedures (3.12%). Common venous drainage of both the right side (5 cases) and the left (4 cases) was prevalent. In a further 3 cases, the middle lobe vein emptied into the right inferior pulmonary vein. Table II presents a detailed list of the venous variations and their frequency.

Discussion

The system of pulmonary veins and arteries comes in a multitude of variations; its classical description, as noted above, fits approximately half of the general population. Calculating the frequency of variations that can potentially be dangerous is challenging, as the available literature lacks relevant data. In their work, Sivrikoz and Tulay noted variations of the arterial system during 6/55 right-sided lobectomies and 4/30 left-sided lobectomies [4]. The progress of a procedure burdened with increased anatomical risk depends on

Tab. I. The anatomic variations of the arterial system described in surgical reports in the order of frequency. The number of observed cases is provided in brackets

Two separate A2R branches [17]
Two arteries running to the middle lobe [8]
Two arteries running to the lingular segments (4L and 5L) [5]
Common branching point for A2R and A6R [4]
Two A6L branches [4]
Separate branching point for A1R and A3R [3]
Common A1+A2+A3 trunk from the right pulmonary artery [3]
Three branches to segment 2R [2]
Branch A6R from the A4+A5 trunk [1]
Additional A3R branch branching off in the fissure [1]
Branch A7R from the A4+A5 trunk [1]
Separate A1R branch and A2+A3R trunk [1]
Common trunk A1+A2+A3 from the left pulmonary artery [1]
Four branches running to segments 1,2,3L [1]
Very low branching point of A2L [1]
The short trunk running to the lingula divided into 3 branches [1]
Very low branching point of the trunk running to the lingula [1]
Right common arterial trunk divided into 3 branches [1]

the competence and experience of the surgeon. Table III presents the most important variations from this group.

The variations of the arterial supply on the right side concern mostly the number of branches running to individual segments and their branching points, as well as, to a lesser extent, their topography.

One should keep in mind that segments 2R and 3R may be supplied by multiple branches-up to 3 branching off separately from the superior trunk. A common "low" branching point of the arteries running to segments 2R and 6R (Fig. 3A) from the interlobar artery segment can also be problematic; the estimated frequency of its occurrence is varied, ranging from 1.53% to as much as 12% [2, 4]. Multiple branches (two or three) running to the middle lobe may be present in as many as 50% of patients [2]. A common arterial trunk leading to segment 7L and to the segments of the middle lobe (4R and 5R) has also been described [4]. The doubling of the branch leading to segment 6R is reported with the frequency varying from 6.97% to 12.5% [2, 4]. In approximately 33% of cases, it is reported that the distance between the last branch leading to the superior lobe and the trunk or branches running to the middle lobe may amount to 20 mm. In turn, even though the branch supplying segment 6R most frequently branches off either below or at the level of the middle lobe artery, its proximal divergence is also possible.

The variations on the left side may concern the number of arteries running to the superior lobe, which ranges from 2 to 7 (1-6 or 7 running to the segments of the superior part of the lobe and 1-3 running to the lingular segments) [2]. Arteries leading to segments 2L and 3L may also branch off via a common trunk with branches running to the lingular segments (most notably segment 4L); the frequency of this phenomenon can be estimated at approximately 20% [2].

Tab. II. The anatomic variations of the venous system described in surgical reports in the order of frequency. The number of noted cases is provided in brackets

Common trunk of the right pulmonary veins [5]
Common trunk of the left pulmonary veins [4]
Drainage from the middle lobe emptying into the inferior pulmonary vein [3]
Drainage from the middle lobe emptying into both the superior and the inferior pulmonary veins [2]
Separate atrial orifice of the vein draining the middle lobe [2]
Separate atrial orifice of V6R [1]
Two separate veins running from the middle lobe to the right pulmonary vein [1]
Separate atrial orifice of the lingular vein [1]
Drainage from the lingula emptying into the inferior pulmonary vein [1]

The literature also describes a common trunk for the arteries running to the lingula and the branches leading to segment 7L, which usually branches off from the common basal trunk (distally to both the branches running to the lingula and the branch leading to segment 6L) [4].

Three separate branches to the lingula, a variation considered to be rare, with its frequency estimated at 0.97-2% by different authors, were found by Sivrokoz and Tulay in 1/16 left upper lobectomies (6.25%) [4]. The doubling of the branch leading to segment 6L (Fig. 3B) is relatively common, with the frequency estimated at 7.14-27.2%; the two

Tab. III. Notable variations characterized by higher anatomic risk (see the article for more details)

Variation type	Incidence according to literature reports	Number of cases in our own material
Arterial system		
Common branching point of the arteries supplying segments 2R and 6R (Fig. 3A)	1.53-12%	4
Arteries supplying segment 6R branching off proximally to the middle lobe trunk	N/A	–
Common trunk of the arteries supplying segments 2L, 3L, and the lingual	20%	–
Common trunk of the arteries supplying segment 7L and the lingula	N/A	–
Three separate lingular arteries	0.97-2%	–
Two arteries supplying segment 6L (Fig. 3B)	7.14-27.3%	4
Venous system		
Two separate veins draining the middle lobe (Fig. 3C)	16.6%	1
Middle lobe vein emptying into the left atrium (Fig. 3D)	24-26%	2
Direct drainage from segment 6R (Fig. 3E)	N/A	1
Vein draining the right superior lobe running posteriorly to the intermediate bronchus	3.9-5.7%	
Lingular drainage emptying into the left inferior pulmonary vein (Fig. 3F)	N/A	1
Long common trunk of left pulmonary veins	N/A	–

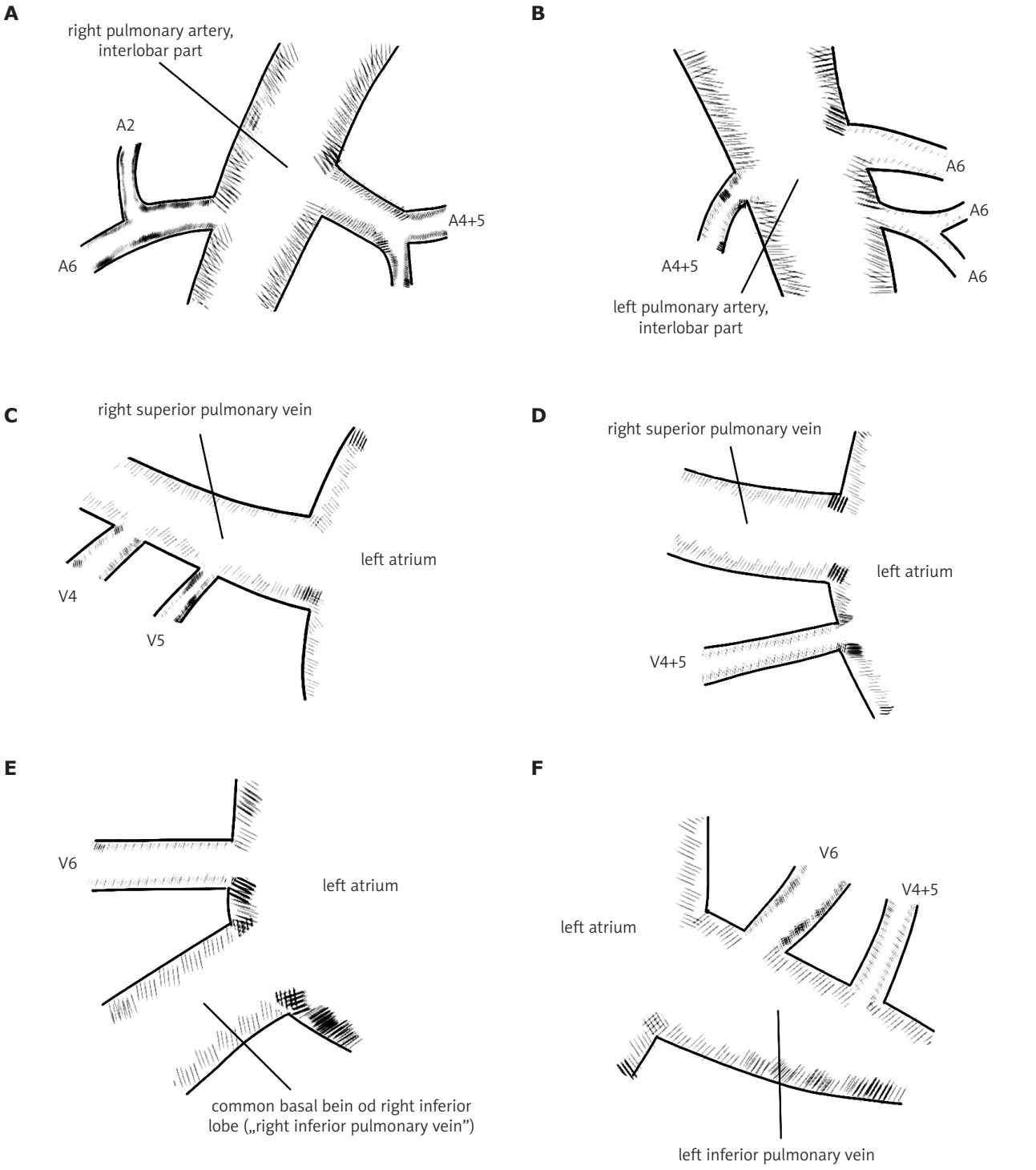

Fig. 3. Variations characterized by "higher anatomic risk" found in authors' own material. Detailed description in text and in Table III

vessels are frequently observed to branch off, respectively, proximally and distally to the lingular branches [2, 4].

Less common variations, regarding the location where the pulmonary arteries branch off from the systemic circulation, are reported as occurring primarily in the pediatric population and are frequently accompanied by congenital heart defects [5, 6].

The classic venous pattern (defined differently by different authors) on the right side pertains to approximately 60-68% of patients [2, 3]. One of the elements differentiating this group is the distance between the point at which the vein from the middle lobe anastomoses with the superior pulmonary vein and the atrial orifice. According to Yazar *et al*., two independent trunks draining the middle lobe and running to the right superior pulmonary vein (Fig. 3C) are to be expected in 16.6% of cases [7]. The most frequently observed variation, however, was a separate orifice of the middle lobe veins in the left atrium (Fig. 3D), which was

present in 24-26% of patients (with regard to the right side only or 9% when considering both sides) [2, 3, 7, 8]. Additional pulmonary veins (up to 5), entering the left atrium independently, were draining various segments of the right inferior lobe – most frequently the upper 6R segment (Fig. 3E) [3]. Drainage from segment 2R emptying into the vein of segment 6R, described by Maciejewski [2], should be mentioned here as well. In the literature there are also described single cases of varied course of the segmental vein of the superior lobe, posterior to the superior lobe bronchus and posterior to the intermediate bronchus, running to the vicinity of subcarinal lymph nodes and constituting a source of unexpected vascular collisions during vessel preparation [9]. The location of the right "posterior" pulmonary vein (one of the branches co-forming the right superior pulmonary vein) posterior to the intermediate bronchus, described in 3.9-5.7% of cases [10], appears to be even more significant. Drainage from the middle lobe to the inferior pulmonary vein was described in 3.3-5.5% of cases [3, 7]. Singular cases of drainage from the middle lobe to the superior and inferior pulmonary veins are also of interest; in such cases, the veins run from segment 4R down to the inferior pulmonary vein and from segment 5R to the superior pulmonary vein circuit. This phenomenon was estimated by one author to occur in approximately 3% of cases [11].

The left side appears to be even less variable, as the double-orifice type of pulmonary vein ending occurs in 86% of patients. More than half of them do not have a developed septum between the orifices. A similar type of close anastomosis, located less than 1 cm from a single common orifice of the left lung drainage in the left atrium, was observed in a further 10% of patients [3]. Lingular drainage emptying into the left inferior pulmonary vein has also been described (Fig. 3F) [11].

The calculated mean distance to the first bifurcation of individual pulmonary veins should be treated with caution, as there are different methods of establishing the boundary between the common drainage of pulmonary veins and the point of their inclusion in the left atrium.

According to Cronin *et al*., there is a statistically significant difference between the length of the superior veins and the shorter inferior veins – 16 mm and 10.2 mm, respectively. Statistically, the shortest segment is to be expected in the case of the right inferior pulmonary vein (mean: 6.97 mm) [8, 10].

The literature describes a common trunk of the left pulmonary veins, the length of which may be 16.8 mm [3] or even 26 mm [8].

The more acute angles of vein anastomoses on the right side (by 6 degrees on average) make the preparation of the more variable right-sided circuit even more difficult [10].

A clear tendency, congruent with literature reports, can be observed in our patient data. Although the frequency of the variations (8.99% and 3.56% for arterial and venous vessels, respectively) is lower than could be expected based on the literature data, this can be attributed to a defect of the retrospective study, as some of the variations were not considered "surprising" by experienced surgeons, which resulted in their omission from the routine procedure descriptions. Nevertheless, most of the variations, including those potentially dangerous, were reported in our material (Table III). Statistical conclusions should not be drawn from the presented data, nor should they be compared directly to the mentioned literature data, as they pertain to the description of a narrow operating field and constitute casuistic reports, rather than comprehensive anatomical information. Another limitation of the presented data considered by the authors of this study is the impossibility of interpreting certain morphometric data (e.g. interpreting statements such as "a short trunk of the pulmonary vein" or "low A2R branching point"), which resulted in the presentation of solely topographical descriptions. Planning a prospective study aimed at creating a comprehensive, intraoperative description of pulmonary vessels would surely be of use.

The increasing importance of minimally invasive techniques for performing lung tissue resections, such as VATS, has led to the search for efficacious methods of avoiding dangerous complications during such procedures. One undoubtedly efficacious method of evaluating pulmonary circulation is multi-slice computed tomography with 3D image processing (3D-MSCT); evidence for its precision is provided by numerous studies [8, 12, 13]. An increasing number of literature reports suggest that, within this protocol, computed tomography should be routinely performed before each thoracotomy or video-assisted thoracoscopic surgery in order to detect the potential variations described above. This form of examination may reduce the number of dangerous vascular complications [13-16].

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