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FOLIA MORPHOLOGICA

ISSN: 0015-5659

e-ISSN: 1644-3284

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DOI: 10.5603/FM.a2023.0011

Article type: Review article

Submitted: 2022-08-12

Accepted: 2022-09-26

Published online: 2023-02-16

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Jakub Wąsik et al., Lung segments from anatomy to surgery

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ABSTRACT

Bronchopulmonary segments are of increasing interest to clinicians because surgical procedures are emerging that maintain as much pulmonary function as possible. The conventional textbook borders between these segments, their many anatomical variations, and their numerous lymphatic or blood vessels, make them challenging for surgeons, especially thoracic surgeons. Fortunately, because imaging techniques such as 3D-CT are developing further, we can see the anatomical structure of the lungs in detail. Moreover, segmentectomy is now seen as an alternative to a more radical lobectomy, especially for lung cancer. This review explores the connection between the anatomical structure of the lungs, especially their segments, and surgical procedures. Further research on minimally invasive surgical procedures is timely as we can diagnose lung cancer and other diseases ever earlier. In this article, we will look at the latest trends in thoracic surgery. Importantly, we propose a classification of lung segments in reference to surgery difficulties due to their anatomy.

Key words: bronchopulmonary segment, lungs, diagnosis, thoracic surgery, anatomy, systematic review, segmentectomy, cancer

INTRODUCTION

In the structure of the lungs we can distinguish specific divisions into lobes, which in turn are divided into bronchopulmonary segments. The right lung has three lobes comprising 10 bronchopulmonary segments. The left lung is divided into two lobes, which also comprise 8-10 segments. Each segment has its own bronchus and is supplied by segmental branches of the pulmonary artery. Their main function is to deliver oxygen to the distal parts of the lungs [1].

Lung anatomy is highly variable, starting with the division into the bronchial tree, in which a cardiac bronchus or tracheal bronchus can be observed [21]. The pulmonary fissures and even the lobes also vary [10,52]. Finally, the segments are variable; for instance, there can be an additional segment [23].

Pulmonary segments are important in the clinic, starting with CT imaging showing changes in the lungs. Identifying segments on this basis can be difficult owing to the intersegmental planes of the lungs that divide the lobes into segments [11], so they are marked in various ways such as by inflation-deflation or applying contrast. One of the most common procedures in thoracic surgery is segmentectomy, in which a specific segment is excised [12]. This is often performed to treat benign lesions or cancer [19]. It can be performed by videotoracoscopy or robot or by open access. Each of these methods has advantages and disadvantages [88].

The main purpose of the present review is to explain how lung anatomy and its variability, especially in the segments, affect surgical procedures such as segmentectomy. Due to the division of the lung segments in the literature based on the bronchus that supplies it, we will make another division of the bronchopulmonary segments. It will be based on intersegmental planes and may facilitate the assessment of the difficulties of the surgery. As lung cancer is still a major challenge in oncology, particular emphasis is placed on minimally invasive procedures such as segmentectomy rather than the more radical lobectomy. This article will contain much information on the topic. We will also refer to one of the newer and less well known surgical procedures, subsegmentectomy.

CONTROVERSY ABOUT DIVISION

It is worth noting how recently the nomenclature relating to segmentation of the lobes of the lungs was adopted. The current account of segmentation was introduced by Jackson and Huber in 1943 [3]. They did not fully agree with the terminology proposed by other researchers because the names of individual segments did not quite correspond to their anatomical orientation in space. Additionally, they observed anatomical variations in the lung fissures, which will be discussed later. Therefore, they concluded that the lungs should be divided according to the bronchial distribution [3].

However, this did not end the discussion about division because, as Boyden observed in 1953 [44], there was still no consistency in marking segment numbers, particularly in relation to the bronchial tree (although he noted that some medical textbooks such as Gray had already adopted the terminology proposed by Jackson and Huber [3]). His objection concerned, *inter alia*, the nomenclature of the B7 and B8 bronchi, especially the omission of the B7 bronchus on the left side of the lung on the basis of comparative anatomy and the rarity of its lesions [44]. Boyden [44] also wished to adhere to the terminology adopted by Jackson and Huber [3] until the matter was discussed by an international committee [44]. A year later, Kassay commented on this discussion, supporting Boyden's suggestions [45], and mentioned the subsuperior bronchus, which we will also look at later in view of its clinical implications.

ANATOMY

To begin with, a definition of “the bronchopulmonary segment” is worthwhile. The bronchopulmonary segment is a pyramid-shaped part of a lobe with its base facing towards the pleural surface and its apex facing the root of the lung [1,2]. Each segment is named after the tertiary bronchus that supplies it, which originates from the secondary lobar bronchus [1].

The three lobes of the right lung are divided into 10 bronchopulmonary segments. The two lobes of the left lung are also divided into 8-10 segments. Each segment is supplied by branches of the left and right pulmonary arteries, which supply the left and right segments, respectively [1]. These branches are further divided into smaller segmental and sub-segmental vessels. The pulmonary artery divides below the aortic arch at the level of the tracheal spur [4].

The segmental and subsegmental pulmonary arteries are generally parallel to the segmental and subsegmental bronchi and are named according to the bronchopulmonary segments they supply [4]. Thus, when a segment is marked as S4, we designate its artery as A4. The same convention is used for veins and bronchi.

At this point, a more precise description of the division into segments is needed [1-6]. There are three segments in the superior lobe of the right lung, apical (S1), posterior (S2) and anterior (S3), two in the middle lobe, lateral (S4) and medial (S5), and five in the the inferior lobe, superior (S6), medial-basal (S7), anterior-basal (S8), lateral-basal (S9) and posterior-basal (S10) [1,2]. The superior and inferior lobes of the left lung are each divided into five segments. The following are distinguished in the superior lobe: apical (S1), posterior (S2), anterior (S3), superior lingula (S4) and inferior lingula (S5). In the inferior lobe we distinguish: superior (S6), medial basal (S7), anterior basal (S8), lateral basal (S9) and posterior basal (S10) [1,2] – Fig. 1, 2.

The quoted number of left lung segments (8-10) varies [1,3,5] because the medial (S7) and anterior basal (S8) segments are combined into an anteromedial segment (S7+S8), while the apical (S1) and posterior (S2) segments together give the apicoposterior segment (S1+S2) [6]. This occurs because the anterior and medial segments originate from a single branch of the lower lobe bronchus [2].

ANATOMICAL VARIATION

The division of the bronchial tree is key to the division of the lungs into segments. Ghaye et al. [21] studied bronchial abnormalities in patients undergoing imaging tests and found that an accessory cardiac bronchus (ACB) occurred in 14 of 17,500 patients (0.08%). The ACB results from an abnormal evolution of the heart bud during the first week of embryo development [60]. Anatomically speaking, it arises from the inner wall of the right main or intermediate bronchus [61].

Another anatomical variant described by Ghaye et al. [21] is the tracheal bronchus, which occurred in 35 patients out of the 17,500 tested (0.2%). Although the name suggests an origin from the trachea, the study showed that most tracheal bronchi originated from distal bronchi (68.6%) and only a few from the trachea (22.9%). The tracheal bronchus is the result of additional tracheal outgrowth early in development [62]. Knowledge of the structure of the lung, in particular its vascularization and the anatomical variations of the fissures, lobes and hilum structures, has important clinical implications. For example, the apical segment can be supplied by two branches of the segmental artery of the lower right lobe [4]. Additional lobes or fissures can cause radiographs to be misinterpreted [8].

Martín-Ruiz et al. [9] studied anatomical variations of the lungs by dissecting the lungs of 17 cadavers and examining bronchoscopies of 50 hospital patients. Only 37.31% of lung pairs showed no variability [9]. In this study, the right lower lobe showed the highest percentage variability; the middle and left lower lobes showed the lowest. A dissection study by Bostanci et al. [10] also revealed that 77% of lungs had anatomical variations in their fissures (though neither lung had accesory or absent lobes) [10]. Gonlugur et al. [51] conducted bronchoscopies on a large number of patients (1880 male and 670 female) over eight years to identify major variations of the tracheobronchial tree. The most common variation was a bifurcate pattern in the upper lobe of the right lung, and an additional bronchus after the lingular division in the left. However, these variants were not frequent; only 67 patients (2.6% of the population studied) showed major variations.

The azygos lobe is interesting. It is not an additional lobe, but a part of the upper lobe of the right lung; it does not have its own bronchus and does not correspond to any specific bronchopulmonary segment [52]. It is made up of the arch of the azygos vein, which creates a depression that can be called a fissure in this lobe [2,53]. Its frequency is low [2,10,53], so it can be perceived as a different anatomical structure with or within the lung on CT images, even by some medical residents [84]. Interestingly, as suggested in the extensive study by Yurasakpong et al. [83], it could be associated with genetic factors (such as Turner's syndrome) and/or cardiopulmonary malformation. Because of this anomaly, the apical segment lies on the medial or mediastinal side of the depression [10]. It is usually diagnosed by chance during a chest X-ray or CT [85]. It is also found in children, but has not been implicated in recurrent infections [85]. There are descriptions of the azygos lobe in the literature that also refer to surgery.

The first case we will describe was presented by Akhtar et al. [52]. A 55-year-old male presented with a complaint of dry cough and dyspnea and chest X ray and chest CT were performed. The azygos lobe was visible on radiograms thanks to the azygos fissure [52,53].

This lobe is important in surgery because the azygos vein and its mesenteriole can cover the sympathetic chain [54].

The second case was presented by Gill et al. [55]. During a thoracoscopic sympathectomy, an azygos lobe was spotted in a patient with hyperhidrosis. Care was taken not to injure the azygos vein, otherwise the surgery would have been converted to a thoracotomy [55].

There are also descriptions of a left azygos lobe in the literature, but it is extremely rare [86,87].

Table 1 shows how many anatomical variants there can be of just one element, i.e. the pulmonary fissure [10,37,38,43].

Table 1. Comparison of the frequencies of complete, incomplete and absent fissures in lungs based on autopsies

Study	**Right lung, frequency %**						**Left lung, frequency %**		
	Oblique fissure			**Horizontal fissure**			**Oblique fissure**		
	Complete	**Incomplete**	**Absent**	**Complete**	**Incomplete**	**Absent**	**Complete**	**Incomplete**	**Absent**
West et al. (2020)	64.2	35.8	-	22.2	66.7	11.1	81.5	16.0	2.5
Bostanci et al. (2019)	-	68.4	-	-	84.5	4.3	-	63.0	-
Sudikshya et al. (2018)	69.6	30.4	-	52.2	34.8	13.0	48.2	51.9	-
George et al. (2014)	-	3.1	-	-	35.4	3.07	-	15.1	-

SURGICAL PROCEDURES

Computed tomography (CT) is used to visualize the lung segments. However, as previously mentioned, the automatic formation of images of segments based on CT can be hampered by dissimilarities in pulmonary fissures or disease [8]. Using imaging methods such as CT, it is difficult to distinguish each lung segment by tracking the course of the intersegmental planes of the lungs [11], which divide the lobes into segments. Intersegmental veins also run through these planes [2].

In surgical procedures, inflation-deflation is used to distinguish a segment, using the difference in ventilation between the target and other segments [11]. In this method, the bronchus connected to the segment we want to excise is ligated, while the rest of the lung is inflated by forcing air into the bronchi [56]. This enables us to distinguish visually between the uninflated segment and the rest. Another method, the opposite of inflation-deflation, was presented by Kamiyoshihara et al. [56]. It involves introducing air through a butterfly needle into the selected segmental bronchus, which expands the segment [13,14]; air is forced into the distal part of the bronchus while the proximal part is constricted [56].

The above-mentioned methods are limited, because if the intersegmental planes are separated by electrocoagulation, air can escape from the intersegmental space and the inflated lung collapses [15]. This of course complicates the procedure because the inflation and deflation line must then be reestablished. Another limitation is the difficulty of locating this plane in emphysema patients [14,16]. Lung diseases such as emphysema and interstitial pneumonia [19] can lead to pre-indications for surgical procedures such as segmentectomy, which we will focus on later.

One of the newer methods for separating a bronchopulmonary segment is ligation of the target segmental artery, as presented by Zhao et al. [11]. The segmental artery is ligated with a stapler block, and then unilateral ventilation is performed and this artery is cut. The visual changes are observed. The target segment darkens owing to ischemia and therefore also hypoxia, while the rest of the lungs remain pink [11].

Gao and Liu [17] proposed the designation of arteriopulmonary segments instead of bronchial segments because in most cases studied (90%) the segmental bronchi were accompanied by segmental arteries visible on CT imaging (by administering contrast intravenously [17]). All this could be distinguished owing to the segmented arrangement of the arteries that formed arteriopulmonary segments with visible gaps between them. Moreover, these segments were visible from any viewpoint, anterior, lateral or posterior [17].

The abovementioned intersegmental plane is significant for segmentectomy. If there is only one plane to identify, then segment resection is considered technically simple; however, if there are two or more, it is more challenging for the entire operating team, especially the thoracic surgeon [18]. Intersegmental veins serve as anatomical landmarks for preparing the middle part of the intersegmental plane [19]. In contrast, the demarcation line on the lung surface helps when the peripheral part of the intersegmental plane is prepared [19,20]. The demarcation line is created on the basis of the previously mentioned difference between segment deflation and inflation, and it is marked by electrocoagulation so the activity does not have to be repeated [7]. For an upper lobe segmentectomy, the middle plane is identified first and then the peripheral one [74].

Anatomical variations of the bronchi are worth mentioning, specifically their influence on treatment. Deviations of bronchial divisions from the norm most often concern the lobes and segmental bronchi [21]. One example of bronchial variation is a displaced left apicoposterior bronchus (B1+2) described by Yanagiya et al. [22]. Left lung segmentectomy (S1 + S2) was performed on a male patient with a ground-glass nodule. Of course, chest CT with 3D imaging was very helpful in this procedure. The bronchial abnormality arose at the back of the left main pulmonary artery, so the bronchus had to be accessed from the posterior side [22].

Maki et al. [23] observed an additional bronchi (B*) in 129 (24.0%) patients undergoing CT imaging. Martín-Ruiz et al. [9] (previously mentioned in the context of anatomical variations of the lungs) provided quantitative information about B*: it occurred in 19.4% of cases, mainly on the right side (most in the right lower lobe, then the right upper lobe). Similar results were obtained by Nagashima et al. [63] from 3D-CT images of patients with changes in the respiratory system or mediastinum before surgery. A subsuperior segmental bronchus was detected in 55 cases (20.4%) [63].

Liu et al. [24] distinguished three types of subsuperior segmental bronchus according to the direction. The first is a posterior bronchus between B6 and B10 (known as the narrow sense of a subsuperior segmental bronchus), observed in 10.5% of patients. The second is a lateral one between B6 and B9 (4.6%) and the third is anterior, between B6 and B8 (1.8%). This bronchus is also associated with a change in the intersegmetal plane [24].

If there is a B*, how is it connected to the segment? An additional segment called the subsuperior segment (S*) can be distinguished between S6 and S8-S10, coexisting with the accessory bronchus and having its own vascularization [24,63]. There is very little literature about S*.

Shimizu et al. [25] described two patients who underwent segmentectomy. The first had two nodules in the S9 and S* segments of the right lung. By applying traction on B* they found an additional segmental artery (A*). The surgeon made a decision about S* segmentectomy with S9 wedge resection on the basis of CT images and tumor location. The second patient had a pulmonary hamartoma at the boundary of the S6 and S* segments. In this case, it was decided to perform a bisegmentectomy. In both cases, the presence of B* and A* had to be taken into account (although there was no additional vein to collect blood from this segment, nor were lymph vessels mentioned). Sometimes, if the tumor is on the border between two segments, as in the second case, bisegmentectomy should be considered to ensure an appropriate surgical margin [25].

In another case report by Liu et al. [64], the patient had a nodule in S* of the left lower lung. There were anatomical similarities to the earlier case in that the segment had its own bronchus and artery. In this case, removing the nodule by wedge resection would have been difficult, so a segmentectomy was performed. The independent S* resection was intended to ensure more fuctional reserve. A uniportal VATS was used to minimize muscle and intercostal nerve injury.

Both of these cases can be considered very important for S* segmentectomy. Shimizu et al. [25] were the first to perform the procedure using four ports, while Liu et al. [64] were the first to perform it using a single port. Most importantly, as the authors [25] of the first case report noted, such operations are technically possible. On the other hand, Maki et al. [23] noted that single segmentectomy of S* using pulmonary veins to distinguish the intersegmental planes would be difficult because there are multiple intersegmental veins and S* is a small segment. Interestingly, a subsuperior bronchus, especially in the right lung, had already been described by Kassay [45], who added that it merits an update of the nomenclature.

Other variations concern the previously-mentioned lung fissures. These variations have clinical implications as patients with an incomplete fissure are more likely to experience postoperative air leakage following a lobectomy, which can necessitate a sleeve lobectomy [26]. Sleeve lobectomy is performed if a tumor arises at the origin of a lobar bronchus; it focuses on removing the lobe of the lung with part of the main bronchus [65]. It is not difficult to guess that this location makes resection of the part of the lung affected by the tumor the only possibility, if complete pneumonectomy is to be avoided [65].

We mentioned earlier that 3D-CT using intravenous contrast is needed to visualize the course of the pulmonary vessels. However, the surgeon cannot rely on radiographic images alone; they have a margin of error. Therefore, it is also important to determine the intersegmental plane in the target lung in a different form or as a supplement to inflation-deflation. To determine the segment, indocyanine green (ICG) is administered; it binds to lipoprotein α1 in the blood [28] and fluoresces.

There are different ways to implement this. One is transbronchial administration with an ultrathin bronchoscope [28,40], followed by airflow to accelerate diffusion. Before the ICG is administered, the target segmental blood vessels and bronchi are separated [27], so the target segment has no blood supply and is therefore non-fluorescent. Another way is to administer the ICG intravenously [66]. An infrared camera is used to observe the colored segments, which assume a light green color [40]. The diode emits at 760-805 nm wavelength [28,66], which is captured by ICG bound to the plasma protein; reflected light with a similar wavelength (830 nm) is then captured by the camera [66]. This method of ICG fluorescence imaging is widely used, not only in segmentectomy, because it has side effects and is simple [28]. The intersegmental planes can be identified quickly in the vast majority (88-95.6%) of cases; the contrast fluorescence is maximum after 20-30 seconds [27,29,66]. In most cases the intersegmental plane disappears within two minutes [27,29], which should be enough time for the surgeon to mark it by electrocoagulation [7].

It is important not to give too much ICG. As noted by Wada et al. [40], if a nontarget segment has an excess of the solution, dots appear on the referred segment, precluding separation of the intersegmental plane [40]. Another limitation on this method is the variable thickness of the pleura [40], or diseases such as pulmonary emphysema [29].

Zhang et al. [30] reported a new method, evaluated by both *in vivo* research and surgery, for determining interstitial planes by administering methylene blue into the target segmental bronchus using a syringe with an intravenous needle, causing that segment to turn blue [30]. This is an interesting discovery but it has limitations. In the *in vivo* study the blue color lasted at least 30 minutes, but the authors [30] did not specify how long it remained during the operation; they only mentioned that the mean was three minutes [30].

SEGMENTECTOMY

One of the most common procedures in thoracic surgery is segmentectomy, involving resection of a given lung segment [12]. The essence of this procedure is to isolate and divide the segmental bronchus, and then excise it along with the peripheral lung parenchyma [31]. Not only the segmental bronchi are excised, but also arteries and intrasegmental veins, with possible preservation of intersegmental veins [12]. In most cases, the surgery begins with ligation of the segmental pulmonary vein, and then, depending on the segment, ligation of the bronchus or artery [31]. Segmental bronchi are separated by surgical staplers [16] or ligated with a silk thread [33]. There are several indications for this treatment. It is performed for metastases or benign lesions, and it is an option for early-stage lung cancers such as non-small cell lung cancer (NSCLC), or for patients who are not typed for standard lobectomy [19,32]. Another indication, although definitely less common, is lung infection [42]. Along with wedge resections, it is one of the most frequently used methods for sublobar resection [33]. Among the most frequently excised segments are those in the superior lobe of the right lung [32,34]. Two tables are presented below: table 2 summarizes the histological diagnoses in patients who underwent segmentectomy, and table 3 gives the statistics of the types of segmentectomy.

Table 2. Comparision of histological diagnoses in patients undergoing segmentectomy

	Suzuki et al. [18]	**Yamashita et al. [69]**	**Hwang et al. [70]**	**Cao et al. [73]**
n	552	90	100	809
Squamous cell carcinoma	38 (6.9%)	11 (12%)	15 (15%)	182 (22.5%)
Adenocarcinoma	483 (87.5%)	74 (82%)	80 (80%)	529 (65.4%)
Large cell carcinoma	1 (0.2%)	-	-	-
Non-small carcinoma	30 (5.4%)	-	-	-
Others	-	5 (6%)	5 (5%)	98 (12.1%)

Note: in Yamashita et al. [69], adenocarcinoma *in situ* and minimally invasive adenocarcinoma were also included with adenocarcinoma

Table 3. Types of segmentectomy

	Pischik and Kovalenko, 2018	Gossot et al., 2016	Hwang et al., 2014	Yamashita el al., 2012	Ojanguren et al., 2016
Right lung	40%	41.7%	43.0%	51.1%	47.3%
S1	5.6%	0.4%	-	6.7%	-
S2	8.9%	0.4%	5.0%	6.7%	-
S3	2.2%	1.7%	5.0%	7.8%	0.6%
S6	10%	9.8%	17.0%	10%	10.3%
S7	-	-	1.0%	-	-
S8	1.1%	0.4%	3.0%	2.2%	0.6%
S1+S2	6.7%	17.4%	-	1.1%	23.0%
S9+S10	1.1%	0.9%	-	2.2%	0.6%
Leftlung	60%	58.3%	57.0%	48.9%	52.7%
S2	1.1%	0.4%	-	-	0.6%
S3	2.2%	-	-	2.2%	-
S4	-	-	-	1.1%	-
S6	7.8%	14.5%	9.0%	7.8%	13.9%
S8	-	0.9%	-	3.3%	-
S10	1.1%	-	1.0%	-	-
S1+S2	15.6%	7.7%	-	3.3%	7.8%
S9+S10	-	2.1%	-	1.1%	3.6%

For segmentectomy, a chest CT scan is necessary to visualize the veins and arteries [15,16,33]. The patient receives intravenous contrast, which shows the courses of blood vessels, making it possible to reconstruct those courses on the images [74]. Three-dimensional tomography has the advantage over two-dimensional because the surgeon can view the image from all sides and freely zoom in and out. This is essential for locating structures, including pathological ones such as a nodule deep in the lung parenchyma on the border between two segments [12]. In such cases, three-dimensional computed tomographic angiography (3D-CT angio) can help to determine the vascularization of the lung very accurately, along with the tiny arteries around the tumor [67]. It can also assist with imaging during surgery with the C-arm [16].

The C-arm is a great convenience for the surgeon since the lung volume can change because of inflation or collapse. It also allows the location of the tumor to be monitored continuously and its distance assessed. This shows the importance of cooperation between radiologists and surgeons, because radiographic images facilitate the ligation and dissection of segmental vessels and reveal changes [16,67].

The technical aspects of the procedure should also be discussed, focusing not only on lung cancers or anatomical variations. Segmentectomy is performed under general anesthesia with double-lumen endotracheal tube intubation [34,70]. There are several methods of surgical access to the lung segment. Video-Assisted Thoracic Surgery (VATS) can be used, during which the patient lies in the lateral decubitus position, and the working port is performed 4-7 cm in the fourth or fifth intercostal space [14,34]. The number of access ports is usually 1-4 [19]. Thus, additional ports of smaller diameter can be made, for example in the seventh intercostal space in the anterior axillary line, or the eighth/ninth intercostal space in the posterior axillary line [14,68]. During the operation with a single-port system, additional ports can be made if the surgeon encounters problems such as difficult access to nodules or pleural adhesions [13]. An endoscope is inserted through one port, which acts as an extension of the surgeon's eye and is necessary throughout the operation. It allows the operation to be previewed on the screen [69]. Before the surgeon starts working on the segment, a preliminary examination is needed to exclude conditions that preclude surgery such as pleural cancer [68].

A more automated variation of VATS is a robotic operation [75] in which the surgeon controls the robotic arms with the surgical instruments using foot pedals and a console [76].

Robot arms mimic the movements of human shoulders and wrists, but have the obvious advantage of filtering out physiological tremor [77]. Although studies show that this is the most expensive treatment option because of the cost of robotic-specific supplies, the hospitalization cost is reduced because the median length of stay is shorter than with VATS and open approaches [88, 89].

Another method is segmentectomy with an open approach [78]. As the name suggests, axillary thoracotomy or posterolateral thoracotomy is performed in this case, with possible muscle sparing [79, 80]. The duration of surgery is shorter than with VATS or the robotic technique, but the median hospital stay is the longest [88, 89].

Since the procedures are aimed at minimizing invasiveness, we ask whether, in relation to anesthesia, new methods are also tested for the benefit of the patient or the medical staff. The literature throws some light on this. Liu et al. [13] recently reported on the possibility of using nonintubated uniportal thoracoscopic segmentectomy instead of intubation for patients with early lung cancer, which could reduce the number of surgical complications resulting from endotracheal intubation. However, as they point out, it is a newly-developed method with risks, such as hypoxia or hypercapnia in patients with impaired respiratory function.These methods without intubation had been proposed earlier; in 2014, a similar method was presented by Hung et al. [47], also using intravenous fentanyl as premedication. The difference lay in the surgical access; a method with three ports was used. Both studies mention the possibility of reflex cough during manipulations around the hilum of the lungs, which can be prevented by a vagal nerve block. The nonintubated method was also described by Liu et al. [48], who noted the importance of studies on the long-term prognosis for patients undergoing such surgery.

It is important to remember lymph drainage in the lungs, including drainage through the intersegmental veins. If these are associated with the tumor their removal should be considered because tumor cells could migrate through the lymphatic vessels [15]. There can be lymph nodes at the beginning of a segmental bronchus, so they must be cleared of lymph and evaluated by a surgeon [34].

Topol and Masłoń [41] observed that a small percentage (5.2%) of lymphatic vessels in their cadaveric study crossed the borders of bronchopulmonary segments. A small proportion of these vessels (7.4%) also run to lymph nodes in another region, so adjacent segments should be carefully observed because of the possibility of metastasis. Watanabe et al. [49] found that patients with non-small cell lung cancer (NSCLC) with mediastinal lymph node metastasis (pN2) were more likely to develop upper mediastinal metastases in upper segment lesions than the basal segment. They were also more likely to develop metastases to the pericardium if there was metastasis to the superior mediastinum [49]. Lin et al. conducted similar studies on adenocarcinoma [50]. They showed that patients with basal segment tumors had a lower probability of freedom from recurrence than those with upper segment tumors [50].

It was mentioned earlier that segmentectomy is an option for patients who do not qualify for lobectomy, which is undoubtedly more extensive surgery. The two methods should be compared to see the potential advantages and disadvantages of segmentecotmy. Compared to lobectomy, performed routinely in lung cancer patients [42], segmentectomy entails slightly more blood loss during surgery, as well as air leakage. However, this difference is not large; the median was 44.5 vs 50 ml [18] in a study by Suzuki et al. [18] on comparable groups of patients who underwent lobectomy (n=554) and segmentectomy (n=552). Another study also reported low intraoperative blood loss in segmentectomy, the median being 60 ml [34]. Segmentectomy also had a shorter mean operation time than lobectomy for stage I of the TNM classification in NSCLC, which had a significant impact on the older patients who underwent surgery [32]. There were greater decreases in FVC (forced vital capacity), FEV1 (forced expiratory volume in 1 second) and MVV (maximum voluntary ventilation) in patients undergoing lobectomy than segmentectomy (one year after surgery), although, as in lobectomy, there was a significant decrease in DLCO [35]. The risk of complications does not differ significantly from that in lobectomy, the most common ones being bronchopneumonia, prolonged air leak, and atrial fibrillation [42]. Segmentectomy is also associated with low postoperative mortality [18,32,34,42,69]. To prevent air leakage, continuous over-and-over suturing should be instituted; and to prevent later leakage, sealing materials such as polyglycolic acid felt can be used [7,14].

Possible complications can also arise from variant anatomy: incorrect division of the intersegmental vein, or the accidental cutting of one of the veins supplying the bronchopulmonary segment, can cause postoperative hemoptysis [12,71,72]. Another example is confusion of the variant lingular segmental artery with an anterior segmental artery during a left upper or anterior segmentectomy [12].

The abovementioned anatomical variations show how important anatomical knowledge is for performing a segmentectomy procedure. Cooperation by the patient is also important; he should return regularly for postoperative check-ups, having a chest X-ray and CT scan to ensure that the tumor has been completely resected and there is no recurrence [70].

Is segmentectomy similar for each segment, or are some segments easier or more difficult to access operatively; and if there are differences, where do they come from? The literature indicates that there is no simple answer. Suzuki et al. [18] and Oizumi et al. [36] defined a simple segmentectomy as one that takes place along one intersegmental plane, or has been described in the literature; it concerns the S6 segment of the right lung and the S5-S6 segments of the left lung. More studies focusing on this division including both simple and difficult segmentectomies would be worthwhile because, as Oizumi et al. [36] noted, many factors are involved in the technical difficulty including the angles of the preparation surface, the number of cases described, and the location of the bronchial pulmonary artery within the segment. A similar impression can be obtained from, for example, Yotsukura et al. [27], who described simple segmentectomy with reference to left S1 + 2 and S3, left S4 + 5, S6, or basilar segments. It is worth describing the technique of the operation with reference to the abovementioned superior segment. Yang et al. [31] describe the resection beginning with mobilization of the inferior pulmonary vein to identify a vein from the target segment, followed by division of a venous branch with a linear stapler. The artery is then ligated so that the lung parenchyma can be divided.

There is no doubt that segmentectomy is one of the more demanding procedures because of the sizes of the structures involved, and their fleshiness and delicacy. The surgeon aims to minimize the impairment of lung function, so the operation is performed with the use of a camera, which can also be a disadvantage if to the image cannot be seen physically but only by previewing it on screen. For a difficult segmentectomy, the criterion could be, for example, segment size. For instance, S9 and S10 are rather small segments, so creating an intersegmental plane for them can be technically difficult [23].

In a segmentectomy to treat cancer, the surgical margins should be extending at least 2 cm outside the lesion or should be 2 cm greater than the tumor size [12,18,72]. For this to be possible, the size of the segment should be taken into account. Ueda et al. showed that the right medial-basal (S7) is smallest and the left apicoposterior segment (S1+S2) largest, which bears on the possibility of segmentectomy of any given segment [39]. This report is very important for anticipating the success of a segmentectomy. However, it has disadvantages, considering that if there is a tumor in S1 or S2, only a S1+S2 bisegmentectomy should be performed. Ueda et al. [39] was cited by Kawakita et al. [7], who reported a successful S7 segmentectomy in a patient with a metastasis in this segment. They noticed that S7 segmentectomy is rare because this segment is so small. Sarsama et al. estimated the volume of the S6 segment from vein, artery and bronchus areas based on CT image reconstruction [81]; the vein gave the largest segmental volume, while the bronchus gave the smallest. This study shows that segment volume and intersegmental planes can differ depending on the reference point adopted [81].

HOW TO DIVIDE A BRONCHOPULMONARY SEGMENT FROM ANATOMY TO SURGERY?

Due to the different operational divisions of all segments into the simple and difficult ones in the above-mentioned literature, we propose divison of the segments based on their anatomy. The criterion is the number of intersegmental planes surrounding the segment. It is related to the necessity to mark segments in the case of surgical procedures with the use of intersegmental planes. The segment that is easier to operate on is cut by 1 intersegmental plane, while the more difficult segment is cut by 2 or more. As to S2 in right lung, there are two intersegmental planes - one is a plane between S1 and S2, and the other is a plane between S2 and S3. We believe that this is an objective classification that can be used in operational practice.

Table 4. Division of the bronchopulmonary segments surgery procedures

	Wąsik et al. (2022)		**Suzuki et al. (2019)**		**Handa et al. (2018)**		**Oizumi et al. (2011)**	
	Right lung	Left lung	Right lung	Left lung	Right lung	Left lung	Right lung	Left lung
Simple	S4-S6	S5, S6	S6	S4-S6	S6	S1-S6	S6	S5, S6
Difficult	S1-S3, S7-S10	S1-S4, S7-S10	S1-S5, S7-S10	S1-S3, S7-S10	S1-S5, S7-S10	S7-S10	S1-S5, S7-S10	S1-S4, S7-S10

Classification method	Intersegmental plane	Intersegmental plane	Intersegmental plane and surgical procedures	Intersegmental plane and literature reports

The division is similar to that in Suzuki et al. [18], however, they did not distinguish between the S4-S5 split in the left lung, but wrote it as a lingular segment. With reference to their study [18] and Oizumi et al. [36] wonders why marking S4-S5 segments of the right lung as difficult. From an anatomical point of view, pulmonary vein anomalies such as right middle lobe pulmonary vein may be a challenge for right lung S4 and S5 segmentectomy [93]. The presence of the phrenic nerve near the hilum of the lung is also an important element [94]. But we have not found a clear answer in the literature why they are omitted.. The example of how they are omitted is no data in table 3 for S4 and S5 segmentectomy in the right lung. This can be also explained by the small mean volume in the case of S4, but in the case of S5 it is similar to S6 [90]. The intersegmental planes, not the volume, may be the more important factor. This is shown by an example of a larger mean volume of S4 than S5 in the left lung, yet it is S4 that is considered more difficult in surgery [91].

An interesting division was proposed by Handa et al. [92], who assigned the segmentectomy to the left upper division segment to this simple one. Also in their study, the S4-S5 division in the left lung was not distinguished. This division seems important to us because in the case of the S4 of the left lung, there are two intersegmental planes - between the S3 and S4 and between S4 and S5.

Based on the literature, we believe that separate S4 and S5 segmentectomes of the right lung should also be considered, which are technically possible, but more often performed as S4 + S5 bisegmentectomies [94].

SUBSEGMENTECTOMY

An extended segmentectomy can be performed to secure the resection margins, based on incising the adjacent fragments in a non-anatomical way or cutting the adjacent subsegment [15]. This brings us to subsegmentectomy, much less commonly mentioned in the literature than segmentectomy, but meriting a separate section in this review. Since segmental bronchi are divided into lobar bronchi, we can also add subsegments to them. For example, we can distinguish subsegments S6a, S6b, S6c in the S6 segment of the left lung [57]. A subsegmentectomy is performed for small tumors or when, for example, a tumor is near the pulmonary hilum [57]. The procedure is similar to segmentectomy. It begins with preoperative three-dimensional lung reconstruction using CT after administration of iodinated contrast medium to visualize veins and arteries [57,58]. The procedure is then performed under general anesthesia. For lung access, the surgeon can for example perform a single-port thoracoscopy with a 3.5–4.0 cm incision (or 3-5 cm, depending on the operator's decisions and accounts in the literature) at the midaxillary line over the fourth or fifth intercostal space [58,59]. Anatomically, it achieves the same function as dividing blood vessels and bronchi and then preparating them [58].

Chang et al. [59] compared single-port VATS segmentectomy with single-port VATS subsegmentectomy and showed that subsegmentectomy could have advantages over the former method in selected cases. The operation time was similar in both groups, though slightly shorter for subsegmentectomy (the authors stated that there was a larger proportion of infectious diseases in the segmentectomy group). A greater difference could be seen in another parameter: there was less intraoperative blood loss during subsegmentectomy (median 25.3 versus 81.4 ml). This is in line with the results of Kato et al. [57], where the median was 19 ml for subsegmentectomy. In a more recent study by the same author [33], who compared segmentectomy and subsegmentectomy patients, there were two statistically significant differences. First, the median time of surgery for the first procedure was longer by 11 minutes (178 vs 167 minutes). Second, the median bleeding from segmentectomy was 40 ml greater (53 vs 13 ml). These results encourage further development of minimally invasive surgical procedures [33,57,59].

CONCLUSIONS

To sum up, lung segments are anatomically variable, for example in the bronchial tree and vascularization or lymph drainage. Despite this known variability, there are no current supplements to them in surgical procedures, as the example of the subsuperior segment shows. Medics must depend on future research focusing on bronchopulmonary segment surgery that will allow the duration of procedures to be reduced and preserve lung functionality. We tried to organize the collected data in the literature on the division of segmentectomy into simple and difficult. We have made an anatomical division which is also used in other clinical studies so we believe that it is possible to extend the surgery to other bronchopulmonary segments.

Ethical approval and consent to participate

The cadavers belonged to the Department of Anatomical Dissection and Donation, Medical University of Lodz.

Funding

The authors have no financial or personal relationship with any third party whose interests could be positively or negatively influenced by the article’s content. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest: None declared

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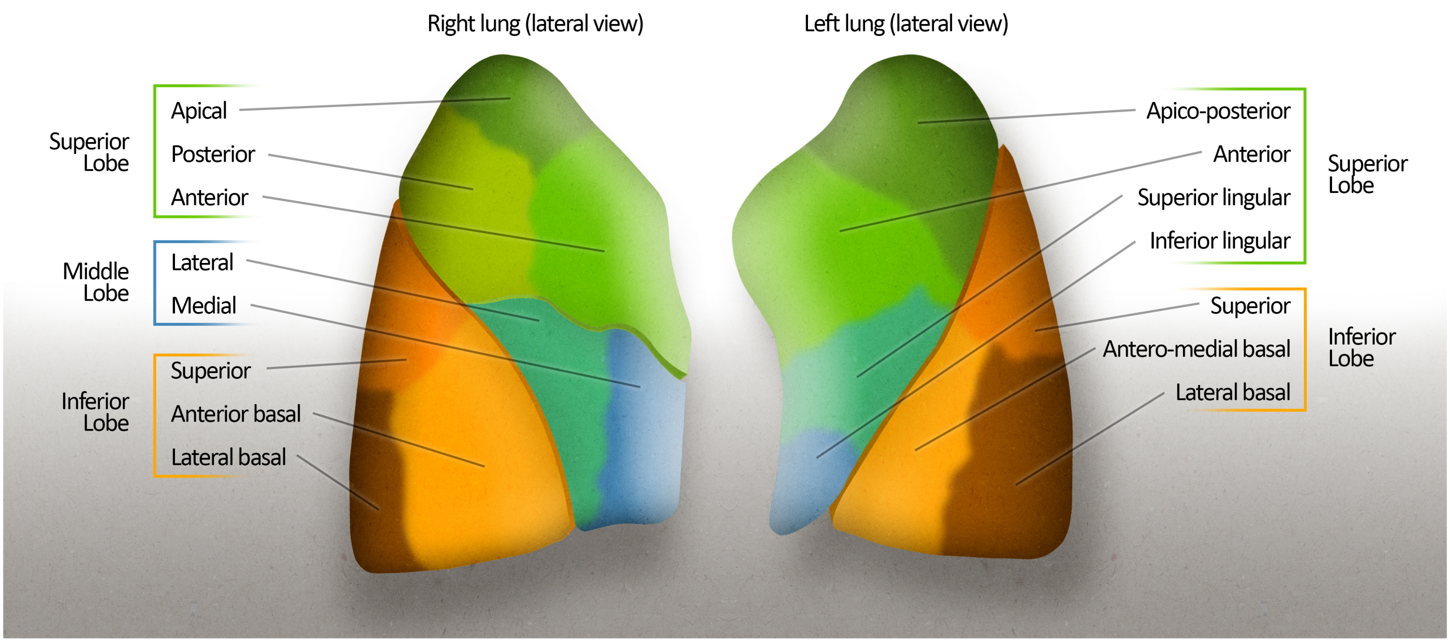
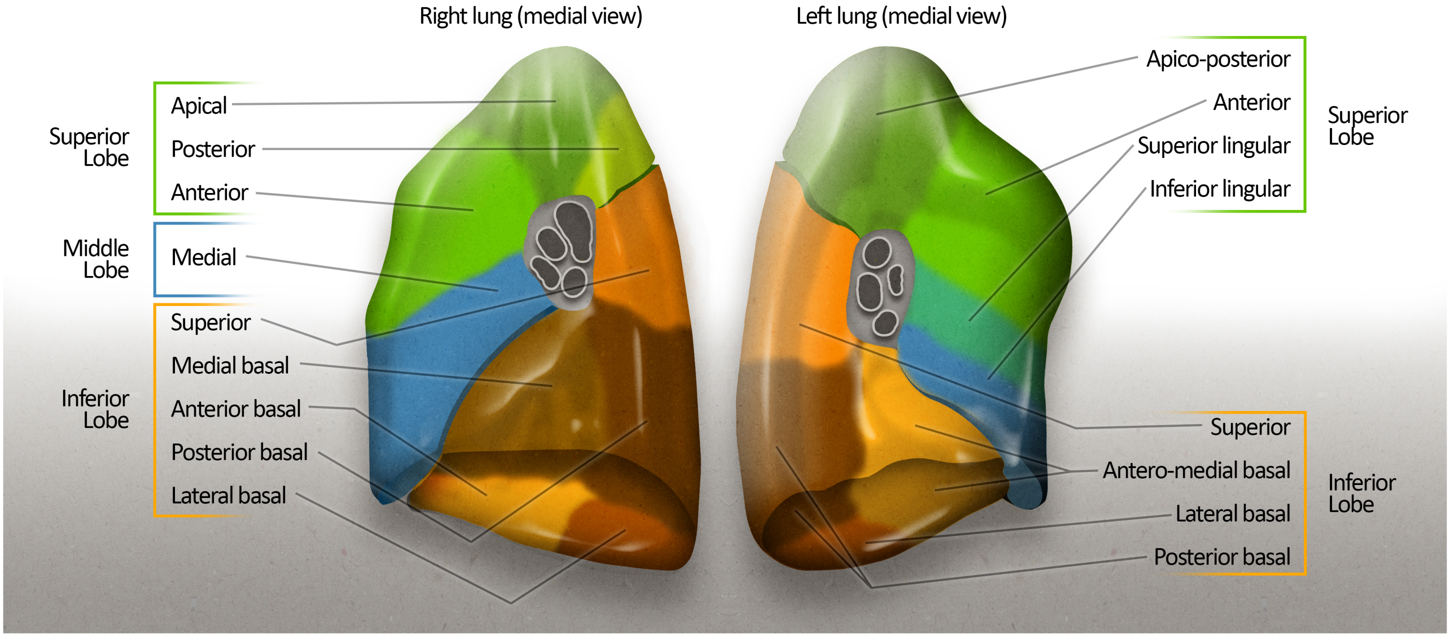


Right lung (lateral view)
Left lung (lateral view)
Superior Lobe
Apical
Posterior
Anterior
Middle Lobe
Lateral
Medial
Inferior Lobe
Superior
Anterior basal
Lateral basal
Apico-posterior
Anterior
Superior lingular
Inferior lingular
Superior Lobe
Superior
Antero-medial basal
Lateral basal
Inferior Lobe



Right lung (medial view)
Left lung (medial view)
Superior Lobe
Apical
Posterior
Anterior
Middle Lobe
Medial
Inferior Lobe
Superior
Medial basal
Anterior basal
Posterior basal
Lateral basal
Apico-posterior
Anterior
Superior lingular
Inferior lingular
Superior Lobe
Superior
Antero-medial basal
Lateral basal
Posterior basal
Inferior Lobe