Segmentectomy-oriented anatomical model for enhanced precision surgery of the left upper lobe

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Title: Segmentectomy-oriented anatomical model for enhanced precision surgery of the left upper lobe

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Informed Consent Statement: An opt-out approach was utilized in lieu of obtaining written
informed consent.

Article word count: 3,470
GLOSSARY OF ABBREVIATIONS:

3D-CT, three-dimensional computed tomography
LUL, left upper lobe
RUL, right upper lobe
SPV, superior pulmonary vein
IPV, inferior pulmonary vein

CENTRAL PICTURE LEGEND:
The three-dimensional planning defines intersegmental planes and veins for segmentectomy

CENTRAL MESSAGE:
The segmentectomy-oriented anatomical model of the left upper lobe utilizing three-dimensional computed tomography helps identify vital anatomical features, thereby optimizing surgery.

PERSPECTIVE STATEMENT:
Utilizing a novel three-dimensional computed tomography workstation for segmentectomy brings unprecedented precision in identifying intersegmental planes and veins. The insights gained in the present study, such as the negative correlation between transverse S^3 and the central vein, can lead to more tailored surgeries that reduce complications and enhance patient outcomes.
ABSTRACT

Objective: To optimize surgical outcomes and minimize complications in complex segmentectomy of the left upper lobe, we investigated the topographical anatomy of the left upper lobe and developed a segmentectomy-oriented anatomical model.

Methods: A state-of-the-art three-dimensional computed tomography workstation was used to visualize the inter-segmental planes and associated veins to categorize the anatomical patterns influencing surgical procedures during left upper lobe segmentectomy. This included the central vein affecting S\textsuperscript{1+2} (apicoposterior segment) segmentectomy, the transverse S\textsuperscript{3} (anterior segment) affecting S\textsuperscript{3} segmentectomy, and other venous branching patterns in 395 patients who underwent thoracic surgery at our institution.

Results: The central vein was observed in 32% of the patients, necessitating access from the interlobar area after segmental artery and bronchus division. Transverse S\textsuperscript{3} incidence was 27%, revealing that only one-third of the patients required complete left upper lobe transection between S\textsuperscript{4} and S\textsuperscript{3} during S\textsuperscript{3} segmentectomy. A significant negative correlation was observed between the presence of transverse S\textsuperscript{3} and the central vein (<10% of patients with the central vein had transverse S\textsuperscript{3} and vice versa). In 6% of patients, the lingular segmental veins partially or entirely drained into the inferior pulmonary vein, potentially causing excessive or insufficient resection during surgery.

Conclusion: This study offers valuable insights into the topographic anatomy of the left upper lobe and presents a segmentectomy-oriented anatomical model for complex segmentectomies. Our approach enables a more precise and individualized surgical planning for patients undergoing segmentectomy based on their unique anatomy, which could thereby lead to improved patient outcomes.

Keywords: left upper segmentectomy; segmental veins; anatomical model; three-dimensional computed tomography
Abstract word count: 248
INTRODUCTION

With the increasing detection of early-stage lung cancer in the older adult population, the use of lung-preserving resections such as wedge resection and segmentectomy has grown globally. A recent large prospective trial comparing segmentectomy and lobectomy (JCOG0802/WJOG4607L) demonstrated the superiority of segmentectomy over lobectomy for early stage, small lung cancers. The non-inferiority of sublobar resection to lobectomy regarding patient survival, as demonstrated in another large prospective trial comparing sublobar resection (including both segmentectomy and wedge resection) and lobectomy (CALGB140503), further supports the use of sublobar resection, including segmentectomy.

During segmentectomy, proper identification and division of the inter-segmental plane are crucial; therefore, the effectiveness with which the corresponding inter-segmental vein is managed determines the quality of the segmentectomy. Our group developed an anatomical model using three-dimensional computed tomography (3D-CT), based on the relationship between the pulmonary vein and bronchus in the right upper lobe (RUL) specifically for successful segmentectomy in the RUL. Recent studies have explored the complexities of left upper lobe bronchovascular anatomy, particularly focusing on the branching patterns of segmental bronchovascular structures. Although these investigations are enhancing the precision of segmentectomies, they have yet to establish a standardized anatomical model.

Simple or typical segmentectomies, defined as segmentectomies that require division of a single, linear inter-segmental plane including right S₆, right basilar (S₇⁻₁₀), left upper division (S¹+² + S³), left lingular (S⁴ + S⁵), left S₆, or left basilar (S₈⁻₁₀), are most frequently performed in the left upper lobe (LUL). A previous study investigated the lung segmental volume and demonstrated that the left S¹+² possessed the largest volume, followed by the right S³ and left S³. Given that the LUL includes two segments among the top three
volumetric segments, single complex segmentectomies, such as S\(^{1+2}\) or S\(^3\) segmentectomies, should be considered if oncologically feasible.

Precise identification and division of the inter-segmental plane along the corresponding inter-segmental vein are crucial for segmentectomy. There are several anatomical challenges for LUL complex segmentectomy, including 1) the left central vein, which is a pulmonary venous branch draining from S\(^{1+2}\) and running between the upper division and the lingular segment, which leads to challenges in identification of the inter-segmental veins during S\(^{1+2}\) segmentectomy, 2) the transverse S\(^3\) (anterior segment); the S\(^3\) that transects the LUL from the anterior to the interlobar hilum requires the transection of the LUL during S\(^3\) segmentectomy, and 3) other anatomical anomalies of the pulmonary veins such as an aberrant lingular vein draining into the inferior pulmonary vein. However, the incidence of these anatomical challenges and their correlations have not yet been reported.

To address the knowledge gaps in the topographical segmental anatomy of the lungs and achieve technical advancements in LUL complex segmentectomy, we investigated the bronchovascular anatomy of the lung using a novel 3D-CT workstation capable of precisely reconstructing inter-segmental and intra-segmental veins and creating a segmentectomy-oriented anatomical model.

**PATIENTS and METHODS**

**Reconstruction of 3D-CT**

Between May 2017 and December 2021, 413 patients underwent contrast-enhanced CT before thoracic surgery at the Shinshu University Hospital. During this period, we used two types of CT scanners: Light Speed VCT Vision (GE Healthcare, US) until December 2019, and Revolution CT (GE Healthcare, US) from January 2020 onwards. All contrast-enhanced 3D-CT examinations were performed using 0.63-mm-thick full resolution scans. The images
constructed using Digital Imaging and Communications in Medicine data were transferred to
a workstation with the REVORAS™ (Ziosoft, Tokyo, Japan) 3D image-processing software,
and 3D-CT reconstruction images of the pulmonary bronchus and vessels were created
using the volume-rendering method. Patients with a history of lung resection in LUL (n=9),
atelectasis in LUL due to the tumor (n=2), and unevaluable cases due to poor CT images
(n=4) and anatomical abnormalities (n=3) were excluded. The remaining 395 patients were
enrolled in the study, including those with primary lung cancer (n=273), metastatic lung
cancer (n=57), benign lung tumor (n=11), mediastinal tumor (n=11), and other diseases
(n=38). This study was approved by the Institutional Review Board of Shinshu University
Hospital (Project ID 4938, Nov 6, 2020), and an opt-out approach for study involvement was
utilized in lieu of obtaining written informed consent.

**Definition of pulmonary segments and pulmonary veins with corresponding drainage areas**

We used the nomenclature of the pulmonary segments and veins in the LUL, as
described by Nomori and Okada. The LUL is composed of four segments, including the
S^{1+2} (apicoposterior segment), S^{3} (anterior segment), S^{4} (lingular superior segment), and S^{5}
(lingular inferior segment). There are three subsegments (a, b, and c) in the S^{1+2} and S^{3} and
two subsegments (a and b) in the S^{4} and S^{5}. S^{1+2}a represents the apical subsegment, S^{1+2}b
represents the posterior subsegment, and S^{1+2}c represents the lateral subsegment of the S^{1+2}.
S^{3}a represents the posterior (lateral) subsegment, S^{3}b represents the anterior (medial)
subsegment, and S^{3}c represents the superior subsegment of the S^{3}. S^{4}a represents the
posterior (lateral) subsegment and S^{4}b represents the anterior (medial) subsegment of the S^{4}.
S^{5}a and S^{5}b represent the superior and inferior subsegments, respectively, of the S^{5}.

The pulmonary veins and corresponding drainage areas (vein/drainage segments) were
as follows: $V^{1+2}/S^{1+2}$, $V^3/S^3$ and $S^4$, $V^4/S^4$ and $S^5$, and $V^5/S^5$.

Two inter-segmental veins run through the inter-segmental plane between $S^{1+2}$ and $S^3$: $V^{1+2}a$ (anterior plane between $S^{1+2}a$ and $S^3c$) and $V^{1+2}d$ (posterior plane between $S^{1+2}c$ and $S^3a$). Similarly, two inter-segmental veins run through the inter-segmental plane between $S^3$ and $S^4$: $V^3b$ (anterior plane between $S^3b$ and $S^4b$). An additional intersegmental vein running through the posterior plane between $S^3a$ [or $S^{1+2}c$] and $S^4a$ was not defined in the Nomori and Okada nomenclature. In the study, we have introduced the term $V^3t$ to define this specific inter-segmental vein. One inter-segmental vein ($V^4b$) runs through the inter-segmental plane between $S^4$ and $S^5$. In general, several intra-segmental veins run inside a lung segment along the inter-sub-segmental plane between two subsegments. The intra-segmental veins running between the two subsegments were as follows: $V^{1+2}b$ (between $S^{1+2}a$ and $S^{1+2}b$), $V^{1+2}c$ (between $S^{1+2}b$ and $S^{1+2}c$), $V^3a$ (between $S^3a$ and $S^3b$), $V^3c$ (between $S^3b$ and $S^3c$), $V^4a$ (between $S^4a$ and $S^4b$), and $V^5a$ (between $S^5a$ and $S^5b$).

Differentiating pulmonary veins with a Voronoi diagram

Using REVORAS™, inter-segmental or inter-sub-segmental planes can be determined based on the theory of the Voronoi diagram, in which an inter-segmental plane between segments $x$ ($S^x$) and $y$ ($S^y$) is located at the midpoint between the two peripheral branches from $B^x$ and $B^y$ (or $A^x$ and $A^y$). We illustrated the inter-segmental or inter-sub-segmental planes using the segmentectomy planning function of the 3D workstation (Supplemental Video S1). Pulmonary veins running along the inter-segmental or inter-sub-segmental planes were differentiated based on the aforementioned relationship between the veins and segments (or subsegments) (See Figure 6 for the Central Picture).

Anatomical challenge 1: the left central vein
In our previous study on the RUL, we categorized segmentectomy approaches based on the combination of anterior and central veins. This framework guided our current investigation on the segmental veins of the LUL, and their anterior and central counterparts. In the RUL, the central vein is defined as a pulmonary venous branch located in the center of the right upper lobe between the right $B^2$ (posterior segmental branch) and $B^3$ (anterior segmental branch), running caudally through the interlobar area to the upper lobe bronchus and finally draining into the right superior pulmonary vein (SPV). By contrast, the anterior vein of the RUL is defined as the pulmonary venous branch located anterior to the RUL bronchus that drains into the SPV.

Although the anterior and central veins have not been defined on the left side, the $V^{1+2}$ of the LUL corresponds closely to the anterior and central veins of the RUL. Similar to that in the right side, the left anterior vein was defined as the pulmonary venous branch draining from the $S^{1+2}$, running anterior to the upper division of the bronchus ($B^{1+2} + B^3$), and finally draining into the left SPV. In contrast, the left central vein was defined as the pulmonary venous branch draining from the $S^{1+2}$, initially running between $B^{1+2}$ and $B^3$, subsequently running around $B^3$ posteriorly, and finally running between $B^3$ and the lingular bronchus ($B^{4+5}$) and draining into the left SPV.

We classified $V^{1+2}$ into three subtypes based on the combinations of the anterior and central veins: anterior type (no central vein), anterior with central type (both anterior and central veins), and central type (no anterior vein). The anterior with central type was further divided into the anterior ‘a’ with central type and the anterior ‘ab’ with central type. In the ‘a’ type, the $V^{1+2}a$ (inter-segmental vein between $S^{1+2}$ and $S^3$) drains into the anterior vein and the $V^{1+2}b$ (intra-segmental vein of $S^{1+2}$) drains into the central vein. In the ‘ab’ type, both the $V^{1+2}a$ and $V^{1+2}b$ drain into the anterior vein. The incidence of each subtype was also determined.
Anatomical challenge 2: the transverse S\(^3\)

During left S\(^3\) segmentectomy, some surgeons prefer to transect the LUL between the upper division (S\(^{1+2}\) + S\(^3\)) and lingular segment (S\(^4\) + S\(^5\)) and then divide the inter-segmental plane between S\(^{1+2}\) and S\(^3\) to complete S\(^3\) segmentectomy. This maneuver, which involves transection of the LUL, is based on the belief that the S\(^3\) is located in the middle of the LUL and crosses from the anterior hilum to the interlobar area. However, in some cases, the S\(^3\) is only located in the anterior area of the upper division, and the posterior area of the upper division only comprises the S\(^{1+2}\). We defined the S\(^3\) that transverses from the anterior hilum to the interlobar area as the transverse type and the S\(^3\) that does not transverse as the non-transverse type. The incidence of transverse and non-transverse S\(^3\) was investigated. The chi-square test was performed using SPSS version 27 (SPSS Inc, Chicago, IL, USA) to analyze the relationship between S\(^3\) transverse and the central vein. Statistical significance was set at \(p < .05\).

Anatomical challenge 3: the variety of inter- or intra-segmental veins draining from the S\(^3\) segment

During S\(^3\) segmentectomy, the inter-segmental veins between S\(^3\) and S\(^{1+2}\) (e.g., V\(^{1+2}\)a) and between S\(^3\) and S\(^4\) (e.g., V\(^3\)b) will be divided or preserved, depending on the unique anatomical and oncological conditions. However, the intra-segmental vein of S\(^3\) (V\(^3\)c), which drains into the SPV, the anterior vein, or V\(^3\)b, should be divided during S\(^3\) segmentectomy. Therefore, knowledge of the drainage pattern of the V\(^3\)c before S\(^3\) segmentectomy is crucial for developing an appropriate segmentectomy plan for S\(^3\) segmentectomy. We investigated the drainage pattern of the V\(^3\)c and classified it according to the drainage veins of the V\(^3\)c.
Anatomical challenge 4: the variety of lingular segmental vein ($V_{4+5}$)

During lingulectomy ($S_4 + S_5$ segmentectomy), the $V_{4+5}$ drainage vein is divided. In most cases, the procedure is simple. However, a potentially challenging drainage pattern of the $V_{4+5}$ may be encountered during lingulectomy, including multiple stems of the $V_{4+5}$ and abnormal $V_{4+5}$ drainage into the inferior pulmonary vein (IPV). The drainage patterns were investigated in this study.

RESULTS

Incidence of central vein

The central vein was observed in 126 patients (32%), indicating that during $S_1^1+2$ segmentectomy, the inter-segmental vein between $S_1^1+2$ and $S_3$ would be identified and exposed in one-third of the patients only after dividing the artery and bronchus. The most frequent $V_{1+2}$ subtype based on the combination of the central and anterior veins was the anterior type (68%), followed by the anterior ‘a’ with central (20%), the anterior ‘ab’ with central (9%), and central (3%) types (Figure 1). Further branching patterns of the $V_{1+2}$, based on $V_{1+2b}$ and $V_{1+2d}$ are illustrated in Supplemental Figures S1 and S2, respectively.

Incidence of the transverse $S_3$ and its correlation with the central vein

A transverse pattern of $S_3$ was observed in 108 patients (27%) and a non-transverse pattern in 287 patients (73%) (Figure 2). This result suggests that during $S_3$ segmentectomy, less than one-third of patients require transection of the LUL. The potential correlation between the presence of the transverse $S_3$ and that of the central vein was also examined, as both significantly affected LUL segmentectomy. Among the 108 patients with transverse $S_3$, the central vein was only observed in four patients (4%). Conversely, among 126 patients with central vein involvement, the transverse $S_3$ was only observed in four patients (3%).
Therefore, we identified a significant negative correlation between transverse S3 and the central vein (P<.001) (Table 1).

**V3 classification based on the V3c drainage pattern**

V3, the drainage vein from S3, was classified into three types based on V3c (intra-segmental vein of S3): 1) V3c into the anterior vein, 2) V3c into the SPV, and 3) V3c into V3b. The V3a (posterior intra-segmental vein) was excluded from this classification because of numerous drainage patterns and non-existence in one-third of the cases (Supplemental Table S1). The most common type was V3c into the SPV (45%), followed by V3c into the anterior vein (35%), and V3c into V3b (20%) (Figure 3).

**V4+5 classification based on the number of stems and the presence of draining into the IPV**

Figure 4 shows the V4+5 classification based on the number of V4+5 stems, and detailed drainage patterns are provided in Supplemental Table S2. The one-stem type accounted for 55.1% of the cases, followed by the two-stem (37%), three-stem (7.6%), and four-stem (0.3%) types. Additionally, the branching pattern of V4+5 was classified into three types according to whether V4+5 drains into IPV (Figure 5): the most common were SPV (94%), followed by SPV+IPV (4.5%), and IPV (1.5%) types.

**DISCUSSION**

In this study, we delved into the bronchovascular anatomy of the LUL by focusing on its segmental topographical anatomy. We developed a segmentectomy-oriented anatomical model with several strengths and novelties: 1) It allows for automated and precise identification of inter-segmental planes, including inter-sub-segmental and intra-segmental planes, based on the Voronoi diagram theory. This, in turn, enables accurate identification and
classification of the corresponding veins. 2) Through this model, novel segmentectomy-oriented anatomical features, such as a negative relationship between the transverse $S^3$ and central vein, were discovered. These findings promote the development of streamlined and tailored approaches for precision segmentectomy in the LUL (See Figure 7 for the Graphical Abstract).

Boyden\textsuperscript{17} and Yamashita\textsuperscript{18} described the segmental anatomy of the lung before the advent of CT, which has been widely accepted among thoracic surgeons. In these studies, segmental distribution, including the location of the inter-segmental planes, was based on findings obtained by injecting a colored gelatin solution into the segmental bronchus and vessels using the lungs of human cadavers.\textsuperscript{18} The drawbacks of traditional anatomical methodologies include the requirement for cadavers and their time-consuming nature.

Recently, advancements in 3D-CT technology have enabled the peripheral visualization of bronchovascular structures, contributing to improvements in anatomical classification, preoperative simulation, and intraoperative navigation.\textsuperscript{19,20} Early 3D-CT, however, was unsuitable for identifying the inter-segmental planes; therefore, identification of the corresponding inter-segmental vein depended solely on the shape and pattern of adjacent segmental bronchovascular structures that were shown on 3D images.\textsuperscript{5,21,22} However, recent technical advancements in 3D-CT have enabled precise identification of the inter-segmental and inter-sub-segmental planes. A novel 3D-CT software, “REVORAS\textsuperscript{TM}” can draw peripheral broncho-vascular structures more accurately than previous 3D-CT software using artificial intelligence and revised algorithms. Based on accurate peripheral bronchial and pulmonary arterial structures, virtual inter-segmental and inter-sub-segmental planes can be precisely depicted using the Voronoi diagram theory. Through this approach, we observed an unnamed inter-segmental vein (which we have defined $V^3t$) in 375 patients (98%) that runs between $S^3a$ (or $S^{1+2}c$) and $S^4a$, as per the Nomori and Okada nomenclature. This finding
deviates from previous reports\textsuperscript{7, 8, 9, 10} and enriches our anatomical comprehension of the posterior plane between the left upper division and lingular segments. Therefore, this function is useful not only for preoperative simulation and intraoperative navigation, but also for the precise identification of inter-segmental and inter-sub-segmental (intra-segmental) veins running along the corresponding planes.

Previous studies have examined the pattern of segmental veins in the LUL but have often provided ambiguous definitions of the segmental, anterior, and central veins. For instance, Zhang et al. categorized patterns based on a combination of anterior and central veins and found a different distribution than our study. This discrepancy may arise from potential confusion between V\textsuperscript{1+2}d and V\textsuperscript{3}t. In our study, we have clarified these definitions and established a segmentectomy-oriented anatomical model, which gives rise to the following clinical implications.

In this study, we focused on the anatomically specific features directly related to left S\textsuperscript{1+2} and S\textsuperscript{3} segmentectomies, which are the most commonly performed single segmentectomies.\textsuperscript{11} Intraoperative identification of the inter-segmental veins and dissection along them are key procedures during lung segmentectomy. Specifically, during S\textsuperscript{1+2} segmentectomy, the inter-segmental veins between S\textsuperscript{1+2} and S\textsuperscript{3} (V\textsuperscript{1+2}a and V\textsuperscript{1+2}d) should be identified intraoperatively. In the case of anterior V\textsuperscript{1+2}, which is the most popular subtype of V\textsuperscript{1+2} (68%), the inter-segmental veins can be easily accessed from the anterior hilum, which means that we can identify the inter-segmental plane at the beginning of surgery (Supplemental Figure S3). However, in the case of the central vein (32%), at least one of the two inter-segmental veins could not be identified from the anterior hilum. Instead, access to these veins was only possible from the interlobar area after dividing the segmental artery and bronchus (Supplemental Figure S4). Therefore, in patients undergoing left S\textsuperscript{1+2} segmentectomy, the presence of a central vein should be checked preoperatively because it significantly affects
the surgical procedure.

We also investigated the transverse S$^3$ and central veins and demonstrated their incidence and mutually exclusive relationships. During S$^3$ segmentectomy, transection of the LUL is not required, and segmentectomy can be completed only by anterior dissection in cases of non-transverse S$^3$, which is more than twice as common as transverse S$^3$ (non-transverse vs. transverse, 73% vs. 27%). We prefer to avoid transection of the LUL during S$^3$ segmentectomy in cases of non-transverse S$^3$, which leads to reduction of unnecessary stapling and potential removal of the lung parenchyma of the adjacent segment.

In this study, we utilized a novel 3D-CT workstation that enabled evaluation of the shape and distribution of each segment, including presence of the transverse S$^3$. However, most conventional 3D-CT workstations do not possess this function, which is one of the limitations of this study regarding its application in clinical practice. Our study found a strong negative correlation between the transverse S$^3$ and central vein. This finding helps predict the presence of transverse S$^3$ since the possibility of transverse S$^3$ is low in patients with a central vein, which can be detected by conventional 3D-CT images.

We analyzed the V$^4+5$ classification according to the number of V$^4+5$ stems by referring to analysis of the right middle lobe$^{22}$ and divided them into one to four stem types. Furthermore, our findings of another V$^4+5$ classification can be utilized not only in segmentectomy, but also in lobectomy. We found an aberrant lingular vein draining into the IPV in 6% of patients (Supplemental Figure S5). This anomaly may cause significant issues during both left upper and lower lobectomies, including congestion of the lingular segment after the left lower lobectomy, bleeding from the interlobar area during the left upper lobectomy, and potential excessive division of both the SPV and IPV based on an intraoperative misunderstanding of the pulmonary veins. To avoid possible malpractice during surgery, we should carefully evaluate 3D-CT images preoperatively.
In the accompanying video, we highlighted three pivotal aspects of LUL segmentectomy bearing clinical relevance that require further elucidation. First, the frequency of LUL transection in S\(^3\) segmentectomy is crucial for preoperative planning and can influence surgical outcomes. Second, understanding the prevalence of the central vein in the LUL is vital as it dictates the decision regarding surgical approach and the difficulty of identifying inter-segmental planes. Finally, recognizing common aberrant draining patterns of the lingular vein (V\(^4+5\)) is essential for avoiding complications such as bleeding or inadvertent vessel ligation. These elements collectively serve to enhance surgical planning, intraoperative navigation, and ultimately, patient outcomes, and their further exploration may offer valuable insights that can be integrated into a more individualized and effective surgical strategy for LUL segmentectomy.

This study had several limitations, including its retrospective nature, relatively small patient cohort, and single-institutional design that included only Japanese patients, that could have affected study outcomes. In addition, we analyzed the major inter- and intra-segmental veins in the LUL and did not include the following in our current analysis: small venous branches, bronchial branching patterns, and arterial branching patterns. Furthermore, the usefulness of this model for LUL segmentectomy has not been evaluated.

In conclusion, in this study, we developed a segmentectomy-oriented anatomical model of the LUL using a novel 3D-CT workstation to accurately identify the inter-segmental planes and corresponding veins. Our findings provide valuable insights into the topographical anatomy for complex LUL segmentectomies. Moreover, we believe that our approach could lead to more precise and individualized surgery for patients undergoing segmentectomy, tailored to each patient's unique anatomy.

**Acknowledgments**
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REFERENCES


Tables

Table 1. Correlation between the transverse $S^3$ type and the central vein

<table>
<thead>
<tr>
<th>S$^3$ type</th>
<th>Central vein</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Present (n=126)</td>
<td>Absent (n=269)</td>
<td>P-value</td>
<td></td>
</tr>
<tr>
<td>Transverse (n=108)</td>
<td>4 (3)</td>
<td>104 (39)</td>
<td>&lt;.001</td>
<td></td>
</tr>
<tr>
<td>Non-transverse (n=287)</td>
<td>122 (97)</td>
<td>165 (61)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data are shown as number (%).
**Supplemental Table S1.** Drainage pattern of V³a, the intra-segmental vein between S³a and S³b.

<table>
<thead>
<tr>
<th>Drainage site of V³a</th>
<th>n=375</th>
</tr>
</thead>
<tbody>
<tr>
<td>No existence</td>
<td>130 (32.9)</td>
</tr>
<tr>
<td>V³t</td>
<td>127 (32.2)</td>
</tr>
<tr>
<td>V³b</td>
<td>117 (29.6)</td>
</tr>
<tr>
<td>Central vein</td>
<td>14 (3.5)</td>
</tr>
<tr>
<td>Anterior vein</td>
<td>3 (0.8)</td>
</tr>
<tr>
<td>V³c</td>
<td>2 (0.5)</td>
</tr>
<tr>
<td>V¹+²d</td>
<td>2 (0.5)</td>
</tr>
</tbody>
</table>

Values are presented as n (%)
### Supplemental Table S2. Details of the drainage patterns of V^4+5^ according to V^4+5^ stem classification

<table>
<thead>
<tr>
<th>Classification of lingular vein</th>
<th>One stem type (n=218) (55.11%)</th>
<th>Two-stem type (n=146) (37.0%)</th>
<th>Three-stem type (n=30) (7.6%)</th>
<th>Four-stem type (n=1) (0.3%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPV</td>
<td>205 (94.0)</td>
<td>SPV+SPV</td>
<td>SPV+SPV+V't</td>
<td>SPV+SPV+SPV+SPV</td>
</tr>
<tr>
<td>Common stem with V^3</td>
<td>8 (3.7)</td>
<td>SPV+V' t</td>
<td>SPV+V'b+V' t</td>
<td></td>
</tr>
<tr>
<td>IPV</td>
<td>5 (2.3)</td>
<td>SPV+V'b</td>
<td>SPV+SPV+SPV</td>
<td></td>
</tr>
<tr>
<td>SPV+IPV</td>
<td>10 (6.8)</td>
<td>SPV+V't+IPV</td>
<td>SPV+V'b+IPV</td>
<td></td>
</tr>
<tr>
<td>SPV+Central vein</td>
<td>6 (4.2)</td>
<td>SPV+SPV+V'b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPV+V^a</td>
<td>2 (1.4)</td>
<td>SPV+SPV+IPV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V'b+V'b</td>
<td>1 (0.7)</td>
<td>SPV+V'b+V't</td>
<td>1 (3.3)</td>
<td></td>
</tr>
<tr>
<td>V't+V'b</td>
<td>1 (0.7)</td>
<td>SPV+V'b+IPV</td>
<td>1 (3.3)</td>
<td></td>
</tr>
<tr>
<td>V't+IPV</td>
<td>1 (0.7)</td>
<td>SPV+V'b+V'b</td>
<td>1 (3.3)</td>
<td></td>
</tr>
<tr>
<td>Central vein+IPV</td>
<td>1 (0.7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPV+IPV</td>
<td>1 (0.7)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are presented as n (%). SPV, superior pulmonary vein; IPV, inferior pulmonary vein. *Percentages in parentheses indicate the proportion according to the classification of the lingular vein.

SPV, superior pulmonary vein; IPV, inferior pulmonary vein.
FIGURE LEGENDS

Figure 1 $V^{1+2}$ classification according to the combination of the anterior vein and central vein.

Figure 2 Representative images of transverse and non-transverse $S^3$ types with schematic depiction of the intra- and inter-segmental veins.

3D-CT, three-dimensional computed tomography; LLL, left lower lobe.

Figure 3 $V^3$ classification according to the drainage site of $V^3c$.

SPV, superior pulmonary vein.

Figure 4 $V^{4+5}$ classification according to the number of $V^{4+5}$ stems.

SPV, superior pulmonary vein; IPV, inferior pulmonary vein.

Figure 5 $V^{4+5}$ classification according to the drainage site of $V^{4+5}$ into the superior pulmonary vein and inferior pulmonary vein.

SPV, superior pulmonary vein; IPV, inferior pulmonary vein

Figure 6 The three-dimensional planning defines intersegmental planes and veins for segmentectomy.

Supplemental Figure S1 Subclassification was based on $V^{1+2}b$ running through the dorsal or ventral side of $B^{1+2}$ in the anterior type, and the anterior with central ab type.

Supplemental Figure S2 Drainage patterns of $V^{1+2}d$ running between $S^{1+2}c$ and $S^3a$. 
SPV, superior pulmonary vein.

Supplemental Figure S3 Representative case displaying $S^{1+2}$ segmentectomy plan for a patient with the central vein from the cranial and posterior views using three-dimensional computed tomography imaging.

LLL, left lower lobe

Supplemental Figure S4 Representative case of the $S^{1+2}$ segmentectomy plan for a patient with the central vein showing 3D-CT cranial and posterior views. The central vein was only identified in the interlobar area after dividing the segmental artery and bronchus.

3D-CT, three-dimensional computed tomography; LLL, left lower lobe.

Supplemental Figure S5 Representative case displaying a patient with $V^{4+5}$ draining into the inferior pulmonary vein. SPV, superior pulmonary vein; IPV, inferior pulmonary vein; LLL, left lower lobe

Supplemental Video V1 This video demonstrates the application of our 3D-CT workstation, REVORAS, in precisely identifying intersegmental planes and their corresponding veins in the left upper lobe. The video further elucidates how this technology will contribute to resolving key clinical questions in segmentectomy and offers a practical overview of the intricate anatomical features crucial for successful segmentectomy procedures.
<table>
<thead>
<tr>
<th>V^{1+2} drainage into</th>
<th>Anterior vein</th>
<th>or</th>
<th>Central vein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior type:</td>
<td>68%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior with Central</td>
<td>20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central type:</td>
<td>3%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Diagram showing V^{1+2} drainage into Anterior vein or Central vein with different types and percentages.](image)
<table>
<thead>
<tr>
<th>V^3c into anterior vein: 35%</th>
<th>V^3c into SPV: 45%</th>
<th>V^3c into V^3b: 20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Diagram of V^3c into anterior vein]</td>
<td>![Diagram of V^3c into SPV]</td>
<td>![Diagram of V^3c into V^3b]</td>
</tr>
</tbody>
</table>

Anterior vein

V^3c

V^3C

V^3C

V^3C

V^3C

SPV

SPV

SPV

V^b

V^b

V^b

V^t

V^t

V^t
<table>
<thead>
<tr>
<th>Stem Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>One stem type</td>
<td>55.1%</td>
</tr>
<tr>
<td>Two-stem type</td>
<td>37.0%</td>
</tr>
<tr>
<td>Three-stem type</td>
<td>7.6%</td>
</tr>
<tr>
<td>Four-stem type</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

[Diagrams of the different stem types with labels V1+V3, V1+V5, V4+V5, V4+V5]
<table>
<thead>
<tr>
<th>SPV type: 94%</th>
<th>SPV+IPV type: 4.5%</th>
<th>IPV type: 1.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
<td><img src="image3" alt="Diagram" /></td>
</tr>
</tbody>
</table>

- **SPV type: 94%**
  - V"a"a
  - V"b"a
  - V"c"a
  - V"d"a
  - V"e"a

- **SPV+IPV type: 4.5%**
  - V"a"a
  - V"b"a
  - V"c"a
  - V"d"a
  - V"e"a

- **IPV type: 1.5%**
  - V"a"a
  - V"b"a
  - V"c"a
  - V"d"a
  - V"e"a
\( V^{1+2a} (S^{1+2a}/S^{3c}) \)

intersegmental vein
<table>
<thead>
<tr>
<th>Anterior type</th>
<th>Anterior with central ab type</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V^{1+2b}) dorsal type: 76%</td>
<td>(V^{1+2b}) dorsal type: 54%</td>
</tr>
<tr>
<td>(V^{1+2b}) ventral type: 24%</td>
<td>(V^{1+2b}) ventral type: 46%</td>
</tr>
</tbody>
</table>

![Diagram of Anterior type and Anterior with central ab type]
<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Into anterior type</td>
<td>46%</td>
</tr>
<tr>
<td>Into central type</td>
<td>22%</td>
</tr>
<tr>
<td>Into V^t type</td>
<td>21%</td>
</tr>
<tr>
<td>Non-existence type</td>
<td>11%</td>
</tr>
</tbody>
</table>

![Diagram](image_url)
<table>
<thead>
<tr>
<th>S'1+2 segmentectomy plan</th>
<th>Identification and division of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A'1+2</td>
</tr>
<tr>
<td></td>
<td>B'1+2</td>
</tr>
<tr>
<td></td>
<td>Central vein</td>
</tr>
</tbody>
</table>
**S^{4+5} segmentectomy plan**

Caudal view

- S\(^{1+2}\)
- S\(^{3}\)
- S\(^{4+5}\)
- LLL
- SPV
- IPV
- V\(^{4+5}\)