

# Demarcation of arteriopulmonary segments: a novel and effective method for the identification of pulmonary segments

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## Abstract

**Objective:** Each pulmonary segment is an anatomical and functional unit. However, it is fundamentally difficult to precisely distinguish every pulmonary segment using the conventional pulmonary intersegmental planes from computed tomography images. Building arteriopulmonary segments is likely to be an effective way to identify pulmonary segments.

**Methods:** The thoracic computed tomography images of 40 patients were collected. The anatomic structures of interest were extracted in the transverse, sagittal, and coronal planes using the semi-automated segmentation tools provided by Amira software. The intrapulmonary vessels were subsequently segmented and reconstructed. The distributions of the pulmonary arteries, veins, and bronchi were observed. In patients with pulmonary masses, the mass was also reconstructed.

**Results:** The three-dimensional reconstructed images showed the branches of the pulmonary artery ramified up to their eighth order covering the entire lung as well as evident intersegmental gaps without pulmonary arteries. The segmental artery was closely accompanied by the segmental bronchi in 486 pulmonary segments (90% of total number of segments). The size and spatial location of the pulmonary mass within a pulmonary segment were also clearly visible.

**Conclusions:** Demarcation of arteriopulmonary segments can be used to precisely distinguish every pulmonary segment and provide its detailed anatomical structure before pulmonary segmentectomy.

## Keywords

Lung, arteriopulmonary segment, pulmonary artery, computed tomography, pulmonary mass, segmentectomy

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## Introduction

The lungs are divided into many pulmonary segments by pulmonary intersegmental planes, and each segment is an anatomical and functional unit of lung parenchyma. Pathological changes in diseased lung tissue may endanger one or more pulmonary segments.<sup>1-3</sup> Increasingly more patients with early-stage lung cancer are undergoing pulmonary segmentectomy.<sup>4-11</sup> Therefore, the importance of identifying exact pulmonary segments that are affected by disease progression has attracted the attention of radiologists and thoracic surgeons.<sup>12-14</sup>

Nevertheless, it is fundamentally difficult to precisely distinguish every pulmonary segment using the conventional pulmonary intersegmental planes from computed tomography (CT) images. Research has confirmed that only a small proportion of intersegmental planes can be identified on thoracic CT scans, and their imaging appearance lacks consistency.<sup>15</sup> In other words, defining a physical boundary similar to the interlobar fissure has proven very difficult and lacks reproducibility.<sup>16</sup> Zuo et al.<sup>17</sup> found that the visualization of intersegmental planes was closely related to the thickness of the planes. Nevertheless, the thickness of the intersegmental planes varied among different pulmonary segments.<sup>17</sup> Conventional segmentation of pulmonary segments is based on their bronchial supply. However, only about fourth-order branches of the bronchial tree can be traced distinctly in CT images, and bronchi are rare in the peripheral portion of the lung.<sup>18-21</sup> Thus, the bronchial tree often appears ambiguous upon observation, and delineation of pulmonary segments based on the bronchi is difficult. It is necessary to find more effective ways to identify pulmonary segments.

*Gray's Anatomy*<sup>22</sup> indicates that each segmental bronchus is accompanied by a

corresponding segmental artery and that the terminal branches of the pulmonary segmental artery end at the edge of the pulmonary segment, making the neighboring segmental arteries mutually independent. Moreover, spiral CT has a powerful capability of delineating pulmonary arteries by tracing them to their sixth- or seventh-order branches (the right or left pulmonary artery is the first-order branch),<sup>23-28</sup> and these pulmonary artery branches abound in each pulmonary segment in CT images.

In the current study, we used a semi-automated segmentation method to segment the intrapulmonary vessels and trace the seventh-order branches of the pulmonary arteries by marking the segmental artery and segmental bronchus with similar colors in one pulmonary segment. These segments discriminated by pulmonary segmental arteries are called arteriopulmonary segments. We considered that building arteriopulmonary segments is likely to be an effective way to identify pulmonary segments.

## Patients and methods

### *Patient recruitment and CT settings*

The current study was performed in accordance with the Declaration of Helsinki and was approved by the Ethical Committees of Jining Medical University (2021-YX-ZR-027, 2021.01-2025.12). Written informed consent was obtained from all participants. The thoracic CT images of all patients included in the study were obtained from the Affiliated Hospital of Jining Medical University. The results were analyzed by two independent experienced radiologists.

A 128-slice spiral CT scanner (Siemens, Erlangen, Germany) was used to scan the whole chest in the caudocranial direction, extending from the apex to the base of the lung in accordance with the Society of Cardiovascular Computed Tomography

guidelines.<sup>29</sup> The contrast medium used was 100 mL of Omnipaque at an iodine concentration of 300 mg/mL. Venipuncture was performed in the forearm, and the contrast medium was injected using a high-pressure syringe at a rate of 3 mL/second. CT scanning was performed with the following scanning parameters: tube voltage, 120 kV; tube current for a standard dose, 400 mA; width of collimating apparatus, 64 mm  $\times$  0.625 mm; examination field, 350 mm; matrix, 512  $\times$  512; and pitch, 0.16/1.

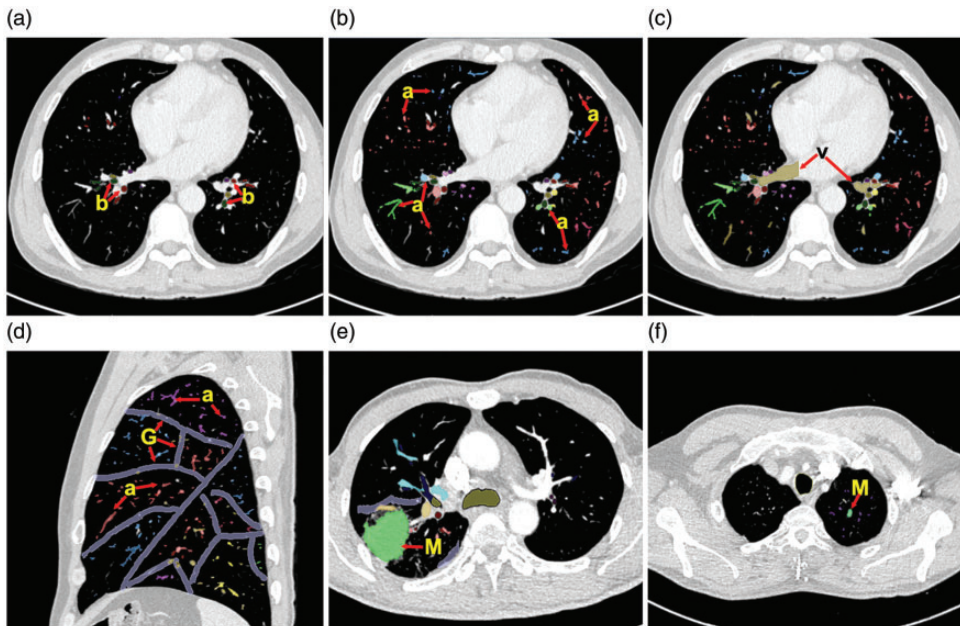
### Data processing

Once all the CT images were aligned, the anatomic structures of interest were extracted in the transverse, sagittal, and coronal planes using the semi-automated segmentation tools provided by Amira 4.1 software (Visualization Sciences Group, Bordeaux, France in collaboration with Zuse Institute, Berlin, Germany). The

different segmental bronchi were marked with different colors to delineate the bronchi (Figure 1(a)). The pulmonary arteries were also segmented, and the different segmental arteries were marked with the same color as the adjacent bronchi with different intensity (Figure 1(b)). All pulmonary veins were also segmented and marked with brown (Figure 1(c)), while the intersegmental gaps without arteries were marked with gray (Figure 1(d)). Finally, the pulmonary mass was segmented and marked with green (Figure 1(e), (f)).

### Statistical analysis

Data are presented as mean  $\pm$  standard deviation and were compared using Student's t-test or one-way analysis of variance with Tukey's post-hoc test as appropriate. PASW Statistics for Windows, Version 18.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical testing.



**Figure 1.** Segmentation of the pulmonary (a) bronchi, (b) arteries, (c) veins, (d) gaps between pulmonary segments, and (e, f) the mass in computed tomography images. b, pulmonary bronchi; a, pulmonary arteries; v, pulmonary veins; G, gaps; M, mass.

with  $p < 0.05$  as the threshold for statistical significance.

## Results

### Participants

This study involved 10 patients with pulmonary masses and 30 healthy subjects as controls. These 40 patients comprised 28 men and 12 women with a mean age of 42 years (range, 26–64 years). The patients' baseline characteristics are detailed in Table 1.

### Distribution of pulmonary arteries and bronchi

In CT images, although most of the bronchi around the hilum of the lung could be distinguished, there were fewer bronchial branches in the peripheral portion of every pulmonary segment. Meanwhile, the branches of the pulmonary artery were diffused into the entire lung, and evident gaps without pulmonary arteries were also observed (Figure 2). In the three-dimensional (3D) reconstructed images, the branches of the pulmonary artery ramified up to their eighth order and covered

the entire lung, whereas the pulmonary bronchi could only be traced to approximately their fourth-order branches (the right or left primary bronchi is the first-order branch) (Figure 3).

### Relationship between segmental bronchi and segmental artery

In the 3D reconstructed images (Figure 4), the number of pulmonary segments was easily determined by visual counting. Of 540 pulmonary segments in 30 healthy subjects, the segmental artery was closely accompanied by the segmental bronchi in 486 pulmonary segments, accounting for 90% of the total number of segments. No branch of these segmental arteries entered the adjacent pulmonary segments, and clear gaps were present between each of the adjacent segmental arteries (Figure 4(a)). The primary branches of 54 segmental arteries entered the adjacent pulmonary segments while closely accompanying the adjacent segmental bronchi (Figure 4(b)), accounting for 10% of the total segments. These branches of the segmental artery, supplying the adjacent pulmonary segments, were considered the adjacent segmental arteries.

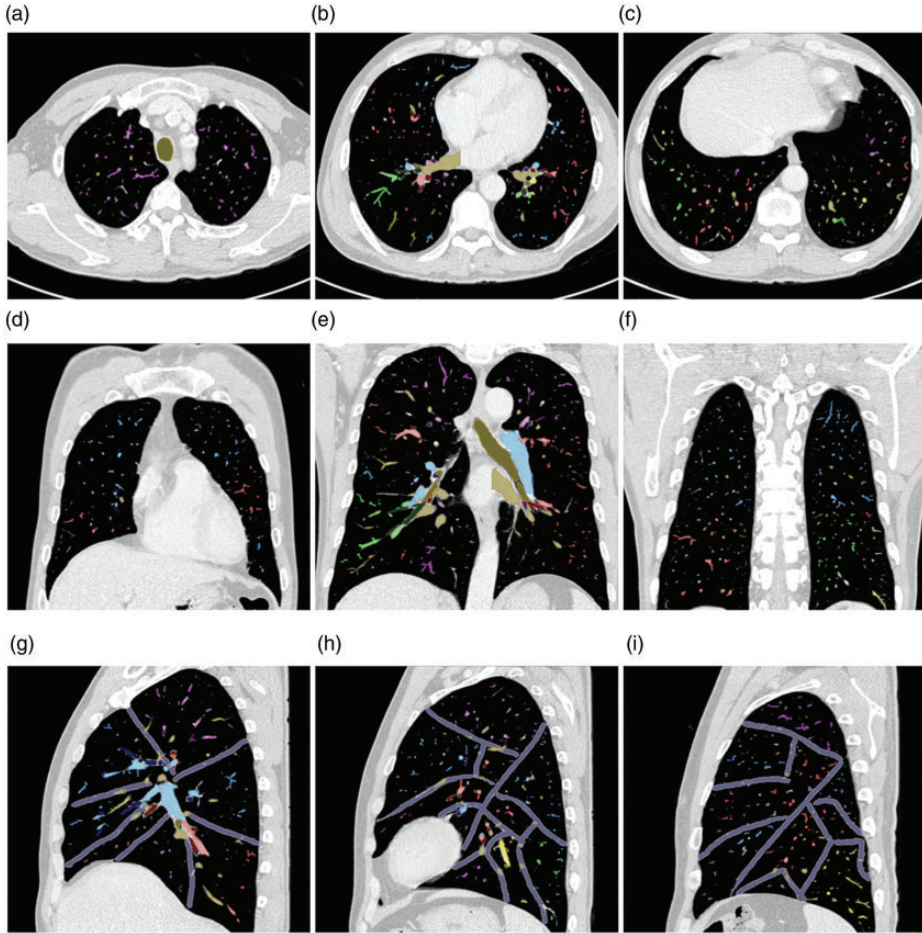
### Arterio-pulmonary segment

In the 3D images, the regions marked with different colors represented the arterio-pulmonary segments (Figure 5). An evident gap could be observed between these adjacent pulmonary segments (Figure 5(d)–(f)). In other words, the arterio-pulmonary segments could be discriminated and the location of different pulmonary segments could be defined by the segmental artery system. In addition, each arterio-pulmonary segment, including the segmental bronchi, segmental artery, and intersegmental and intrasegmental branches of the pulmonary vein, could be observed in any direction (Figure 6).

**Table 1.** Baseline characteristics.

Characteristic	Patients with pulmonary mass	Controls
Age, years	42.6 (12.0)	41.7 (10.8)
Male/female	6/4	22/8
BMI, kg/m <sup>2</sup>	24.8 (3.6)	23.9 (3.2)
Smoking	6	16
Diabetes mellitus	2	5
Hypertension	5	14
Location of mass		
Left	3	–
Right	7	–
Diameter of mass		
≥3 cm	1	–
<3 cm	9	–

Data are presented as n (%) or n. BMI, body mass index.



**Figure 2.** Distribution of pulmonary bronchi and pulmonary arteries in the (a–c) transverse plane, (d–f) coronal plane, and (g–i) sagittal plane.

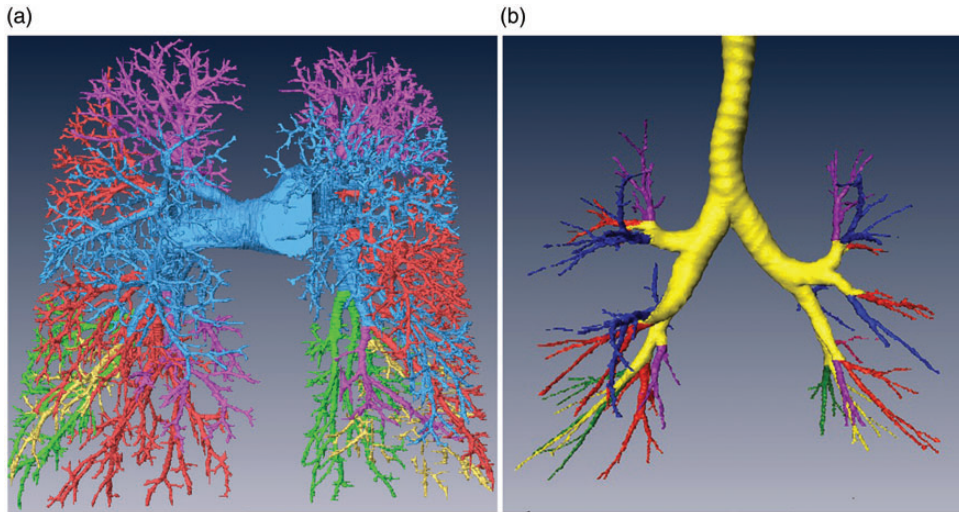
### *Pulmonary mass*

The size and spatial location of the pulmonary mass in a pulmonary segment were clearly visible. Some pulmonary masses occupied various pulmonary segments, and their diameter was  $<2$  cm (Figure 7(a), (b)). In other cases, the mass occupied two or more pulmonary segments (Figure 7(c)).

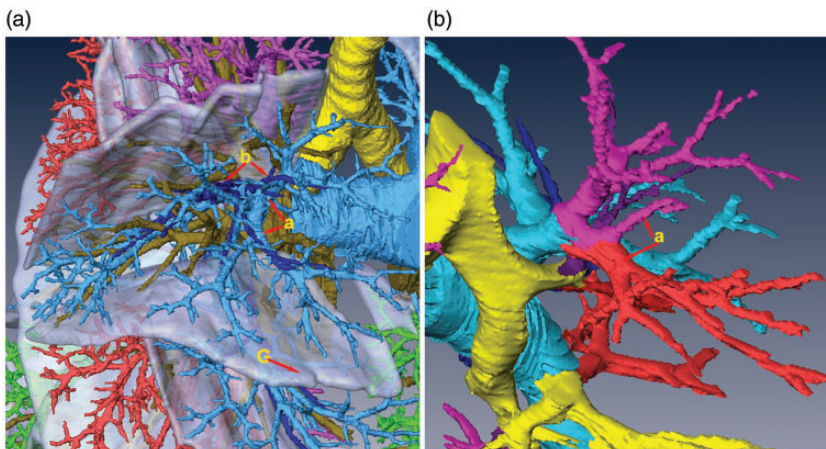
### **Discussion**

The pulmonary intersegmental planes were historically the gold standard for

demarcation of pulmonary segments. However, the imaging appearance of the pulmonary intersegmental plane lacks consistency. The fundamental method for segmenting the lung in CT imaging is delineation of the bronchopulmonary segments, which very often requires inclusion of the pulmonary vein.<sup>26</sup> Many updated methods for automatic and rapid segmentation of the lung into pulmonary segments based on the bronchopulmonary system have been proposed, but none are ideal.<sup>30,31</sup> The automatic approach has



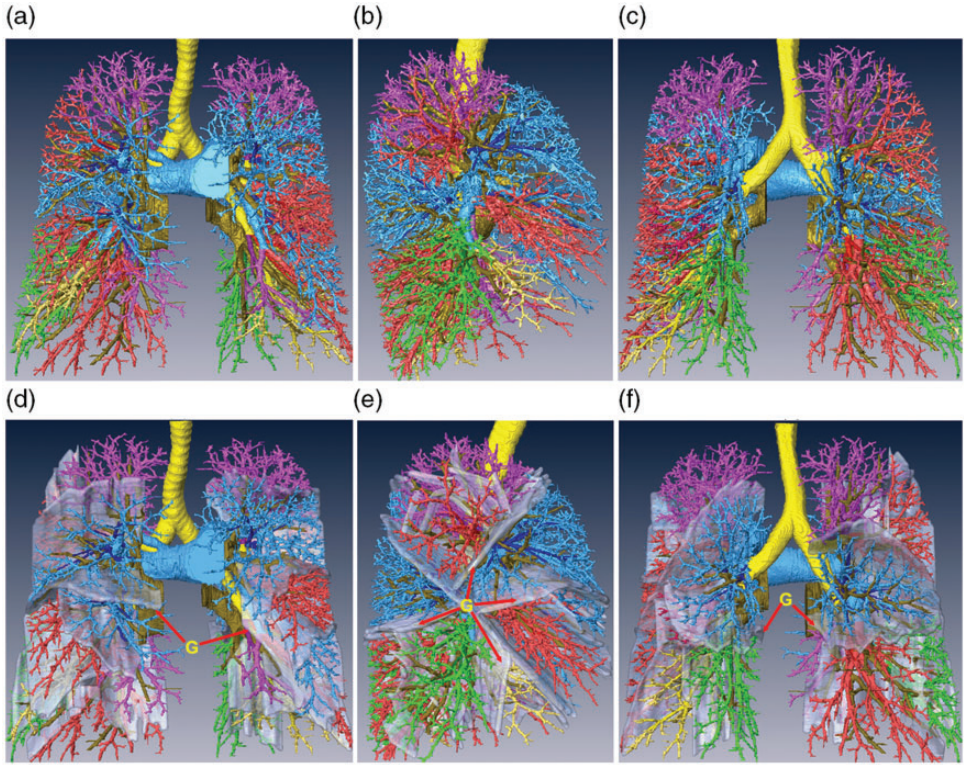
**Figure 3.** Branches of the (a) pulmonary artery and (b) pulmonary bronchi.



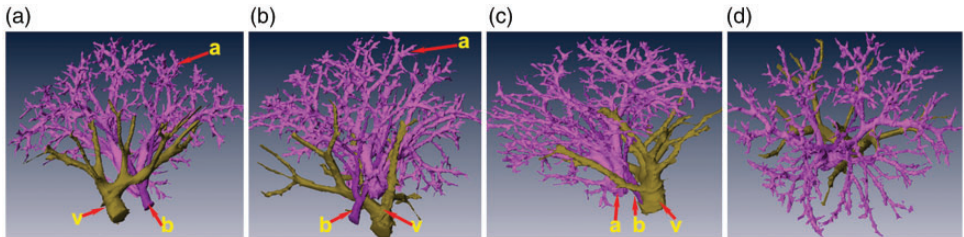
**Figure 4.** (a) The segmental artery was closely accompanied by the segmental bronchi, and (b) the primary branch of the segmental artery entered the adjacent pulmonary segment. a, segmental arteries; b, segmental bronchi; G, gap.

only achieved an overall detection sensitivity of  $\leq 77\%$  compared with the manual approach and is not satisfactory in the clinical setting.<sup>12</sup> In addition, Fu et al.<sup>32</sup> reported that the intersegmental planes are inaccurate when using this method because of the presence of pores of Kohn, canals of Lambert, and direct airway anastomosis. Although Fu et al.<sup>32</sup> confirmed that arterial

ligation alone allowed for identification of the intersegmental planes in 99 (95.2%) patients during thoracoscopic anatomical segmentectomy, they could not accurately identify the intersegmental plane and the spatial location of the mass in a pulmonary segment before the surgical operation to shorten the surgical time. Therefore, we have herein proposed a novel and effective



**Figure 5.** Different arteriopulmonary segments in the (a, d) anterior view, (b, e) lateral view, and (c, f) posterior view.

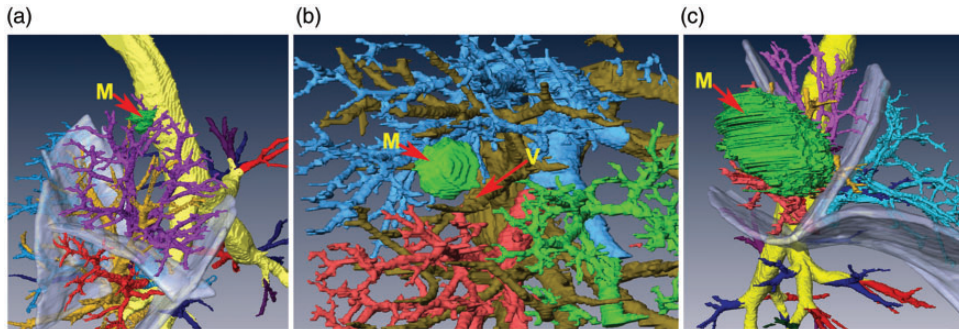


**Figure 6.** Individual arteriopulmonary segment observed in different directions. a, pulmonary arteries; b, pulmonary bronchi; v, pulmonary veins.

way to segment the lung into arteriopulmonary segments.

*Gray's Anatomy*<sup>22</sup> indicates that the pulmonary artery extends along with the bronchi, but it is possible that some bifurcating arteries enter other pulmonary segments. In this study, we used enhanced 128-slice spiral

CT images, which provided higher resolution of the pulmonary artery up to the eighth-order branches. After segmentation of the pulmonary arteries in the CT images, we found that 90% of the pulmonary arteries entered the corresponding pulmonary segments and were accompanied by



**Figure 7.** Lung mass located in (a) the periphery of pulmonary segments, (b) near the edge of adjacent pulmonary segments, and (c) located in two pulmonary segments. M, mass; V, intersegmental vein.

segmental bronchi. However, the remaining 10% of the pulmonary segmental arteries entered the adjacent pulmonary segments and were closely accompanied by the adjacent segmental bronchi; these could be considered the artery for the adjacent segments. Each pulmonary segmental artery matched the corresponding pulmonary segments, and clearly visible gaps were present without overlapping arteries. In summary, the arteriopulmonary segments and bronchopulmonary segments are in accordance with each other. However, the arteriopulmonary segments are more ideal for segmenting the lung because of their outstanding ability to identify the peripheral part of the lung in CT images.

Because each pulmonary segment has its independent segmental artery, segmental bronchi, and intrasegmental and intersegmental vein between the adjacent segments, these vessels should be ligated and cut off during pulmonary segmentectomy.<sup>33,34</sup> Although conventional 3D CT reconstruction can highlight the general anatomical features of the pulmonary vessels,<sup>35–38</sup> and although many new techniques have been proposed to discriminate the pulmonary segments *in vivo*,<sup>39–41</sup> the recognition of intersegmental and intrasegmental structures in the lung is still under development.

For example, our study indicates that 10% of pulmonary arteries have branches entering the adjacent pulmonary segments, which is difficult to assess using conventional methods. An empirical study showed that identification of the branches of pulmonary arteries was very important for successful lung resection.<sup>42</sup> In the worst-case scenario, bleeding from pulmonary arteries during thoracoscopic surgery may compel surgeons to convert to open thoracotomy.<sup>43</sup> Therefore, 10% of these overlapping pulmonary arteries can be problematic and result in surgical failure. Unlike the conventional approach, we segmented the lungs into arteriopulmonary segments in the present study. We found that the spatial location of every segment was distinct, and each segment including the segmental artery and segmental bronchi could be observed and studied in any anatomical direction. Using Amira software, we could compute the diameter, length, angle, and quantity of the pulmonary arteries. The quantity, location, and route of the intersegmental vein surrounding every segment were also visible. Moreover, the spatial location of the mass in a pulmonary segment could be observed in any imaging direction, and the size of the mass could be quantified using Amira software. In short, our novel method



provided the detailed anatomical structure of every segment before pulmonary segmentectomy. This is a great improvement that can be used to guide operations, even intraoperatively.

Finally, this study involved semi-automated segmentation of pulmonary segments, and reconstruction of the region of interest by experienced radiologists requires approximately 0.5 to 2.0 hours for two to three segments. Although performance of this semi-automated segmentation is worthwhile to increase the success rate of a surgical operation, it takes a large amount of time to complete. As indicated by Van Rikxoort et al.,<sup>12</sup> we should propose an automated segmentation method to rapidly segment different pulmonary segmental arteries and thereby trace them to their terminal branches for demarcation of the arteriopulmonary segments.

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### Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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