Anatomical analysis of variations in the bronchus pattern of the left upper lobe using three-dimensional computed tomography angiography and bronchography

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Background: The number of sublobar resections performed is increasing, thoracic surgeons must be familiar with bronchus anatomy and preoperative planning plays an important role in predicting anatomical variations. However, there is few report showing anatomic variations of the left upper lobe (LUL) using three-dimensional computed tomography angiography and bronchography (3D-CTAB), and no in Chinese population. The present study aimed to use 3D-CTAB to describe variations of the pulmonary bronchus of LUL in Chinese population.

Methods: In this retrospective study, we analyzed 3D-reconstruction from patients that performed lobectomy, segmentectomy or subsegmentectomy of the LUL in 2020 at Fujian Medical University Cancer Hospital's Department of Thoracic Surgery. Patients with previous LUL surgery or absence of 3D-reconstruction or without surgery were excluded.

Results: One hundred and sixty-six patients met our criteria. Branching of the left upper bronchus was classified into bifurcated type (99.4%) or trifurcated type (0.06%). The left upper divisional bronchus (B^{1+2+3}) arise as bifurcated (65.65%) or trifurcated type (34.34%). Apicodorsalis bronchus (B^{1+2}) always originated as bifurcated type, while ventralis bronchus (B^{3}) was either bifurcated (94.45%) or trifurcated (5.55%). Lingular bronchus (B^{4+5}) was observed as bifurcated (96.38%) or trifurcated (3.62%) type. When analyzing sublobar divisions of bronchi a total of 14 subtypes were identified, 6 of them were found in the upper divisional bronchus.

Conclusions: Bronchial anatomy of LUL is highly variable, especially in upper divisional bronchus. 3D-CTAB is a useful tool to identify variations in the bronchi pattern, we recommend preoperative planning for sublobar resection.

Keywords: Bronchus; left upper lobe (LUL); three-dimensional computed tomography angiography and bronchography (3D-CTAB); anatomy; variation

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Introduction

Use of chest computed tomography (CT) is widespread nowadays, resulting in an increased detection of small pulmonary nodules. Several studies (1-4) shows that segmentectomy is non inferior to lobectomy when treating T1N0 less than 2 cm in terms of 5-year overall survival, therefore sublobar resection will be a choice for treating early-stage lung cancer in the upcoming years (5,6).

Sublobar bronchi and vessels are subject to high variation, making segmentectomy more challenging than lobectomy. An accurate knowledge of anatomy is therefore require, however rare anatomical variations are not always reported in books. Dissection of corpses has been used in 1940s and 1950s with good results (7,8). Having said that, information gathered were suboptimal due to postmortem modification and scarce availability of cadavers lead this technique to be abandoned. Bronchoscopy is an invasive approach that allows direct visualization of bronchial tree, however exploration of subsegmental bronchi is extremely difficult and comes with high risk of damage and injury (e.g., bleeding) (9). Conventional two-dimensional (2D) CT scan has been largely use as a non-invasive approach for the study of bronchial and vascular anatomy, but inability to visualize third dimension makes understanding of spatial relationship between anatomical structures very difficult.

Three-dimensional (3D) preoperative reconstruction from CT scan is now more diffused thank to improvement of technology, thus allowing thoracic surgeon to visualize pulmonary anatomical structure before procedure (10). This non-invasive method reproduce the finest bronchial and vascular branches with high fidelity. However, nonetheless few studies (11-13) focused on use of this tool to describe anatomic variations of left upper lobe (LUL), and lacked the detailed anatomical information required by thoracic surgeons prior to segmental resection especially in the Chinese population. Because the LUL lobectomy was more difficult and had more surgical complications (14), in a previously published study, we focused on the various lingular artery branching patterns of the LUL using 3D-CT angiography and bronchography (3D-CTAB) in patients scheduled for surgery (15).

In our clinical practice, it is found that the anatomical variation of the LUL bronchus is not consistent with the previous findings. And no analysis of anatomic variation of LUL bronchus in Chinese population has been found. Therefore, we conduct this study. Aim of this study is to describe LUL pulmonary bronchus patterns by using 3D-CTAB, thus creating anatomical 3D models to assist thoracic surgeon and increasing awareness on high anatomical variability when performing sublobar resections. We will also compare results with current available literature. We present the following article in accordance with the STROBE reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-22-598/rc).

Methods

Patients and methods

From January 2020 to December 2020, we analyzed the internal electronical medical records from our institution (Department of Thoracic Surgery, Fujian Medical University Cancer Hospital, Fujian Cancer Hospital) and selected patients with age above 18 years who underwent lobectomy, segmentectomy or subsegmentectomy of the LUL for a pulmonary lesion after 3D-reconstruction. Previous LUL resection or absence of 3D-reconstruction or without surgery were considered exclusion criteria (*Figure 1*). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by regional ethics board of Fujian Cancer Hospital (No. K20220-017-01) and informed consent was taken from all the patients.

3D-CTAB

Bronchial patterns were acquired using a 256-channel MDCT (General Electric Healthcare, Boston, USA), slice thickness was set at 0.625 mm. A total of 35 mL contrast medium was given intravenously at a rate of 5 mL/s, followed immediately by 20 mL normal saline intravenously. The Digital Imaging and Communications in Medicine (DICOM) format data obtained were used to build a 3D model using a dedicated software (IQQA-Lung, EDDA Technology, Princeton, NJ, USA). The system can automatically reconstruct a rough 3D model of the bronchial system. Error identification and defects in distal bronchial imaging were manually modified.

Nomenclature of pulmonary bronchi

Segmental and subsegmental bronchi were named according to classification proposed by Nomori (13) and Yamashita (16): "B^{1+2}" is the apicoposterior segmental

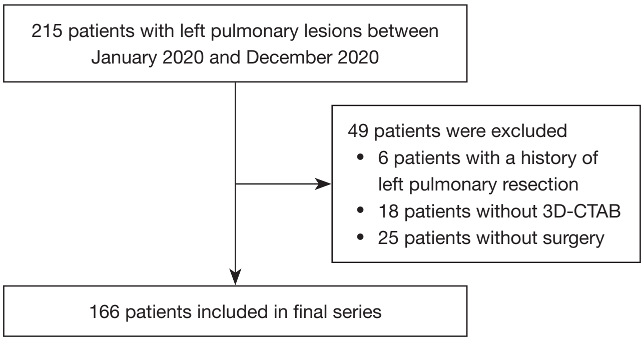


Figure 1 Study flowchart. 3D-CTAB, three-dimensional computed tomography angiography and bronchography.

bronchus and divides into apical ($B^{1+2}a$), dorsal ($B^{1+2}b$) and horizontal ramus ($B^{1+2}c$); "B^3" is the anterior segmental bronchus that, further divided into lateral (B^3a), medial (B^3b) and superior ramus (B^3c); "B^{4+5}" represent the lingular bronchus, that divides into superior (B^4) and inferior (B^5) segmental bronchi; "B^4" is composed of a lateralis (B^4a) and medialis ramus (B^4b): "B^5" is divided into superior B^5a and inferior B^5b. In this article, comma between segmental and subsegmental bronchi indicate a division.

A thoracic surgeon and a radiologist with 10 years of experience independently identified the branching bronchi and the segments and subsegments according to the bronchial lumen diameter and branching direction of the 3D bronchial tree. In cases of disagreement, other radiologists and surgeons with same experience were involved to improve accuracy.

Statistical analysis

Descriptive data analysis was performed using SPSS (IBM SPSS Statistics for Windows, Version 22.0, IBM Corp., Armonk, NY, USA). Data of the age was described as median and range and those of the frequency of the bronchial branches as numbers and percentages.

Results

A total of 166 patients met criteria for this study, 72 were males. Median age was 57 (range, 25–85) years. Type and frequency of the bronchial branches are presented proportionally in *Table 1* and *Figure 2*.

Branching of the left upper bronchus was classified into two types: the bifurcated type was evident in 165 cases (99.4%) (*Figure 3A,3B*) while trifurcated type was the less common (*Figure 3C*). Bifurcated type was further divided in two subtypes: subtype I or "B^{1+2+3},B^{4+5}" was evident in 164 of 166 cases (98.80%) (*Figure 3A*) and subtype II or "B^{1+2},B^{3+4+5}" with B^3 was found only in 1 case (0.60%) (*Figure 3B*).

Looking at the left upper divisional bronchus (B^{1-3}) two types were identified: bifurcation was found in 109 cases (65.65%), while a trifurcation was found less frequently (*Figure 3D-3I*). Bifurcated type was further divided into three subtypes: subtype I or "B^{1+2},B^3", subtype II or "$B^{1+2}a+b$,$B^{1+2}c+B^3$" and subtype III "$B^{1+2}+B^3c$,B^3a+b". These subtypes accounted for 61.44%, 3.61%, and 0.6% respectively. The trifurcated type was also further divided into three subtypes: subtype I ($B^{1+2}a+b$,$B^{1+2}c$,B^3) occurred in 28.92% of cases, subtype II (B^{1+2},B^3a,B^3b+c) was found in 48 patients (4.82%) and subtype III ($B^{1+2}a$,$B^{1+2}b+c$,B^3) was the less common (0.6%).

B^{1+2} was always bifurcated, with subtype I or "$B^{1+2}a+b$,$B^{1+2}c$" being the most common (93.98%) (*Figure 3J*) and subtype II or "$B^{1+2}a$,$B^{1+2}b+c$" occurring only in 10 patients (*Figure 3K*).

The branching pattern of B^3 was divided into two types: 157 cases were bifurcated while trifurcated was observed only in 9 cases (*Figure 3L-3N*). Bifurcated type was further divided into subtype I or "B^3a,B^3b+c" that was found in 138 patients (83.13%) (*Figure 3L*) and subtype II or B^3a+b,B^3c seen in 19 patients (11.45%) (*Figure 3M*).

B^{4+5} originated either as bifurcated in 160 cases (96.38%) (*Figure 3O,3P*) or trifurcated in the rest of cases (*Figure 3Q*). Bifurcated type was divided in subtype I or "B^4,B^5" and observed in 129 of 166 cases (77.71%) (*Figure 3O*) while subtype II or "B^4a,B^4b+B^5" was evident in 31 cases (18.67%) (*Figure 3P*).

Discussion

With the use of thoracic thin-section CT, the detection rate of pulmonary nodules increases, and some research results (1-4,17-21) have shown that the prognosis of segmentectomy is no worse than that of lobectomy in patients with metastatic lung tumors or early lung cancer. The JCOG0802 study is a randomized controlled trial to confirm whether segmentectomy is not inferior to lobectomy in regard to prognosis. This study revealed that in patients with invasive peripheral non-small cell lung cancer with a maximum diameter ≤2 cm, the air leakage rate of segmentectomy was higher than that of lobectomy (6.5% *vs.* 3.8%; P=0.04), but there was no difference in

Table 1 Frequency of the bronchial branches of the left upper pulmonary lobe

Bronchus	Type	Subtype	Present study, n=166	Jiang (8), n=85	Boyden (7), n=50	Zhao (11), n=216	Le Roux (12), n=1,000	Nomori (13)
Left upper bronchus	Bifurcated	–	99.40%	84.00%	73.00%	–	83.00%	–
		I	98.80%	–	–	–	–	–
		II	0.60%	1.30%	2.40%	–	–	–
	Trifurcated	–	0.60%	16.00%	27.00%	–	14.70%	–
Upper division bronchus	Bifurcated	–	65.65%	–	–	74.00%	–	–
		I	61.44%	–	–	–	–	46.00%
		II	3.61%	–	–	–	–	–
		III	0.60%	–	–	–	–	–
	Trifurcated	–	34.34%	–	–	23.00%	–	–
		I	28.92%	17.00%	–	–	–	27.00%
		II	4.82%	–	–	–	–	27.00%
		III	0.60%	–	–	–	–	-
Apicodorsalis bronchus	Bifurcated	I	93.98%	–	–	–	–	65.00%
		II	6.02%	–	–	–	–	35.00%
Ventralis bronchus	Bifurcated	I	83.13%	–	–	–	–	90.00%
		II	11.45%	–	–	–	–	–
	Trifurcated	–	5.42%	–	–	–	–	–
Lingular division bronchus	Bifurcated	I	77.71%	86.70%	–	99.10%	–	–
		II	18.67%	9.30%	15.00%	–	–	–
	Trifurcated	–	3.61%	4.00%	–	–	–	–

the incidence of other complications (5). Meanwhile, the JCOG0804 study (6) evaluating the effectiveness and safety of sublobar resection for peripheral lung cancer with consolidation tumor ratio ≤0.25 and maximum tumor diameter ≤2.0 cm found that sublobar resection was the preferred surgical procedure as long as adequate surgical margin was available. In addition, segmentectomy provides valuable surgical opportunities for patients who are ineligible to undergo standard lobectomy (22).

In order to perform segmentectomy successfully, the thoracic surgeon must have a thorough understanding of the anatomy of the bronchus. However, the anatomical variation of bronchus is complex. In the past, the anatomical variation of bronchus was analyzed through autopsy, tracheoscopy and 2D-CT, but due to many adverse factors, more accurate and detailed anatomical analysis could not be carried out. However, the reconstruction of 3D-CTAB eliminated interference from images of blood vessels and lung tissue and allowed a full view of the bronchus branching without blind spots. At the present study we perform a systematic analysis of the LUL by 3D-CTAB and review the differences between our results and those of previous reports (*Table 1*).

In this study, two types of branching were seen in the left upper bronchus. The bifurcated type was seen in 99.4% of cases in our study, which was considerably higher than the frequency reported by Jiang (8) (84%), Boyden (7) (73%), and Le Roux (12) (83%).

We found that the left upper divisional bronchus also had two branching types; a bifurcated type (65.65%) and trifurcated type (34.34%). This compares with the figures presented by Nomori (13) 46% and 54%, and Zhao (11) 74% and 23%, respectively.

However, the more detailed classification and occurrence

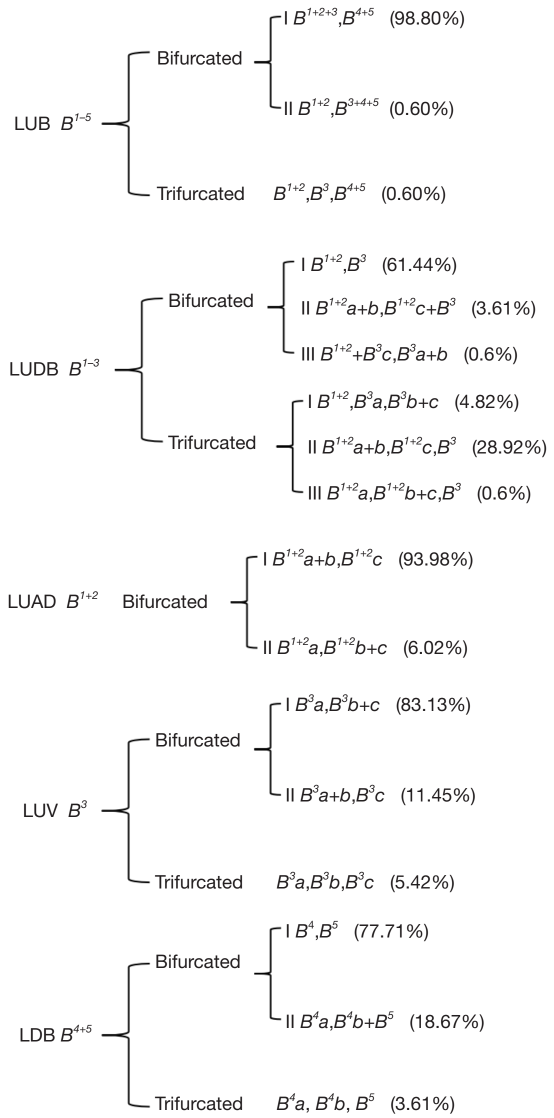


Figure 2 Type and frequency of the bronchial branches of the left upper pulmonary lobe. LUB, left upper bronchus; LUDB, left upper division bronchus; LUAD, left upper apicodorsalis; LUV, left upper ventralis; LDB, lingular division bronchus.

probability of bronchus have been rarely involved in previous studies. In this paper, the segmental and subsegmental bronchus of the LUL were analyzed by 3D-CTAB, and classified and summarized in detail.

We found the most common type B^{1+2} was $B^{1+2}a+b$,$B^{1+2}c$ (93.98%), and the most common type B^3 was B^3a,B^3b+c (83.13%). We also found that in one patient (0.6%), B^3 originated in the lingual segmental bronchus and not from the left upper divisional bronchus, which is a rare bronchial variation. Anatomic variation had also been reported by Jiang (8) and Boyden (7), with a 1.3% and 2.4% incidence, respectively.

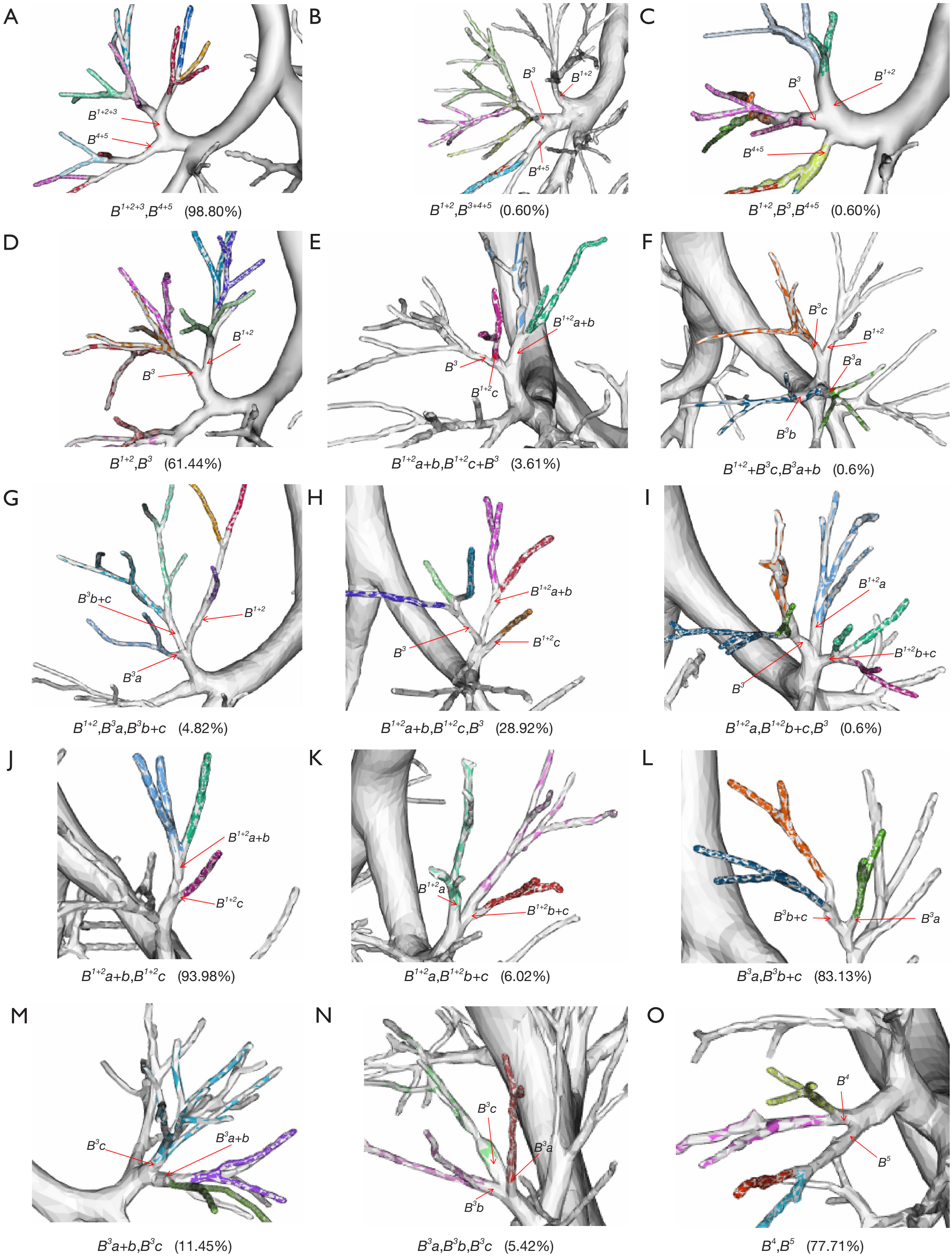
All bronchi of the lingual segmental bronchus were derived from the left superior lobar bronchus, then subdivided into two types and three subtypes, with the incidence of the "B^4,B^5" type being the highest (77.71%). Jiang (8) dissected 85 cadavers and found the "B^4,B^5" type accounted for 86.7%, the "B^4a,B^4b+B^5" type accounted for 9.3%, and the "B^4a,B^4b,B^5" type accounted for 3.61%, which is similar to our results. However, Zhao (11) reported that 99.1% of the lingual segmental bronchus types was "B^4,B^5".

In anatomical segmentectomy or subsegmentectomy, it is extremely important to master the types of the segmental and subsegmental bronchus. When planning a major lung resection the risk of conversion vary from 6.2% to 9.6%, being higher in video-assisted thoracic surgery (VATS) with unexpected bleeding as the leading cause (21,23). Accurate preoperative study (24,25) can reduce this risk to 2.6% and up to 0%, when a printed 3D model is available. In addition, surgical procedure change according to branching types and therefore a precise preoperative identification of variations is a mainstay when planning sublobar resection.

For example, there are many anatomical variations in the left upper divisional bronchus. In 3.61% of patients in our study, $B^{1+2}c$ was derived from B^3. If 3D reconstruction was not performed, $B^{1+2}c$ would probably be removed when S3 resection was performed. Similarly, 0.6% of the patients had B^3c derived from B^{1+2}, and it is likely that the B^3c would have been removed if S^{1+2} resection had been performed without 3D reconstruction. Finally, in 34.34% of patients, the left upper divisional bronchus was trifurcated type, and it was easy to damage the B^{1+2} or B^{1+2} subsegmental bronchus performing S^{1+2} or S^3 resection.

Therefore, understanding the segmental bronchial pattern and its rare branching patterns by preoperative 3D reconstruction is a necessary condition for accurate segmentectomy and subsegmentectomy.

Our study also had some limitations. First, because of 3D-CTAB data only. The small bronchimay have been missed, creating a bias in our results. Second, bronchial reconstruction is closely related to the degree of bronchial dilation in patients, and the failure of maximum deep inhalation during CT scan may lead to incomplete bronchial reconstruction. Third, the sample size of this study is small, and a larger and multi-center study is required to confirm the results.


A
B^{1+2+3}
B^{4+5}
B^{1+2+3},B^{4+5} (98.80%)
B
B^{3}
B^{1+2}
B^{4+5}
B^{1+2},B^{3+4+5} (0.60%)
C
B^{3}
B^{1+2}
B^{4+5}
B^{1+2},B^{3},B^{4+5} (0.60%)
D
B^{1+2}
B^{3}
B^{1+2},B^{3} (61.44%)
E
$B^{1+2}a+b$
B^{3}
$B^{1+2}c$
$B^{1+2}a+b$,$B^{1+2}c+B^{3}$ (3.61%)
F
$B^{3}c$
B^{1+2}
$B^{3}a$
$B^{3}b$
$B^{1+2}+B^{3}c$,$B^{3}a+b$ (0.6%)
G
$B^{3}b+c$
B^{1+2}
$B^{3}a$
B^{1+2},$B^{3}a$,$B^{3}b+c$ (4.82%)
H
$B^{1+2}a+b$
B^{3}
$B^{1+2}c$
$B^{1+2}a+b$,$B^{1+2}c$,B^{3} (28.92%)
I
$B^{1+2}a$
$B^{1+2}b+c$
B^{3}
$B^{1+2}a$,$B^{1+2}b+c$,B^{3} (0.6%)
J
$B^{1+2}a+b$
$B^{1+2}c$
$B^{1+2}a+b$,$B^{1+2}c$ (93.98%)
K
$B^{1+2}a$
$B^{1+2}b+c$
$B^{1+2}a$,$B^{1+2}b+c$ (6.02%)
L
$B^{3}b+c$
$B^{3}a$
$B^{3}a$,$B^{3}b+c$ (83.13%)
M
$B^{3}c$
$B^{3}a+b$
$B^{3}a+b$,$B^{3}c$ (11.45%)
N
$B^{3}c$
$B^{3}a$
$B^{3}b$
$B^{3}a$,$B^{3}b$,$B^{3}c$ (5.42%)
O
B^{4}
B^{5}
B^{4},B^{5} (77.71%)

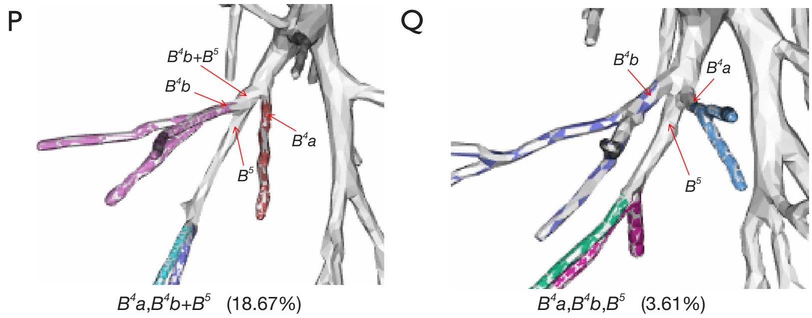


Figure 3 Type and frequency of the bronchial branches of the left upper pulmonary lobe. (A-C) Types and frequency of the left upper bronchus. (D-I) Types and frequency of the left upper divisional bronchus. (J,K) Types and frequency of the B^{1+2}. (B,L-N) Types and frequency of the B^3. (O-Q) Types and frequency of the B^{4+5}.

Conclusions

We identified 14 subtypes of LUL bronchus patterns using 3D-CTAB, with upper division bronchus being more subject to variations in Chinese population. 3D-CTAB is capable of detecting the finest bronchial branches, assisting thoracic surgeon during preoperative planning. We strongly believe that 3D-CTAB is an instrument that a thoracic surgeon should be familiar when undertaking segmental and subsegmental pulmonary resections.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://atm.amegroups.com/article/view/10.21037/atm-22-598/rc

Data Sharing Statement: Available at https://atm.amegroups.com/article/view/10.21037/atm-22-598/dss

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-22-598/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by regional ethics board of Fujian Cancer Hospital (No. K20220-017-01) and informed consent was taken from all the patients.

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