Research on Anatomical Types and Variations of Lung Segment Bronchi Based on Artificial Intelligence 3D Reconstruction Technology

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Abstract: Aims: To investigate the anatomic type and variation of segmental bronchus based on artificial intelligence 3D reconstruction technology. Methods: The image data of 200 patients who underwent thin-layer enhanced chest CT examination in the Department of Thoracic Surgery of Shandong Public Health Clinical Center from December 2021 to December 2022 were selected. The bronchi and blood vessels of the affected side of the lung were reconstructed according to the CT scanning data of the patients, and the anatomic types and anatomic variations of the bronchi of each lung segment on the affected side were observed and statistically analyzed. Results: There were basically four anatomical types of the right superior lobar bronchus, of which the three branching subtypes B^1, B^2 and B^3 are the most common anatomical types. There are two types of right middle lobe bronchus, of which the B^4 and B^5 subtypes are the most common anatomic types. For the left lung, 4 types of segmental bronchus were found and (B^{1+2}a+b, B^{1+2}c), (B^3a, B^3b+c) was the most common anatomical type. Two types of bronchus were found in the left superior lobe of the lung. Type B^4 and type B^5 were the most common anatomical types. In addition, there were 3 types of bronchi in the dorsal segment of the left inferior lobe, and 3 types in the anterior, external and posterior basal segment bronchi of the left inferior lobe, among which B^8, B^9+B^{10} (57.6%) were the most common. Conclusion: The anatomical types of segmental and subsegmental bronchus are complex and varied, and there may be rare anatomical variations. Therefore, before performing relevant operations, it is necessary to be familiar with the relevant operations and the branch types of corresponding bronchus in advance to ensure the smooth operation.

***Keywords*:** bronchi, anatomy, artificial intelligence, 3D reconstruction

1. Introduction

Lung cancer is one of the most commonly diagnosed cancers in the world and a leading cause of cancer death. Approximately 2.2 million patients are diagnosed with lung cancer each year[1], of which 75% die within 5 years[2], seriously affecting human health [3]. Surgical treatment is still the most important means of lung cancer treatment. With the rapid development of surgical treatment technology for lung cancer, more accurate and minimally invasive surgical methods for lung cancer have been paid more and more attention [4].

Segmental resection of lung, which is not inferior to lobectomy in tumor treatment, is becoming an important surgical option for early lung cancer [5,6]. With the continuous development of lung nodule screening, the detection rate of early lung cancer continues to increase[7], and more and more patients need segmental resection. Anatomical segmental resection requires accurate identification and removal of bronchial tubes, arteries, and veins at the pulmonary segment or even subsegment level[8], while the anatomical structure at the pulmonary segment and subsegment level is complex and diverse, so the surgical requirements for accurate segmental resection are higher. Artificial intelligence (AI) 3D reconstruction technology uses 3D medical imaging and computer surgical assistance system to reconstruct pulmonary blood vessels and bronchus by using CT examination data, which can display the anatomical structure of lungs in stereo, especially the three-dimensional structure and direction of the bronchus of blood vessels in each lung segment. It provides powerful technical support for accurate lung segment resection, and has been paid more and more attention in assisting the diagnosis and treatment of lung nodules. This study studied the image data of 200 patients who underwent thin-layer enhanced chest CT examination in the Department of Thoracic Surgery of Shandong Public Health Clinical Center from December 2021 to December 2022. The bronchi and blood vessels of the affected side of the lung were reconstructed according to the CT scan data of the patients, and the anatomic types and anatomic variations of the bronchi of each lung segment on the affected side were analyzed. The objective is to provide imaging reference for thoracic surgeons to perform anatomic pulmonary segmentectomy.

2. Materials and methods

2.1 Research object

In this study, we analyzed the imaging data of 200 patients who underwent thin-section enhanced chest CT examination in the Department of Thoracic Surgery of Shandong Public Health Clinical Center from December 2021 to December 2022, including 106 males and 94 females, aged 18 to 70 years old, with an average age of 56.8±14.2 years old. Among the 200 patients, there were 168 cases of lung cancer and 32 cases of tuberculosis and inflammatory lesions. CT examination revealed the lesion sites: right lung 115 cases, left lung 85. This study met the requirements of the Declaration of Helsinki and was approved by the Ethics Committee of Shandong Public Health Clinical Center. All patients signed informed consent.

2.2 Inclusion and exclusion criteria

Inclusion criteria:

1) Patients agreed to be included in this project and sign the relevant informed consent;
2) Over 18 years old;
3) Thin-slice CT scan was performed in our hospital.

Exclusion criteria:

1) A history of mental illness;
2) A history of lung surgery;
3) A person with significant lung or physical disease that causes bronchial distortion;
4) There were obvious pneumothorax, hemothorax, pleural effusion resulting in pulmonary atelectasis.

2.3 Methods

2.3.1 CT scan and 3D reconstruction

128-slice CT machine made by Siemens (Somatom definition AS) was used for scanning. Scan range from thoracic entrance to adrenal level. Scanning parameters: The tube voltage was 120kV, the tube current was 200-300mA, the scanning layer thickness was 2mm, and the layer spacing was 1mm. The patient was placed in a supine position, and the contrast agent iodihexyl (containing 300mg/mL) was injected through the anterior cubital vein at a rate of 3 ml/s. After scanning, the images of lung window and mediastinal window with thickness of 2mm were automatically reconstructed into thin lung window and mediastinal window images (layer thickness 1mm, layer spacing 1mm). Thin-slice CT data of reconstructed patients were imported into 3D Slicer 3D reconstruction software in DICOM format to reconstruct the bronchi and blood vessels of the affected side of the lung.

2.3.2 Imagine analysis

Two thoracic surgeons independently and double-blind analyzed the 3D reconstructed images to determine the anatomic type of the bronchus in the diseased side of the lung segment. When the interpretation results were inconsistent, both sides reached a consensus after discussion.

2.4 Observational indexes

The anatomic type and anatomic variation of bronchus in each lung segment on the affected side were observed and analyzed.

2.5 Statistical analysis

SPSS 25.0 software was used for statistical analysis. The measurement data are expressed as mean ± standard deviation, and the counting data are described as frequency and percentage. Kappa value was used to evaluate the consistency test of observation results between two observers. Kappa value > 0.80: good consistency; > 0.60-0.80: general consistency; > 0.40-0.60: poor consistency; ≤0.40: poor consistency.

3. Results

3.1 The result of consistency examination

The consistency test Kappa values of the anatomical types of segmental bronchus analyzed by the two observers were 0.91-0.95, indicating a good consistency.

3.2 Anatomic type of right superior lobar bronchus

In 115 cases of right lung, there were four anatomical types of right superior lobar bronchus, 38 cases of two-branch type (33.0%), 73 cases of three-branch type (64.5%), 4 cases of four-branch type (3.5%). Two-branch type and three-branch type were divided into 6 and 5 subtypes, and four-branch type was divided into 2 subtypes. Three branching subtypes B^1, B^2, B^3 (68 cases, 59.1%) were the most common anatomic types of the right superior lobar bronchus (Figure 4).

Table 1. Anatomic type and proportion of right superior lobar bronchus

Right superior lobar bronchial branch type	n (%)
Bifurcated type	
B^1+B^2, B^3	20(17.4%)
B^1+B^3, B^2	4(3.5%)
B^2+B^3, B^1	2(1.7%)
B^2+BX1a, BX1b+B^3	10(8.7%)
B^1+BX2a, BX2b+B^3	1(0.9%)
Others	1(0.9%)
Tribranched type	
B^1, B^2, B^3	68(59.1%)
B^1a, B^2, B^1b+B^3	2(1.7%)
B^1a+B^2, B^1b, B^3	1(0.9%)
B^1+B^2, B^3a, B^3b	1(0.9%)
Others	1(0.9%)
Tetrameric type	
B^1a, B^1b, B^2, B^3	3(2.6%)
B^1, B^2a, B^2b, B^3	1 (0.9%)

Note: "+" meant bronchial co-trunk; ", "was bronchial bifurcation; B^1 was the apical segmental bronchus; B^2 was the posterior segmental bronchus; B^3 was the anterior segmental bronchus; BX was derived from the bronchus adjacent to the normal lung segment or subsegment; B^1a was apical subsegmental bronchus; B^1b was the anterior apical subsegmental bronchus; B^2a was the posterior subsegmental bronchus, B^2b was the posterior subsegmental bronchus. B^3a was the anterior external subsegmental bronchus; B^3b was the anterior medial subsegmental bronchus.

3.3 Anatomic type of right middle lobe bronchus

In 115 cases of right lung, there were 2 types of right middle lobe bronchus, 110 cases (95.7%) of two-branch type and 5 cases (4.3%) of three-branch type. The two branches were divided into four subtypes, of which B^4 and B^5 subtypes (106 cases, 92.2%) were the most common anatomic types of the right middle lobe bronchus. The tricladism is divided into two subtypes, as shown in Table 2.

Table 2. Anatomical types and proportion of bronchus in the right middle lobe of the patient

Right middle lobe bronchial branch type	n (%)
Bifurcated type	
B^4, B^5	106(92.2%)
B^4a, B^4b+B^5	2(1.7%)
B^4+B^5b, B^5a	2(1.7%)
Tribranched type	
B^4a, B^4b, B^5	3(2.6%)
B^4, B^5a, B^5b	2(1.7%)

Note: "+" meant bronchial co-trunk; ", "was bronchial bifurcation; B^4 was the lateral segmental bronchus; B^5 was the medial segmental bronchus; B^4a was the outer subsegmental bronchus of the lateral segment, B^4b was the inner subsegmental bronchus of the lateral segment. B^5a was the upper subsegmental bronchus of the medial segment, and B^5b was the lower subsegmental bronchus of the medial segment.

3.4 Anatomic type of left apical posterior bronchus

In 85 cases of left lung, there were 4 types of segmental bronchus in the left upper lobe, 54 cases of two-branch bronchus (63.5%), 29 cases of three-branch bronchus (34.1%), and 2 cases of four-branch bronchus (2.4%). The bifurcated type could be divided into 5 subtypes, among which (B^{1+2}a+b, B^{1+2}c) and (B^3a, B^3b+c) were the most common anatomical types of the right upper lobe proper segment bronchus. Besides, the tribranched type was divided into three subtypes and only one type of tetramerism was found (Figure 3).

Two types of bronchi were found in the upper lobe of the left lung, with 82 cases (96.5%) of bifurcated bronchi and 3 cases (3.5%) of tribranched bronchi. The bifurcated type was divided into four subtypes, among which B^4 and B^5 were the most common anatomical types of the left upper lobe lingual bronchus. Moreover, the tricladism is divided into two subtypes (Figure 3).

Table 3. Anatomical types and proportion of posterior apical bronchus of the patient's left lung

Left apical posterior bronchial branch type	n (%)
Proper segment	
Bifurcated type	
(B^{1+2}a+b, B^{1+2}c),(B^3a, B^3b+c)	38(44.7%)
(B^{1+2}a+b, B^{1+2}c), (B^3a, B^3b, B^3c)	11(12.9%)
(B^{1+2}a, B^{1+2}b+c), (B^3a, B^3b+c)	2(2.4%)
(B^{1+2}a, B^{1+2}b+c), (B^3a, B^3b+c)	2(2.4%)
(B^{1+2}a+b, B^{1+2}c), (B^3a+b, B^3c)	1(1.2%)
Tribranched type	
(B^{1+2}a+b, B^{1+2}c) , (B^3a, B^3b+c)	25(29.4%)
(B^{1+2}a+b, B^{1+2}c) , (B^3a+b, B^3c)	1(1.2%)
(B^{1+2}a+b, B^{1+2}c) ,(B^3a, B^3b, B^3c)	3 (3.5%)
Tetrameric type	
B^{1+2}a+b, B^{1+2}c, B^3a, B^3b+c	1(1.2%)
Lingular segment	
Bifurcated type	
B^4, B^5	60 (70.6%)
B^4a, B^4b+B^5	19 (22.4%)
B^4a, (B^4b+B^5a, B^5b)	2 (2.4%)
Others	1(1.2%)
Tribranched type	
B^4a, B^4b, B^5	2 (2.4%)
B^4a, B^4b+B^5a, B^5b	1(1.2%)

Note: "+" meant bronchial co-trunk; ", "was bronchial bifurcation; B^{1+2} was the apical posterior segmental bronchus; B^3 was the anterior segmental bronchus; B^4 was the upper lingual segmental bronchus; B^5 was the inferior lingual segmental bronchus; B^{1+2}a was the apical subsegmental bronchus. B^{1+2}b was the posterior subsegmental bronchus. B^{1+2}c was the posterior apical external subsegmental bronchus; B^3a was the anterior external subsegmental bronchus; B^3b was anterior medial subsegmental bronchus; B^3c was the anterior superior subsegmental bronchus; B^4 was the upper lingual segmental bronchus; B^5 was the inferior lingual segmental bronchus; B^4a was the external subsegmental bronchus of the superior lingual segment; B^4b was the anterior subsegmental bronchus of the superior lingual segment; B^5a was the upper subsegmental bronchus of inferior lingual segment; B^5b was the inferior subsegmental bronchus of the inferior lingual segment.

3.5 Anatomic type of left anterior and posterior segmental bronchus of left lung

In 85 cases of left lung, there were 3 types of dorsal segmental bronchus in the left inferior lobe, 84 cases (98.8%) of single branch type, 1 case (1.2%) of double branch type. The single branch type was further divided into three subtypes: double branch type (54 cases, 63.5%), triple branch type (29 cases, 34.1%) and quadrubranch type (2 cases, 2.4%, Figure 4).

Three types of anterior, external and posterior basal segmental bronchus were found in the left inferior lobe of the lung, of which type B^8, B^9+B^{10} (57.6%) were the most common.

Table 4. Anatomical types and proportion of left anterior and posterior bronchus of the patient's left lung

Type of left anterior and posterior bronchial branch of left lung	n(%)
Monobranched type	
Biforked type	
B^6a, B^6b+c	20(23.5%)
B^6b, B^6a+c	2(2.4%)
B^6c, B^6a+b	20(23.5%)
B^6(a)+b, B^6(a)+c	3(3.5%)
B^6a+(c), B^6b+(c)	5(5.9%)
B^6a, B^6c (B^6b absence)	3(3.5%)
Others	1 (1.2%)
Trifurcation type	
B^6a, B^6b, B^6c	28 (32.9%)
B^6a+(c), B^6b, B^6(c)	1 (1.2%)
Quadriforked type	
B^6a, B^6b, B^6c, B^6 (c)	2 (2.4%)
Bifurcated type	
B^6a+c, B^6b	1 (1.2%)
Anterior, external and posterior basal segments	
B^8, B^9+B^{10}	49(57.6%)
B^8+B^9, B^{10}	16 (18.8%)
B^8, B^9, B^{10}	20 (23.5%)

Note: "+" meant bronchial co-trunk; ", "was bronchial bifurcation; B^6 was dorsal segmental bronchus; B^6a was the upper subsegmental bronchus of dorsal segment, B^6b was the external subsegmental bronchus of dorsal segment, and B^6c is the internal subsegmental bronchus of dorsal segment. B^6(a) was the bronchial division of the upper subsegment of the dorsal segment, B^6(b) was the bronchial division of the external subsegment of the dorsal segment, and B^6(c) was the bronchial division of the internal subsegment of the dorsal segment. B^8 was the anterior basal segmental bronchus; B^9 was the lateral basal segmental bronchus; B^{10} was the posterior basal segmental bronchus.

4. Discussion

In recent years, with the screening of low-dose spiral CT, the number of early lung cancer mainly small nodules has increased significantly. Studies have shown that segmental resection has similar oncolologic effects to lobectomy for nodules in stage IA with a diameter of less than 2cm, and the anatomical distance of segmental resection is longer, and the adjacency relationship between segmental bronchus and blood vessels is more complicated and there are more variations. Accurate lung segment removal can protect lung function to the maximum extent, and also meet the maximum requirements of people's health. Therefore, segmental resection has been widely concerned as an alternative to lobectomy in the treatment of small lung cancer, and has become the first choice of thoracic surgeons. However, the types of segmental and subsegmental bronchial branches are complex and diverse. For patients with lung cancer who need to undergo segmental surgery, when the types of target segmental bronchial branches appear anatomic variation, it will greatly increase the difficulty of the surgeon to identify them, and even cause misjudgment. With the rapid development of 3D reconstruction technology in medical imaging, 3D reconstruction technology has been widely used in the preoperative evaluation of thoracoscopic accurate lung segment resection, the setting of surgical plan, the identification of pulmonary bronchus and blood vessels during surgery, and the guidance of teaching. Compared with traditional autopsy research methods, artificial intelligence reconstruction can visually and stereoscopic display branch types and rare anatomical variations of segmental bronchus, locate lung lesions and evaluate the safe range of surgical resection[9], and can perform this technique on a large number of patients, which can make up for the shortcomings of traditional research methods with small number and incomplete data. So as to provide more objective and accurate data for clinical teaching.

In this study, the anatomic types and anatomic variations of bronchus in each lung segment on the affected side of 200 patients were statistically analyzed. The results showed that there were basically four anatomical types of the right superior lobal bronchus of the lung, among which three branching types accounted for the highest proportion, and the B^1, B^2, B^3 subtypes were the most common anatomical types, with an incidence of 59.1%, which was consistent with previous studies [10,11], but the incidence was significantly higher than in previous studies, which may be related to differences in sample size and population differences. In addition, this study also found that there were two types of bronchus in the right middle lobe of the lung, further enriching the bronchus types in the right middle lobe of the lung, among which the B^4 and B^5 subtypes were the most common anatomical types.

For the left lung, 4 types of segmental bronchus were found, (B^{1+2}a+b, B^{1+2}c), (B^3a, B^3b+c) were the most common anatomical types, accounting for 44.7%; Two types of bronchus were found in the left superior lobe of the lung. The incidence of B^4 and B^5 was 70.4%, which were the most common anatomic types. Moreover, there were 3 types of bronchi in the dorsal segment of the left inferior lobe, and 3 types in the anterior, external and posterior basal segment bronchi of the left inferior lobe, among which B^8, B^9+B^{10} (57.6%) were the most common. There were 3 types of bronchial bronchus in the left inferior lobe of the lung, of which 84 cases (98.8%) were single branch and 1 case (1.2%) were double branch. The single branch type was further divided into three subtypes: double branch type (54 cases, 63.5%), triple branch type (29 cases, 34.1%) and quadrubranch type (2 cases, 2.4%). Three types of anterior, external and posterior basal segmental bronchus were found in the left inferior lobe of the lung, of which type B^8, B^9+B^{10} (57.6%) were the most common. The results of this study were consistent with those of previous studies, but there were some differences, such as a slightly higher incidence and no specific type of variation. When performing artificial intelligence 3D reconstruction on patients, the branch types of each segment of bronchus should be fully understood, and preoperative planning should be done in advance to avoid misjudgment, which might lead to surgical failure and risk.

To sum up, the anatomical types of segmental and subsegmental bronchus are complex, and only when we are fully familiar with the common branch types and possible anatomical variations of each lung segment can we carry out more accurate anatomic resection of lung segments or combined subsegments. This study also has some limitations. The sample size is relatively small, and the results of bronchial typing of 3D CT reconstruction of only part of the lung segment undergoing surgery were verified through surgery. The sample size can be further expanded in the future, and a variety of software related studies can be used to obtain more accurate and reliable data.

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