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CT imaging and pathological basis of linear shadow connecting pulmonary segmental artery to horizontal fissure

Chun-Shuang Guan, PhD[a], Shuo Yan, MD[a], Zhi-Bin Lv, MD[a], Lei Sun, PhD[b], Da-Qing Ma, PhD[c], Yan-Song Zhang, MD[d], Ru-Ming Xie, MD[a,*], Bu-Dong Chen, PhD[a,*]

Abstract

To investigate the computed tomography (CT) imaging and pathological basis of the linear shadows connecting pulmonary segmental arteries to horizontal fissure (hereinafter referred to as "linear shadow") on thin-slice CT.

Collect 127 clinical cases to analyze the display and morphology of linear shadows on the thin-slice CT and to measure their length, thickness, and angle. Collect 11 autopsy specimens of coal worker's pneumoconiosis to conduct an imaging and pathology basis control study for the linear shadows.

There is no correlation between the linear shadow and gender, age, and smoking history. Linear shadows are observed in 54.33% of patients. 93.33% of those linear shadows are straight lines. Generally, the lengths are less than 10 mm, the thicknesses are around 1 mm, and the scopes of angles are wide, range from acute angles to obtuse angles. The linear shadow is a banded structure consisting of loose connective tissue, small blood vessels, and small lymphatic vessels due to the visceral pleura recessed and fused into the lung.

Linear shadows are intrinsic to the lung. The linear shadows consist of loose connective tissue, small blood vessels, and small lymphatic vessels.

Abbreviations: 3D = three-dimensional, CT = computed tomography, HU = Hounsfield Unit, kV = kilovolt, mm = millimeter.

Keywords: anatomy, lung, pathology, pleura, spiral computed, tomography

1. Introduction

With the continuous progress of imaging technology, thin-slice lung computed tomography (CT) has been developing rapidly. The thickness of the slice is becoming thinner, and the image quality is improving, which can be corresponded to dissection. The detection rate of intrapulmonary micronodules and various linear shadows have also been increased gradually, which makes thin-slice lung CT a main method for imaging and pathology control study. On thin-slice CT, a linear shadow different from linear shadows of interlobular fissures, accessory fissures, interlobular septa, and fibrous cords can be observed, that is, the linear shadow connecting the pulmonary segmental artery in the middle lobe of right lung to horizontal fissure. This study is carried out to better understand the imaging and pathology basis of this linear shadow.

2. Materials and methods

2.1. Materials

This study was approved by the Review Committee and the Ethics Committee of Beijing Ditan Hospital, Capital Medical University. Written informed consent was waived for the retrospective analyses by the Institutional Review Board. We collected 556 adult patients over 18 years of age who had underwent thin-slice lung CT examinations from October 2018 to November 2019. The exclusion criteria are cases leading to pulmonary structural disorders, such as intrapulmonary disease, pleural lesions, mediastinal lesions, thoracic surgery, etc. Inclusion criteria are cases with normal or basically normal lung CT. A total of 429 patients were excluded from this study. A total of 127 patients were included in the study, aged 18 to 89 years, with an average of 51.520 ± 15.729 years, including 52 females and 75 males.

Complete lung specimens of 13 autopsies from January 2005 to December 2008 were collected from National Research Center for Occupational Safety and Health. The autopsy had been approved by the patients' families. The 11 specimens with

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R-MX and B-DC contributed equally to this work and should be considered co-corresponding authors.

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[a] Department of Radiology, [b] Department of Pathology, Beijing Ditan Hospital, [c] Department of Radiology, Beijing Friendship Hospital, Capital Medical University, [d] Department of Pathology, National Research Center for Occupational Safety and Health, Beijing, China.

[*] Correspondence: Ru-Ming Xie, Department of Radiology, Beijing Ditan Hospital, Capital Medical University, No. 8 Jingshun East Street, Chaoyang District, Beijing 0086100015, China (e-mail: mingrux@163.com); Bu-Dong Chen, Department of Radiology, Beijing Ditan Hospital, Capital Medical University, No. 8 Jingshun East Street, Chaoyang District, Beijing 0086100015, China (e-mail: chenbudong00@126.com).

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uninvolved horizontal fissure were all male, aged 54 to 71 years (an average of 61.556 ± 6.227 years). The specimens were treated using the Heitzman modified method.[1] The complete fresh lungs were injected with 10% formalin solution through the trachea and fixed in the solution for 1 to 2 weeks, and then were removed from the solution and injected with oxygen through the trachea. When the fluid in the lung was exuded entirely from the pleural surface, the CT scan was performed for the inflatable lung specimen. After the CT scan was completed, 10% formalin solution was reinjected into the lung. After 1 day, a gross slide was made with a thickness of 10 mm. The material was taken according to the area of interest on the CT, and tissue slides were made for structure observation.

2.2. Scanning device and scanning method

The scanning equipment of clinical cases was 64-slice spiral CT (GE, vCT, USA). The patient was in the supine position and CT scan is performed at the end of inspiration. Scanning scope: From the lung apex to the diaphragm. Scanning parameters: Tube voltage of 120 kV, automatic tube current, slice thickness and slice spacing of 1.25 mm.

The scanning equipment of lung specimens was 8-slice spiral CT (GE, Lightspeed Ultra, USA), to perform thin-slice CT scan for lung specimens. Scanning parameters: tube voltage of 120 kV, automatic tube current, slice thickness, and slice spacing of 1.25 mm.

2.3. Imaging assessment

Two chest radiologists (with working experiences of 11 and 13 years respectively) assessed the images at the picture archiving and communication system workstation. The conventional window width was 1000 HU and window level - 500 HU, which could be adjusted as needed. Imaging assessment includes axial, coronal, and sagittal images reconstructed using Multiplanar Reformat, and three-dimensional (3D) positioning is used.

The linear shadow connecting pulmonary segmental artery to horizontal fissure (hereinafter referred to as linear shadow) is defined as a high-density linear imaging connecting pulmonary segmental artery to horizontal fissure on thin-slice CT. Assessment parameters include: display, morphology, length, thickness and angle of the linear shadow, and morphology and integrity of the horizontal fissure.

2.4. Statistical methods

The logistic regression analysis was used to determine the relationship between the display of the linear shadows and the gender, age, smoking history, and the integrity of the horizontal fissure. Chi-square was used to determine the differences in the display of the linear shadows among the different positions and those between the morphology of the horizontal fissure. T test was used to determine the differences among the lengths, widths, and angles of the linear shadows.

3. Results

3.1. Display of linear shadows

Logistic regression shows no correlation between the display of linear shadow and gender, age, and smoking history (Table 1). There are 133 assessment records of 127 patients. The arteries that connected linear shadows included the middle lobe, lateral segmental, and medial segmental arteries. The linear shadow was not observed in 58 patients (45.67%, 58/127), and was observed in 69 patients (54.33%, 69/127). The most common connected artery of linear shadow is the lateral segmental artery (59.42%, 41/69), followed by the medial segmental artery (20.29%, 14/69) and middle lobe artery (20.29%, 14/69). There are 75 linear shadows of 69 patients, including 45 linear shadows in lateral segmental artery (60.00%, 45/75), 15 linear shadows in medial segmental artery (20.00%, 15/75), and 15 linear shadows in middle lobe artery (20.00%, 15/75). There were 6 pulmonary segmental arteries connecting with 2 linear shadows, including 4 lateral segmental arteries, 1 medial segmental artery and 1 middle lobe artery. Linear shadows are shown in different positions, and there is no statistical difference between horizontal (42.86%, 57/133), coronal (51.88%, 69/133), and sagittal (53.38%, 71/133) linear shadows ($\chi^2 = 3.449$, $P = .178$). The linear shadow of pulmonary segmental artery has different display rates in different positions (Table 2). But there are only statistical differences between linear shadows connected lateral segmental artery in axial position and linear shadow in coronal and sagittal respectively ($\chi^2 = 4.865$, $P = .027$), and there is no statistical difference in the rest.

Of the 75 linear shadows, only 6.67% (5/75) are arc, and the rest are straight (Fig. 1).

Table 1

***P* value of the correlation between the display of the linear shadow connecting pulmonary segmental artery to horizontal fissure and gender, age, and smoking history.**

	Gender	Age	Smoking history
Lateral segmental artery*	0.504	0.401	0.244
Medial segmental artery*	0.115	0.479	0.928
Middle lobe artery*	0.079	0.337	0.332

* Linear shadows connecting pulmonary segmental arteries to horizontal fissure.

3.2. Lengths, thicknesses, and angles of linear shadows

Measurements of the lengths, thicknesses, and angles of the linear shadows were shown in Table 3. The lengths of the linear shadows are generally less than 10 mm, with the longest linear shadow of 15 mm. Although measurements of the lengths of the

Table 2

Display of the linear shadows connecting pulmonary segmental arteries to horizontal fissure on CT in different positions.

	Visible (%)	Invisible (%)	Total (%)	*P* value
Lateral segmental artery*				
Axial position	33 (73.33)	12 (26.67)	45 (100.00)	.023
Coronal position	41 (91.11)	4 (8.89)	45 (100.00)	
Sagittal position	41 (91.11)	4 (8.89)	45 (100.00)	
Medial segmental artery*				
Axial position	12 (80.00)	3 (20.00)	15 (100.00)	.146
Coronal position	14 (93.33)	1 (6.67)	15 (100.00)	
Sagittal position	15 (100.00)	0 (0)	15 (100.00)	
Middle lobe artery*				
Axial position	12 (80.00)	3 (20.00)	15 (100.00)	.146
Coronal position	14 (93.33)	1 (6.67)	15 (100.00)	
Sagittal position	15 (100.00)	0 (0)	15 (100.00)	

CT = computed tomography.
* Linear shadows connecting pulmonary segmental arteries to horizontal fissure.

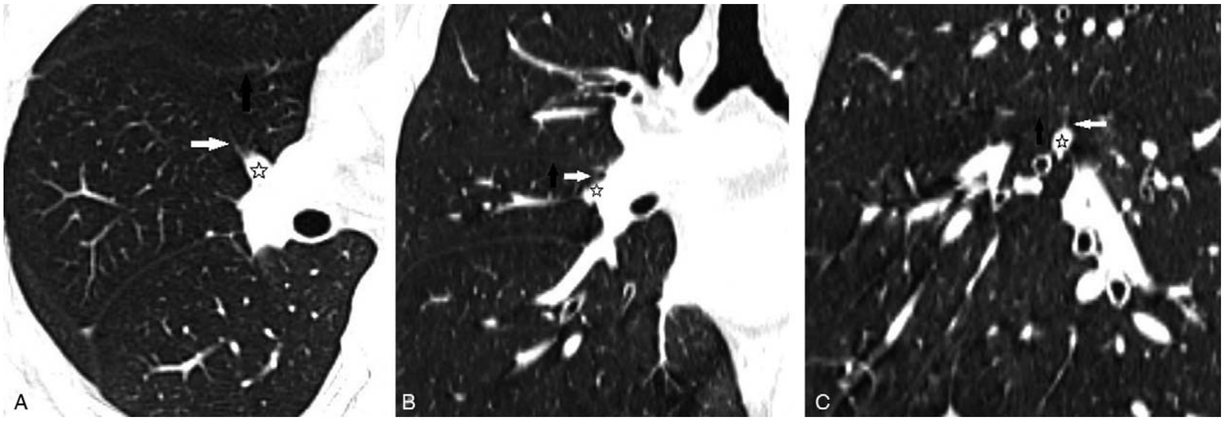

Figure 1. Male, 26 years old. The linear shadow connects the lateral segmental artery to the horizontal fissure in the middle lobe of the right lung. A, Axial position. B, Coronal position. C, Sagittal position. The linear shadow (white arrow) connecting the lateral segmental artery (star) to the horizontal fissure (black arrow) in the middle lobe of the right lung is a straight line, and the morphology of the horizontal fissure does not change.

linear shadows for different arteries are in the order of axial > sagittal > coronal, there is no statistical significance for measurements at different positions.

Most of the linear shadows have the thickness of about 1 mm, and there is no statistical significance for measurements at different positions. There is a wide scope for angles of the linear shadow and the horizontal fissure, ranging from acute angle to obtuse angle.

3.3. Morphology of horizontal fissures pulled by linear shadows

According to the logistic regression analysis, the display rate of the linear shadow is correlated with the integrity of the horizontal fissure. The linear shadows of lateral segmental artery and medial segmental artery are correlated with the integrity of the horizontal fissure ($P = .010$ and .008, respectively), whereas the linear shadow of medial lobe artery is an exception ($P = .265$) (Table 4).

Table 3

Measurements of length, thickness, and angle of line shadows connecting pulmonary segmental arteries to horizontal fissure.

	Length (mm)	Thickness (mm)	Angle (°)
Lateral segmental artery*			
Axial position	2.097 ± 3.636	0.207 ± 0.217	80.760 ± 44.081
Coronal position	1.482 ± 2.311	0.167 ± 0.141	93.154 ± 20.177
Sagittal position	1.357 ± 2.249	0.182 ± 0.161	85.641 ± 24.757
P value	.787	.579	.100
Medial segmental artery*			
Axial position	3.470 ± 5.198	0.123 ± 0.041	82.450 ± 11.384
Coronal position	2.588 ± 4.034	0.131 ± 0.053	88.142 ± 26.188
Sagittal position	2.759 ± 4.447	0.141 ± 0.054	95.009 ± 22.898
P value	.997	.930	.396
Middle lobe artery*			
Axial position	0.555 ± 0.308	0.201 ± 0.250	41.940 ± 13.237
Coronal position	0.540 ± 0.242	0.122 ± 0.026	85.586 ± 20.024
Sagittal position	0.607 ± 0.402	0.143 ± 0.051	100.597 ± 20.348
P value	.539	.860	.042

* Linear shadows connecting pulmonary arteries to horizontal fissure.

37.33% (28/75) of morphologies of horizontal fissures that are pulled by linear shadows are "V" shape (Table 5, Fig. 2). There is no statistically significant difference among the pulmonary segmental arteries connected linear shadows that pull the horizontal fissure ($\chi^2 = 0.152$, $P = .927$).

3.4. Imaging and pathology basis of linear shadows of lung specimens

Thirteen assessments are recorded in 11 lung specimens, no linear shadow is shown in 3 specimens, and medial segmental artery is connected to 2 linear shadows in 1 specimen. In these records, linear shadows are shown in 10 (76.92%, 10/13) records, including 5 linear shadows of lateral segmental artery, 4 linear shadows of medial segmental artery, and 1 linear shadow of middle lobe artery. Linear shadows in the gross lung specimen are shown as gray white lines connecting the pulmonary segmental artery to the interlobar pleura of the horizontal fissure (Fig. 3). The linear shadow is observed on the tissue slide as a banded structure consisting of loose connective tissue, small blood vessels, and small lymphatic vessels due to the visceral pleura recessed and fused into the lung. The banded structure is surrounded by pulmonary alveoli of different sizes (Fig. 3).

4. Discussion

The linear shadow connecting the pulmonary segmental arteries to the horizontal fissure in this study has been mentioned in some literatures, but no in-depth study is conducted.[2,3] To the best of

Table 4

Ratio of the presence of linear shadows connecting pulmonary segmental arteries to horizontal fissure to the integrity of the horizontal fissure.

	Complete horizontal fissure (%)	Incomplete horizontal fissure (%)	Total (%)
Lateral segmental artery*	34 (75.56)	11 (24.44)	45 (100.00)
Medial segmental artery*	13 (86.67)	2 (13.33)	15 (100.00)
Middle lobe artery*	11 (73.33)	4 (26.67)	15 (100.00)

* Linear shadows connecting pulmonary segmental arteries to horizontal fissure.

Table 5

Morphology of horizontal fissure under traction of linear shadow connecting pulmonary segmental arteries to horizontal fissure in normal lung.

	Arc shape (%)	V shape (%)	Total (%)
Lateral segmental artery*	29 (64.44)	16 (35.56)	45 (100)
Medial segmental artery*	9 (60.00)	6 (40.00)	15 (100)
Middle lobe artery*	9 (60.00)	6 (40.00)	15 (100)
Total	47 (62.67)	28 (37.33)	75 (100)

* Linear shadows connecting pulmonary segmental arteries to horizontal fissure.

our knowledge, this is the first systematic analysis for the linear shadow connecting the pulmonary segmental arteries to the horizontal fissure. According to the study, we observe that: first, the linear shadow is observed in 54.33% of normal lung CT images without correlation with gender, age, and smoking history, but with correlating to the integrity of the horizontal fissure. Second, most linear shadows have the length of less than 10 mm; the thickness is about 1 mm; and the scopes of the angles of the linear shadows to the horizontal fissures are wide. Third, the pathological basis of the linear shadow is a banded structure consisting of loose connective tissue, small blood vessels, and small lymphatic vessels due to the interlobar pleura recessed and fused into the lung.

It has been reported in literatures that a normal lung structure would vary with age.[4,5] But there is no correlation between the linear shadow and age in this study. Therefore, the linear shadow is an intrinsic structure in the lung. The linear shadow is shown as a line in most cases, but sometimes it cannot be shown as a line in different positions at the same time and may be only shown as a dot or a very short line at a certain position on an image. The linear shadow can consecutively appear at multiple slices. The linear shadow is also speculated to be a manifestation of membranous structure, which has been confirmed in our previous studies.[3] The display of the linear shadow is correlated with the integrity of the horizontal fissure, which may be caused by that the linear shadow is closer to the inside of the horizontal fissure. It has been reported in literatures that the horizontal fissure is the most common to be incomplete among the 3 interlobular fissures,[6–8] so it causes the correlation between the display of the linear shadow and the integrity of the horizontal fissure.

The display of linear shadow on the CT is similar to the interlobar fissure. There are many studies on interlobar fissures in literatures, and the imaging of interlobar fissures may be related to the slice thickness, resolution, and scanning angle of CT scan, as well as the direction of interlobar fissure, etc.[6–8] These are also applicable to linear shadows. In this study, it is further found that the display of the linear shadow is also correlated with the length and thickness of the linear shadow, angle of the linear shadow with the horizontal fissure, relationship between the pulmonary segmental arteries and the horizontal fissure, the integrity of the horizontal fissure, etc. Linear shadows connecting to different pulmonary segmental arteries have different display rates, and the most common one is the lateral segmental artery.

In 1966, it was mentioned in the literature that the parietal pleura and visceral pleura fused each other in the lung hilum to form connective tissue around the blood vessels and bronchus.[9] In this study, linear shadows in the gross lung specimens are shown as gray white lines connecting the pulmonary segmental arteries to the horizontal fissures, which is further confirmed by histopathology that the linear shadow is a banded structure consisting of loose connective tissue, small blood vessels, and small lymphatic vessels due to the visceral pleura recessed and fused into the lung.

Although linear shadows are intrinsic to the lungs, it is still necessary to identify similar normal and abnormal structures in the lungs on thin-slice CT, such as interlobular septum, segmental septum, pulmonary ligament, fibrous cords, and etc.[2,10] First, the interlobular septa are formed by the inward recession of the visceral pleura, which cannot be seen in normal circumstances unless the interstitium of the interlobular septa are thickened. The interlobular septa are perpendicular to the pleura with the length of about 10 to 25 mm. An entire lobule and part of a lobule can be outlined with punctated or branched lobular cores centrally.[10] However, the linear shadow is generally shorter, with the length of less than 10 mm, which is common on thin-slice CT images, no lobule can be outlined and no lobular cores can be observed near the linear shadow. The 2 ends of the linear shadow are connected with the pulmonary segmental artery and the horizontal fissure respectively. Second, the segmental septum is a thin membranous structure located between 2 or 3 adjacent lung segments. Commonly, the medial margin of the segmental septa connects to the mediastinum and the lateral margin connects to the

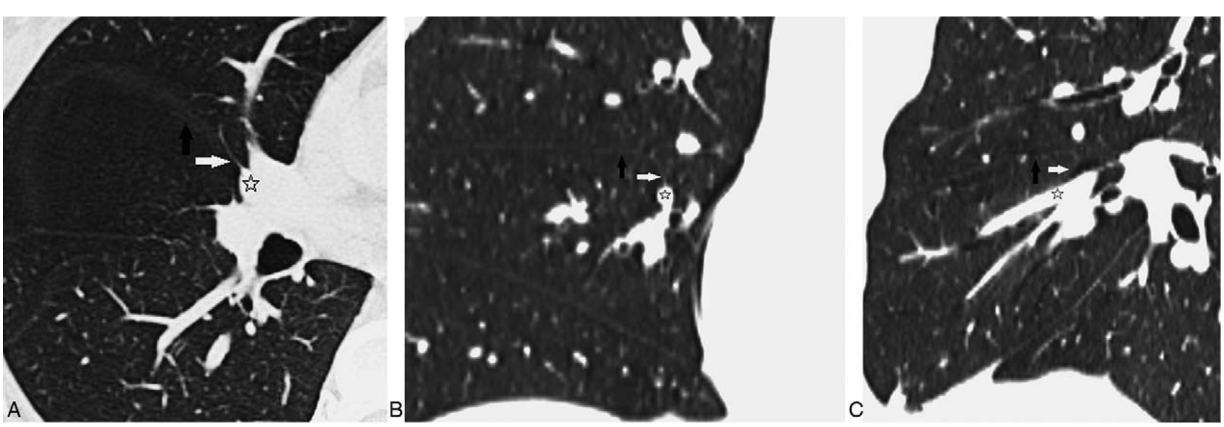

Figure 2. Male, 35 years old. The linear shadow connects the medial segmental artery to the horizontal fissure in the middle lobe of the right lung. A, Axial position. B, Coronal position. C, Sagittal position. The linear shadow (white arrow) connecting the medial segmental artery (star) to the horizontal fissure (black arrow) in the middle lobe of the right lung is a straight line, and the morphology of the horizontal fissure is slightly V-shaped.

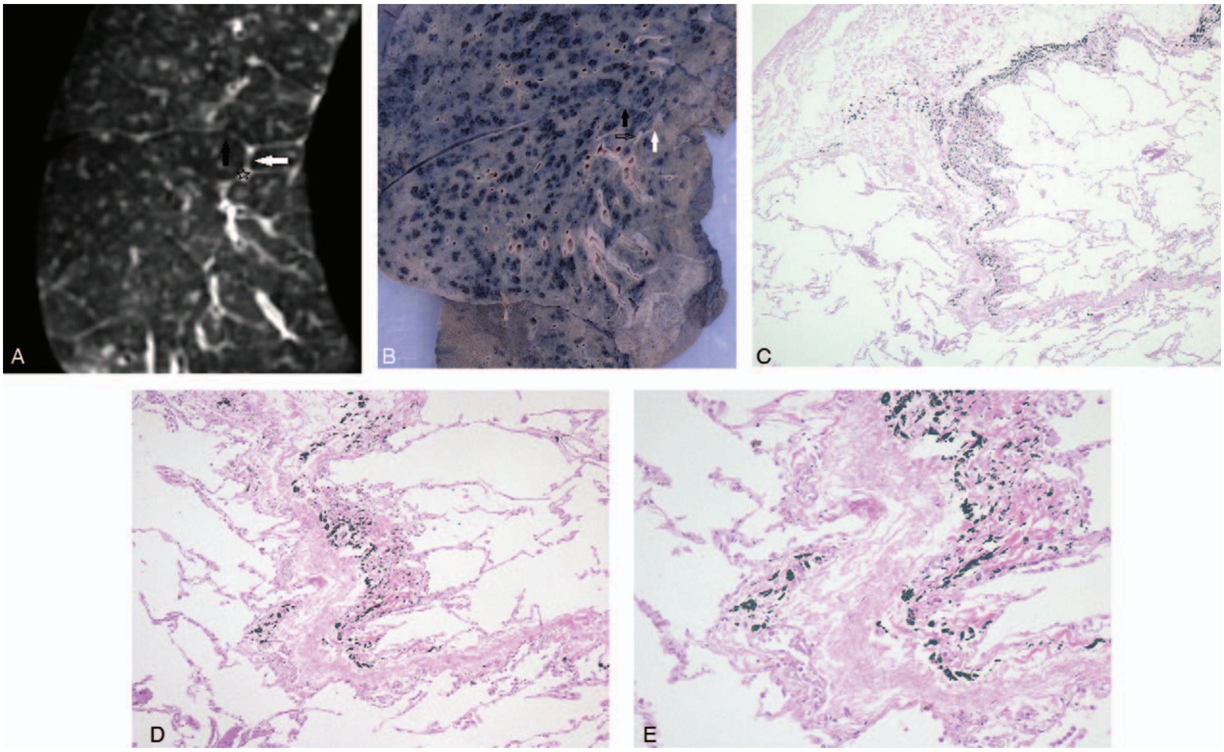

Figure 3. Male, 63 years old, specimen. The linear shadow connects the lateral segmental artery to the horizontal fissure in the middle lobe of the right lung. A, On the coronal CT image, the linear shadow (white arrow) connecting the medial segmental artery (star) with horizontal fissure (black arrow) in the middle lobe of the right lung. B, In the gross lung specimen, the linear shadow is a gray white line (white arrow) connecting the pulmonary segmental artery (blank arrow) to the interlobar pleura of the horizontal fissure (black arrow). (C) In pathological slide (HE, × 40), (D) in pathological slide (HE, × 100), (E) in pathological slide (HE, × 200), the linear shadow is a banded structure consisting of loose connective tissue, small blood vessels, and small lymphatic vessels due to the visceral pleura inward recessed and fused, surrounded with pulmonary alveoli. CT = computed tomography.

pulmonary segmental veins,[2,11] while for the linear shadow connects to the pulmonary segmental artery and the horizontal fissure respectively. Third, the pulmonary ligament is a bilayer membrane-like structure formed by the visceral pleura. The pulmonary ligament is connected to the lower pulmonary veins and extends downward to the diaphragm or free.[11] A beak sign is often seen when the pulmonary ligament is connected to the mediastinum.[11] However, the linear shadows are fixed between the pulmonary segmental arteries and the horizontal fissure, shorter than the pulmonary ligament and cannot be connected to the diaphragm. Fourth, the fibrous stripe is the structure of fibrous tissue formed in the lung, which can appear anywhere in the lung, with 1 or 2 ends of free, unequal length, uneven thickness, and irregular edges. However, the linear shadow is a short straight line with smooth edges, and 2 ends of which are the pulmonary segmental artery and the horizontal fissure respectively.

The clinical significance of accurate linear shadow identification on thin-slice CT: first, the linear shadow can be identified easily, as well as some normal or abnormal structures in the lung. Second, the integrity of the horizontal fissure and middle lobe pulmonary segmental arteries can be easily identified. These are important for the localization of intrapulmonary lesions and the selection of thoracic surgery regimens.

There are some limitations in this research. A further study is needed for the dynamic changes of the linear shadow in lung disease. However, according to its pathological basis, we suspect that the linear shadow may be thickened, thinned, lengthened, or shortened in a certain range, which will be confirmed in future studies. We have studied the linear shadow connecting the pulmonary segmental arteries to the oblique fissure, of which there is a higher incidence than the linear shadow connecting to the horizontal fissure.[3]

In conclusion, the linear shadow connecting the pulmonary segmental artery to the horizontal fissure is a normal structure in the lung, consisting of loose connective tissue, small blood vessels, and small lymphatic vessels. The linear shadow can maintain the stability of the horizontal fissure and lung hilum structures. Accurate identification of the linear shadow connecting the pulmonary segmental artery to the horizontal fissure can help radiologists to identify normal and abnormal structures.

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Author contributions

Data curation: Chun-Shuang Guan, Zhi-Bin Lv, Lei Sun, Da-Qing Ma, Yan-Song Zhang.
Formal analysis: Chun-Shuang Guan, Shuo Yan, Yan-Song Zhang, Ru-Ming Xie.
Investigation: Bu-Dong Chen, Zhi-Bin Lv, Lei Sun, Yan-Song Zhang.

Methodology: Bu-Dong Chen, Chun-Shuang Guan, Shuo Yan, Lei Sun, YanSong Zhang
Resources: Chun-Shuang Guan, Zhi-Bin Lv, Da-Qing Ma, YanSong Zhang.
Software: Shuo Yan.
Visualization: Bu-Dong Chen, Lei Sun.
Writing – original draft: Chun-Shuang Guan, Shuo Yan.
Writing – review & editing: Chun-Shuang Guan, Ru-Ming Xie, Bu-Dong Chen

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