Original Article

Preoperative CT-guided localization of pulmonary nodules with low-dose radiation

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Background: Video-assisted thoracoscopic surgery (VATS) has been widely accepted for the treatment of pulmonary nodules. Prior to VATS, pulmonary nodules can be labeled by computed tomography (CT)-guided hook wire localization, but multiple scans are required, which increases the total radiation dose. We aimed to assess the effectiveness and risks of using low-dose radiation CT to locate lung nodules prior to VATS.

Methods: This study included 158 patients who underwent VATS resection after CT-guided hook wire localization. Based on the CT tube voltage, patients were split into two groups: the low-voltage group (Group A) received 80 kV, while the high-voltage group (Group B) received 120 kV. The two groups' image quality, radiation exposure, localization success and complication rates were compared. The frequencies of intraoperative complications and the types of lung nodules were also compared between the groups.

Results: Successful nodule mapping was obtained in 158 patients. There was no significant difference in age, sex ratio or BMI between the two groups. Subjective imaging quality in both groups met the requirements for location (≥2 points). The signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) in Group A were lower than those in Group B ($P<0.05$). Furthermore, the dose length product (DLP) and effective dose (ED) in Group A were lower than those in Group B ($P<0.05$).

Conclusions: Low-dose radiation CT-guided localization is safe and feasible for identifying uncertain pulmonary nodules before VATS, enabling a significant radiation dose reduction while maintaining mapping accuracy and not increasing complication risk.

Keywords: Hook wire; video-assisted thoracoscopic surgery (VATS); localization; Computer; X-ray imaging; low dose

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Introduction

Lung cancer is the most commonly diagnosed cancer and remains the leading cause of cancer death worldwide (1). With the development of computed tomography (CT) technology, the widespread use of low-dose CT in lung cancer screening and the implementation of lung cancer screening programs, the detection rate of pulmonary nodules has significantly increased (2). The differential diagnosis of pulmonary nodules is difficult and requires diagnosis and radical resection (3). Video-assisted thoracoscopic surgery (VATS) is a minimally radical method that has been widely accepted for the treatment of pulmonary nodules. It has several indisputable advantages over open surgery, such as shorter hospital stays; faster recovery time; decreased intraoperative blood loss, wound infection and postoperative adhesion formation; and enhanced patient comfort. However, VATS does not allow manual palpation of the pulmonary nodules, presenting a challenge in identifying the nodules and resulting in a risk of positioning failure. Furthermore, manual palpation is difficult for a portion of small nodules, especially for ground-glass nodules (GGNs) (4,5). Therefore, several methods to mark target pulmonary nodules during the preoperative period have been developed, such as methylene blue dye, contrast agent, microcoil and radioactive tracers. Multiple studies have reported that pulmonary nodules can be marked prior to VATS by CT-guided percutaneous localization with hook wire or microcoil placement. An experimental animal study showed that semirigid hook wire had better operability and practicality (6,7). Multiple scans are required for prescheduled puncture paths and direct view of position under CT guidance, which increases the total radiation dose. In this study, we aimed to evaluate the success rates and safety of the preoperative localization of small pulmonary nodules using a semirigid single-hook wire under low-dose CT guidance.

Methods

This controlled, prospective study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Institutional Review Board of Tianjin Chest Hospital. Informed consent for VATS and CT-guided positioning was obtained prior to the enrollment of each patient.

Data source and study population

All patients with pulmonary nodules scheduled for CT-guided localization by semirigid single-hook wire before VATS in our department from January 2021 to October 2022 were enrolled. All patients underwent CT evaluation before VATS resection. Determination of whether a patient was considered appropriate for VATS wedge resection was performed by a thoracic surgeon with expertise in VATS and open lung resection. To ensure that the nodules could be safely and availably excised via VATS, the distance from the deepest section of the lesion to the major arteries and veins needed to be at least 2 cm.

Participants were excluded if any of the following criteria were present: no consent for VATS or CT-guided positioning; control of cough not achievable by drugs; bleeding tendency; history of previous ipsilateral thoracotomy; unavoidable pulmonary bullae, pulmonary arteries or veins in the path of the puncture; severe pulmonary hypertension; or severe cardiac or liver dysfunction. All excluded patients underwent standardized clinical therapy by clinicians.

CT scanning

A 256-slice spiral CT scan (Brilliance 256 iCT, Philips, The Netherlands) was used. Patients were classified into Groups A and B based upon different scanning parameters: 80 kV for Group A (low voltage) and 120 kV for Group B. The tube current was modulated automatically in both groups. The image reconstruction layer thickness was 1.5 mm, and the layer spacing was 1 mm, using a soft-tissue algorithm. The lung window had a width of 1,600 HU and a level of 600 HU, and the mediastinal window had a width of 250 HU and a level of 40 HU. The window level and width were adjusted to remove metal artifacts and identify the location of the needle puncture. The scan range was 5 cm surrounding the pulmonary nodules (*Figure 1*). The needle (PAJUNK, German) used was 20-gauge (20G), and the effective length was 12 cm.

Hook wire localization

Hook wire localization was performed 1 h before VATS. The procedure was performed by an experienced radiologist and a thoracic surgeon. The appropriate position (prone, supine or lateral decubitus position) was selected according to the nodule location based on previous imaging results.

The specific steps were as follows. (I) A small-range scan was performed centered on the lesion to determine the best point of the scalp surface and entry point. (II) Local anesthesia was applied around the puncture points after routine disinfection. The anesthetic needle was inserted no further than the chest wall pleura to avoid pneumothorax. (III) The puncture needle was slowly inserted into the pleural cavity. Then, the patient was instructed to control his breath, and the needle was inserted into the lung at the same time. (IV) A small-range scan was performed again to confirm whether any complications, such as pneumothorax or bleeding, had occurred. (V) The needle was advanced

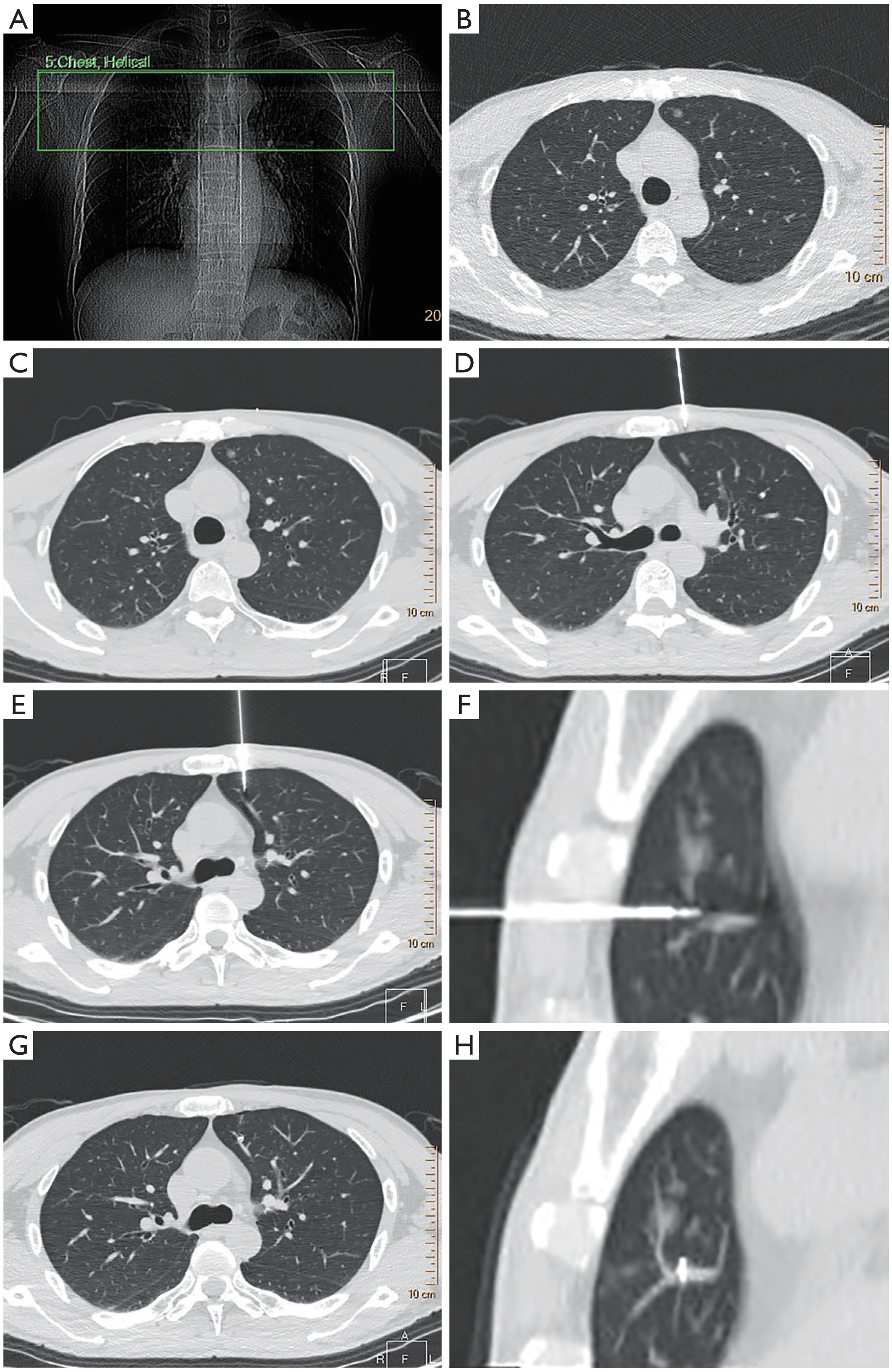

Figure 1 Low-dose CT-guided localization map of a 56-year-old male patient. (A) The green frame is the local scanning area analyzed during the puncture localization process. (B) The ground-glass density nodules were located in the left upper lobe. (C) The metal marker point was located in the anterior chest wall to designate the local anesthesia and puncture needle insertion path. (D) After local anesthesia, the puncture needle was inserted into the chest wall, and the angle and length of needle insertion were identified by local scanning. Because the needle tip did not reach the pleura, it was easy to adjust and avoid complications such as pneumothorax and intrapulmonary hemorrhage. (E) The puncture needle passed into the lung but did not enter the nodule. (F) The sagittal image shows the needle located within 1 cm below the nodule. (G,H) The metal hook wire was successfully positioned as confirmed by a repeat scan after the end of localization. Minimal pneumothorax at the puncture site should be noted. CT, computed tomography.

to the lung tissue near the nodule. In this procedure, the trocar angle could be adjusted according to nodule location. A subsequent CT scan was performed to confirm that the needle was inserted and advanced close to the nodule but not into it (avoiding tumor dissemination). The trocar was adjusted again until reaching the target location. (VI) After successful puncture, the cannula was extracted. Then, the horn of the hook wire was released, and the lung parenchyma around the nodule was anchored. After that, another small-range scan was performed. (VII) After localization, a semirigid wire outside the skin surface was cut to approximately 1 cm and covered with sterile gauze. Finally, the patient was transferred to the operating room for VATS.

Some GGNs or very small nodules could be clearly displayed on the lung window but not on the mediastinal window. In addition, artifacts caused by metal during localization could also affect the judgment of nodules. The window width and window level were adjusted in real time on the lung window image to observe the location of nodules.

VATS procedure

In the VATS procedure, all patients underwent general anesthesia with double lumen endotracheal intubation and single lung ventilation. Single-port laparoscopic surgery was performed with the port located in the 4^{th} intercostal space. The semirigid wire was cut at 3 cm from the visceral pleura. Then, the lesion tissue was lifted with forceps and wedge resected using linear staplers. The resected tissue was placed into a surgical bag and removed from the pleural cavity. Then, according to the results of the frozen section examination, the surgical resection range was determined. If the nodule was diagnosed as benign, metastatic tumor or adenocarcinoma *in situ*, additional resection was unnecessary. If the lung cancer was invasive, patients underwent lobectomy with mediastinal lymph node dissection. Chest radiographs were obtained 1 h after the procedure and 3 h before discharge to exclude massive pleural effusion and pneumothorax.

Image quality evaluation

After the mapping step, retrospective analysis was performed on the image by evaluating objective, subjective and complication measures.

Objective measures: the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated. Specific methods: the average CT value of the ascending aorta, paraspinal muscles and air (the area was 100±5 mm^2) at the same level of the center of the lesion was evaluated. The CT value of the ascending aorta acted as the signal intensity, while the standard deviation of the noise of air acted as image noise. The averaged value of three consecutive level measurements was recorded. SNR = signal intensity/image noise; CNR = (signal intensity-the value of paraspinal muscles)/image noise.

Subjective measures: the images were transmitted to the PACS system. Image quality ratings were performed by 1 radiologist and 1 surgeon without displaying patient information or scanning conditions. Five quality control grades were computed: 5= excellent image quality free of artifacts, where the extent of the lesion was very clear and precise location of the wire location path could be displayed explicitly; 4= good image quality with minor artifacts but fully evaluable to present the location of the wire and choose the appropriate location path. 3= adequate image quality with moderate artifacts, where the extent of the lesion and wire were blurry but acceptable for choosing the location path; 2= poor image/severe artifacts, where the extent of the lesion and wire were blurry and the location path could barely be chosen; 1= extremely poor image, where the lesion and the surrounding tissue were unclear and the location path could not be chosen. A score of two or more points met the location requirements.

Complication measures: the complication and success rates of puncture were assessed by a radiologist and a surgeon. Complications included bleeding and pneumothorax. Location of the wire within 1 cm of the nodule but not into the nodule was defined as successful localization.

Measurement of radiation dose

The dose length product (DLP) and volume CT dose index (CTDIvol, mGy) automatically recorded by the CT scanner after each scan were used for the analysis of radiation dose and effective dose (ED): ED=k×DLP, k=0.014.

Statistical analysis

SPSS 21.0 software (SPSS Inc., Chicago, IL, USA) was used. Continuous variables are expressed as the mean ± standard deviation, and discrete variables are expressed as numbers and percentages. Continuous variables conforming to a normal distribution were analyzed by a two-sample

Table 1 General clinical data in the two groups

Variable	Group A (n=79)	Group B (n=79)	t/χ^2	P
Age (years)	55.86±11.99	57.82±10.23	1.106	0.270
Gender (M/F)	22/57	26/53	0.479*	0.489
Height (cm)	165.13±6.66	166.11±6.96	0.911	0.363
Weight (kg)	58.39±6.70	58.73±7.34	0.306	0.760
BMI, kg/m^2	21.49±2.84	21.32±2.67	0.380	0.704

Data are presented as the mean ± standard deviation or number. *, χ^2 test. BMI, body mass index.

Table 2 Image quality and radiation dose in the two groups

Variable	Group A (n=79)	Group B (n=79)	t/χ^2	P
Subjective scores				
1	0 (0%)	0 (0%)	6.01*	0.111
2	10 (12.66%)	6 (7.59%)		
3	27 (34.18%)	20 (25.32%)		
4	39 (49.37%)	43 (54.43%)		
5	3 (3.79%)	10 (12.66%)		
SNR	23.91±9.25	35.63±7.40	8.795	0.000
CNR	24.30±10.07	39.02±9.26	9.562	0.000
DLP (mGy·cm)	226.30±15.67	578.71±22.71	113.53	0.000
ED (mSv)	3.17±0.22	8.10±0.32	113.53	0.000

Data are presented as the mean ± standard deviation or number (frequency). *, χ^2 test. SNR, signal-to-noise ratio; CNR, contrast-to-noise ratio; DLP, dose length product; ED, effective dose.

t-test; otherwise, a rank sum test was used. Categorical variables were analyzed by the chi-square test. P<0.05 was considered statistically significant.

Results

Comparison of general clinical data

All 158 patients, including 48 males and 110 females, underwent successful location of nodules by CT guidance. There were no significant differences in sex, age, height, weight or BMI between Groups A and B (P>0.05), as shown in *Table 1*.

Comparison of image quality and radiation dose

All of the patients in both groups achieved procedural success immediately, and all images met the location requirements. *Table 2* shows that all scores were above 2 in both groups by subjective measurement. However, the percentage of score =5 and score =4 in Group A was 53.16%, which was lower than that in Group B (67.09%). The percentage of score =3 and score =2 in Group A was 46.84%, which was higher than that in Group B (32.91%). The CNR and SNR in Group B were higher than those in Group A (P<0.05) according to objective measurements. The DLP and ED in Group A were lower than those in Group B (decreased by 44.15% and 44.12%, respectively, P<0.05).

Complications related to location

Pulmonary nodules were found throughout the lung lobe, and the percentage of nodules located in the superior lobe lesion was 52.53%. There was no difference in location

Table 3 Complications related to location and postoperative pathology

Variable	Group A, n (%)	Group B, n (%)	χ^2	P
Location				
RUL	33 (41.77%)	30 (37.97%)	2.192	0.706
RML	2 (2.53%)	1 (1.27%)		
RLL	13 (16.46%)	20 (25.32%)		
LUL	21 (26.58%)	18 (22.78%)		
LLL	10 (12.66%)	10 (12.66%)		
Complications				
None	43 (54.43%)	46 (58.23%)	0.248	0.957
Parenchymal bleeding	26 (32.91%)	24 (30.38%)		
Asymptomatic pneumothorax	8 (10.13%)	7 (8.86%)		
Conversion to thoracotomy	2 (2.53%)	2 (2.53%)		
Histological findings				
Benign lesion			1.899	0.937
Fibrosis	6 (7.59%)	3 (3.8%)		
Tuberculosis	5 (6.33%)	4 (5.06%)		
Fungus	4 (5.06%)	4 (5.06%)		
Lymph node	1 (1.27%)	2 (2.53%)		
Malignant lesion				
MIA/IA	33 (41.77%)	37 (46.84%)		
Carcinoma *in situ*	19 (24.05%)	20 (25.32%)		
AAH	11 (13.92%)	9 (11.39%)		

Data are presented as numbers (frequencies). RUL, right upper lobe; RML, right middle lobe; RLL, right lower lobe; LUL, left upper lobe; LLL, left lower lobe; MIA, microinvasive adenocarcinoma; IA, invasive adenocarcinoma; AAH, atypical adenomatous hyperplasia.

between the two groups. Nodules in both groups occurred most frequently in the right superior lobe, followed by the left superior lobe (*Table 3*).

All nodules were successfully located in all patients in both groups. There was no significant difference regarding complications between the two groups, as shown in *Table 3*. Needle tract bleeding was the most frequent complication in both groups, with 26 patients (32.91%) in Group A and 24 patients (30.38%) in Group B. Some patients experienced asymptomatic pneumothorax, including 8 patients (10.13%) in Group A and 7 patients (8.86%) in Group B. No additional medication or invasive procedures were required for asymptomatic pneumothorax or needle tract bleeding. There were, however, two patients in each group who had a serious pneumothorax and had suffocated, necessitating invasive treatment. Furthermore, no patients in either group experienced excessive bleeding, air embolism or hook wire dislodgement.

Pulmonary nodule postoperative pathology

The VATS procedures were successfully performed in all patients, and there was no difference in pulmonary nodule pathology between the two groups. Malignant nodules predominated in both groups, accounting for 79.75% in Group A and 83.54% in Group B (P=0.682). The majority of malignant nodules, including 33 patients (41.77%) in Group A and 37 patients (46.84%) in Group B, were mildly invasive adenocarcinomas/invasive adenocarcinomas. Adenocarcinoma *in situ* was the next most common diagnosis, affecting 20 patients (25.32%) in Group B and 19 patients (24.05%) in Group A. Nine (five patients in Group A and four patients in Group B) of the 158 benign nodules were diagnosed as tuberculosis. Lung fibroproliferation, fungal infection, and lung lymph nodes made up the remaining benign nodules.

Discussion

VATS has been widely employed in the detection and treatment of pulmonary nodules because it causes less trauma and results in a quicker postoperative recovery than thoracotomy. On the other hand, the detection rate of solitary pulmonary nodules (SPNs) has dramatically risen with the use of low-dose CT, particularly for ground-glass density nodules, which are challenging to localize during surgery due to their hazy borders and faint density. CT-guided localization prior to VATS is therefore becoming more common (8). To locate the needle and positioning wire during CT-guided localization, numerous scans are necessary; however, this raises the patient's radiation exposure. Therefore, it is important to minimize radiation exposure without sacrificing the success of localization. Our research showed that patients' radiation exposure could be greatly decreased while still successfully completing preoperative CT-guided localization with low radiation dosage.

The radiation dose during CT scanning can be decreased by lowering the tube voltage, cutting the tube current, and raising the pitch. Reducing the tube voltage is the most efficient approach to lower the radiation dose for CT because the radiation dose is proportional to the square of the tube voltage value (9). In CT-guided localization, the goal is to minimize the radiation dose by using CT to complete localization, determine the needle insertion path and display the position of the metal hook wire during localization. In this study, participants in Group A received radiation at an approximately 60.86% lower dose than those in Group B thanks to the use of an 80 kV tube voltage. The radiation dose can be further decreased if paired with an iterative reconstruction process and lower tube current scanning (10). However, it is also important to consider timeliness and accomplish quick localization for VATS in CT localization. For simplicity and timeliness, only the tube voltage reduction technique was employed in this study, rather than combining iterative reconstruction and tube current reduction. This is because the CT equipment used in the study has a relatively convenient interface for adjusting the tube voltage. Additionally, different devices employ various reconstruction techniques, and the combination of an iterative reconstruction method with low tube voltage and low tube current can further lower the radiation exposure (10,11).

The puncture and localization structure used during chest CT scanning is a metal structure because the lung has naturally good contrast. This metal structure has a higher CT value on CT images, is quite different from the soft tissue of the chest wall and the density of the lung parenchyma and is easily distinguished on images (12,13). To ensure successful positioning, the path and position of the puncture positioning structure can be examined and clarified by modifying the window's width and level. Additionally, the majority of the patients who underwent CT-guided localization had already had a chest CT scan, which had confirmed the diagnosis of pulmonary nodules. The primary objective of CT-guided localization was changed from pulmonary nodule natural diagnosis to puncture localization success assurance. These factors make completing a low kV scan entirely possible and allow for a suitable reduction in the requirements for image quality. The subjective evaluation ratings of image quality in this study were greater than 2 in both groups, with the majority of the photos clustered in the 3- and 4-point range, and the difference was not statistically significant. However, there were fewer 4- and 5-point images in the low tube voltage group than in the normal tube voltage group, and only three 5-point images were identified in the low tube voltage group (3.79%) *vs.* 10 images (12.66%) in the normal tube voltage group. This demonstrates how image quality is diminished during 80 kV scanning. Low tube voltage simultaneously decreased the CNR and SNR of the images in objective evaluation ($P<0.05$), confirming that low tube voltage had a negative impact on image quality (14). The fact that the operator and CT operator focus primarily on the location of the puncture needle and positioning hook wire, both of which contain metal components and can be clearly displayed on CT scan images, may account for the differences between the subjective and objective results of image quality evaluation. Even if the image quality is very poor, the location of the needle can still be clearly displayed by adjusting the image window width and window level without affecting its localization.

Numerous techniques have been reported in the literature for the localization of pulmonary nodules by VATS; however, they have some drawbacks, including CT-guided methylene blue staining, rapid fluid diffusion in the pulmonary parenchyma, and the risk of spread to the pleura and thoracic cavity, which causes surgical challenges (12,15). Injecting radionuclides is necessary for radiotracer localization, and there are issues with intraoperative radiation exposure as well (16). Indocyanine green (ICG) fluorescent material has been used for lung nodule preoperative localization for VATS. ICG fluorescence is capable of deep tissue penetration and can assist lesion localization. However, ICG remains a novel technique and is not widely used (17). Hook wire localization was first applied to the localization of breast nodules and later to localization before VATS pulmonary nodule resection. With the benefits of speed and accuracy, this method—which employs CT guidance—uses extracorporeal puncture to insert a hook positioning wire into or close to a lesion to facilitate wedge resection of pulmonary nodules. It has since become the most popular preoperative localization technique for pulmonary nodules (4,18). However, there remains a certain risk of complications, such as bleeding, pneumothorax and decoupling (19,20). In this study, complications in the two groups were mainly pulmonary parenchymal hemorrhage and asymptomatic pneumothorax, with incidences of 31.65% (50/158) and 9.49% (15/158), respectively, which were similar to those reported in the literature (21,22). Pulmonary parenchymal hemorrhage was mostly cases of puncture localization needle tract bleeding, and most patients were asymptomatic; a few patients had asymptomatic pneumothorax, but patients underwent VATS within 1 hour after successful localization, so no particularly serious complications occurred. Although 2 patients in both groups had dyspnea symptoms due to a large amount of pneumothorax after successful localization, they were quickly transferred to the operating room, and the final surgical treatment was not affected. Although air embolism is a serious complication of puncture positioning, its incidence is low (0.2–0.6%) (23). We tried to avoid the pulmonary arteries and pulmonary veins during the puncture. The end of the positioning needle does not have to cross the nodule and is only placed beside the nodule. This may be the reason why air embolism did not occur in our study. In addition, the distribution of pulmonary nodules in the two groups was similar, with nodules located mainly in the upper lobes of both lungs, 68.35% (54/79) and 60.76% (48/79), respectively. The final pathological findings of the two groups were similar in benign and malignant distribution, mainly invasive and microinvasive adenocarcinoma, accounting for 41.77% (33/79) and 46.84% (37/79), respectively. These results suggest that CT-guided hook wire localization with a low radiation dose does not increase the incidence of complications and does not affect VATS after localization. It should be noted that in this study, the anchor point was set within 1 cm of the middle nodule, rather than in the nodule, avoiding multiple punctures, reducing the occurrence of complications, preventing lesion spread and improving the localization success rate.

Several limitations were present in this study. First, only two tube voltage schemes were analyzed in this study, without grouping the tube current, and the radiation dose could be further reduced by using a lower tube voltage and tube current combined with iterative reconstruction. Second, we did not observe the intraoperative conditions of patients undergoing VATS, did not follow-up on the cases and did not observe the postoperative conditions of patients in both groups. Third, we did not record the duration of the hook wire procedure. In addition, CT-guided localization is different from CT-guided needle biopsy, and localization beside the nodule can meet the surgical requirements, so we did not determine the nature of pulmonary nodules.

Conclusions

In conclusion, although the CT-guided hook wire localization technique with an 80 vkV low radiation dose can reduce the image quality, CT-guided puncture localization can be completed through subjective evaluation without increasing the incidence rate of complications in patients and significantly reducing the radiation dose in patients, which can be applied to preoperative localization of pulmonary nodules by VATS.

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Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-22-1362/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 the Institutional Review Board of Tianjin Chest Hospital, and informed consent for VATS and CT-guided positioning was obtained prior to each patient being enrolled.

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