Original Article

Use of a novel claw-suture technique for localization of solitary pulmonary nodules: retrospective study and experience from one center

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Background: Video-assisted thoracoscopic surgery (VATS) is more effective for diagnosing and treating solitary pulmonary nodules (SPNs). It is sometimes difficult to localize through use of minimally invasive techniques. We evaluated the feasibility, effectiveness, and safety of a novel localization method for SPNs. Here, we describe our technical process, perioperative results, and accumulated experience over the years.

Methods: Between February 2018 and April 2023, a retrospective study of a novel claw-suture localization technique was conducted in a single center. A total of 490 patients participating in the localization of preoperative SPNs were enrolled. An anchor claw device with four hooks and three-colored sutures was used for localizing nodules under computed tomography (CT). We then evaluated the localization process and the outcomes of the operative procedure (success rate, safety, feasibility, and patient comfort).

Results: A total of 510 SPNs were localized before surgery, and the median size of the nodules was 0.70 cm (range, 0.4–2.0 cm). Additionally, 97.1% of these nodules (495 of 510) were localized successfully without dislodgment or device fracture. Types of failures included not meeting the target value of the distance between the claw and lesion (n=12, 2.4%) and displacement of the device (n=3, 0.6%). Pneumothorax (n=63, 12.4%), parenchymal hemorrhage (n=46, 9.0%), and hemothorax (n=1, 0.2%) were the most common complications that did not require further medical treatment. Pleural reactions were reported in 2 patients (0.4%). A notable correlation was also found between the depth of the pulmonary nodules and the incidence of parenchymal hemorrhage (P<0.001). The median length for the entire process was 12 minutes (7–25 minutes). No patients reported significant pain during the localization process, and the device was retrieved with a 100% survival rate after VATS resection.

Conclusions: This method of claw-suture localization is safe, effective, and feasible and can be used to localize SPNs that are challenging to locate before operation.

Keywords: Localization; solitary pulmonary nodules; computed tomography; video-assisted thoracoscopic surgery; complications

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Introduction

The extensive application of computed tomography (CT) with a low dose and high-resolution in lung cancer screening has resulted in solitary pulmonary nodules (SPNs) being detected more frequently in high-risk populations (1). Particularly, as many as half of these nodules may be cancerous (2). Consequently, precise identification is often pursued for these nodules, particularly when ground-glass opacity (GGO) appears in CT scans.

Conventional methods for diagnosing SPNs suspected to be malignant by needle biopsy have certain limitations (3,4). Robotic bronchoscopy may improve pneumothorax complication rate, but access to these costly systems varies in many parts of the world. Biopsy through percutaneous puncture is usually associated with a high risk of pneumothorax, and sampling failures are prone to occur owing to missed or inadequate tissue sampling (5). Video-assisted thoracoscopic surgery (VATS) may offer a better approach in terms of histological diagnosis and therapeutic purposes (6). However, SPN targeting is sometimes challenging during VATS. The failure of palpation or visualization for a pulmonary nodule occurs in between 54% and 63% of patients with no localization VATS, resulting in conversion to thoracotomy (7). The conversion rate is as high as 65% when these nodules are deeper than 0.5 cm from the pleura of the lung tissue or smaller than 1 cm in size or with a mixed-solid or ground-glass appearance (8). Preoperative localization under CT guidance (microcoils, hook-wires), injection of percutaneous liquid agents (lipiodol, methylene blue), electromagnetic navigation bronchoscopy (ENB), and intraoperative ultrasound (US) have been proposed as solutions to this problem (7,9-11). Among these methods, hookwire is the most common technique for localization of SPNs before surgery, as it has a high success rate (80.5–98.5%) (12). However, it is also associated with a considerably high incidence of chest pain, pneumothorax, parenchyma hemorrhage, hemothorax, dislodgement, vasovagal syncope, and even life-threatening complications such as systemic air embolism (13,14). Microcoils are often implemented in the localization of SPNs, and, compared with hookwires, have certain advantages, with less complaints of discomfort. However, fluoroscopy is usually needed in VATS, which increases radiation exposure to both patients and surgeons (15). In this paper, we share our experience using a new claw-suture method for the localization of SPNs and describe the technical process, complications, success rate, and accumulative experience over the years. This novel method offers a feasible, effective, and safe option for the localization of SPNs. We present this article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1876/rc).

Highlight box

Key findings

- The novel claw-suture system is safe, effective, and feasible and can be used to localize solitary pulmonary nodules (SPNs) that are challenging to locate before operation.

What is known and what is new?

- Preoperative localization under computed tomography guidance (microcoils, hookwires) has been proposed as solution to the localization of SPNs.
- A new method with a claw-suture device for localization of SPNs was developed.

What is the implication, and what should change now?

- The new claw-suture device offers a feasible, effective, and safe option for localization of SPNs and is recommended as a replacement for traditional hookwire localization.

Methods

The Institutional Review Board of Ningbo Medical Center Lihuili Hospital approved this clinical study (No. QT2023PJ036). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Informed consent was taken from the patients or legal guardians.

Patients

We retrospectively analyzed 490 consecutive patients undergoing preoperative localization with a new claw-suture system from February 2018 to April 2023 in Ningbo Medical Center Lihuili Hospital. The criteria for patient inclusion were as follows: (I) seeking surgical management and preoperative localization, with lesion depth within the pleura more than 1 cm from the visceral pleura; (II) lesions not more than 2 cm in size, and (III) a semisolid, solid or GGO apparent in the CT image. Patients with severe comorbidities, such as advanced disease, severe pulmonary hypertension, severe coagulation disorders, or distant metastasis were all excluded from the study.

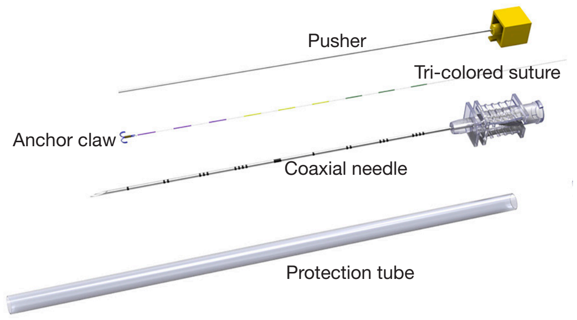

Figure 1 The device consists of a coaxial needle, pusher, anchor claw, tricolored suture, and protection tube.

CT-guided localization

All cases were reviewed by highly experienced radiologists and thoracic surgeons to determine patient candidacy before surgery. Preoperative localizations were implemented by two radiologists with 10 years of localization experience. All cases underwent resection of SPNs after localization. Analyses were not conducted on those who did not complete the entire localization or resection process.

This novel claw-suture device was proposed and designed by Shanghai Chest Hospital and manufactured by Ningbo Senscure Biotechnology Company (Ningbo, China). The related details have been published previously (16). The device comprises a coaxial needle, anchor claw, three-colored suture, protection tube, and pusher (*Figure 1*). A four-hook anchor claw and a length of three-colored suture are the main features of this system.

The localization process was as follows (*Figure 2*): (I) Based on the approximate site of the nodule, the patient was placed in position as appropriate, and then in order to determine point of entry, a CT scan was performed while a metal mesh was in place. (II) According to location of nodule, the best puncture route and site were selected. (III) The puncture site was treated with a 5% solution of lidocaine after the targeted skin was disinfected. The needle was then slowly inserted through the chest wall. (IV) A CT scan was used to ensure that the needle was positioned correctly, and the needle point was positioned in the expected site. (V) As soon as the needle was positioned, the claw-suture system was released, and the last CT scan was completed to check the exact site of the claw after the puncture needle was pulled back. Any complications were observed and documented. Nodule resection was performed within 24 hours after the process.

Surgical procedure

All of the enrolled cases were placed in a suitable position which is beneficial for surgical procedure after general anesthesia, and single-lung isolation ventilation with double-lumen or single-lumen tracheal intubation was conducted. During the exploration by VATS with two or three ports, we pulled sutures into the pleural cavity, gently manipulating the extrapulmonary suture to pull the nodules in a direction that was conducive to resection. Lesions that contained the full claw-suture length were then subjected to wedge resection. Segmentectomy was performed when adequate negative margins could not be obtained. All of the nodules were frozen intraoperatively for pathology. Lobectomy with lymph node sampling or dissection was performed if invasive disease was confirmed by frozen section.

Evaluation

The clinical information, such as gender, age, histopathology, and localization characteristics were collected. The degree of pain, the success rate of localization, the rate of complication, and length of time for localization were assessed until the entire surgery was completed. The criteria for successful localization were as follows: (I) a distance between the claw and nodule not exceeding 1 cm, with the measurement standard being the shortest straight-line distance between the claw and the nodule; (II) the localization device placed and removed stably without any device fracture during the process; and (III) no displacement or dislodgement in any of the localization until the VATS resection was performed. We defined dislodgement as the claw moving into the pleural cavity out of the lung tissue when displacement was interpreted as the claw movement from the initial position but remained in the tissue. The visual analog pain scale was used to measure pain intensity immediately following localization in our study.

Statistical analyses

Categorical variables were expressed as numbers and percentages, while quantitative data were expressed as numbers, median, and range. Bivariate Pearson correlation analysis was used. The statistical analyses were conducted with SPSS 22 (IBM Corp., Armonk, NY, USA). A P value less than 0.05 was considered as a statistically significant difference.

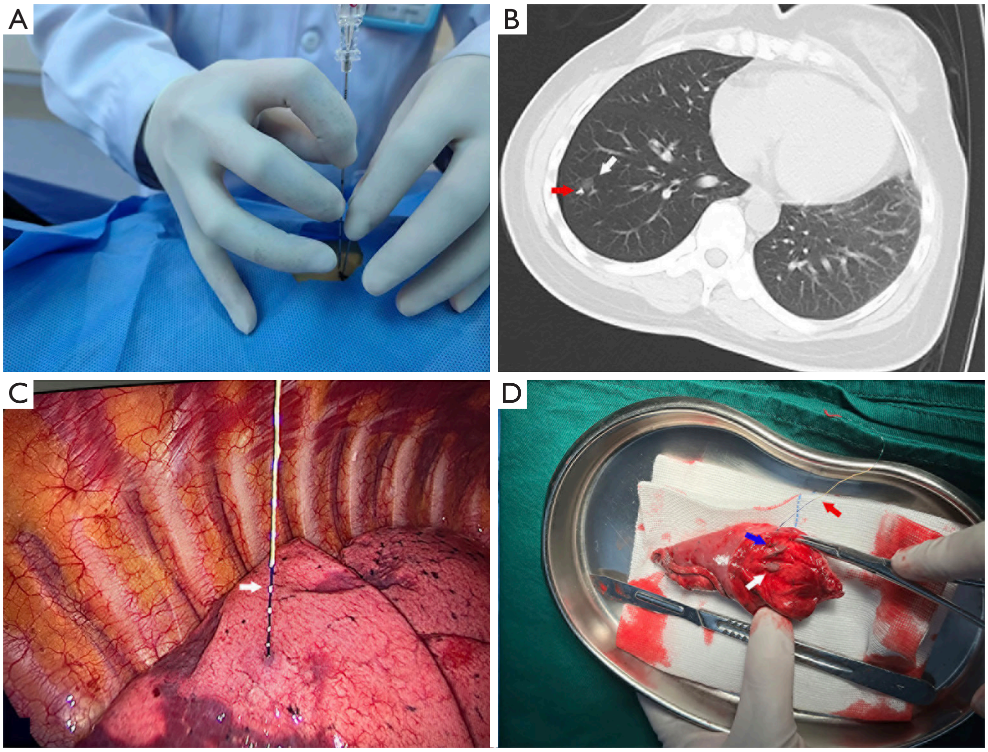

Figure 2 The main process of localization for patients with SPNs. (A) The coaxial needle is inserted through the chest wall based on the location of the pulmonary nodule after a scout CT scan. (B) CT image shows the pulmonary nodule (white arrow) and the claw (red arrow). (C) The tricolored suture (white arrow) is displayed during the first exploration by VATS. (D) The claw (blue arrow), the tricolored suture (red arrow), and the localized pulmonary nodule (white arrow) are displayed after wedge resection. SPN, small pulmonary nodule; CT, computed tomography; VATS, video-assisted thoracoscopic surgery.

Results

Clinical features of patients and lesions

A total of 490 patients with 510 SPNs (338 females and 152 males; median age 53 years; age range, 15–82 years) undergoing preoperative localization were assessed retrospectively in this study. The clinical features are presented in *Table 1*.

These lesion types included GGO (n=408, 80.0%), mixed-solid GGO (n=57, 11.2%), and solid GGO (n=45, 8.8%). The median size of lesions was 0.70 cm (0.4–2.0 cm). The median depth of nodule was 0.90 cm (0–4.6 cm) from the visceral pleura. The lesions were completely resected at the beginning, and all were immediately identified via frozen section intraoperatively. Additionally, 448 lesions (87.8%) underwent wedge resection, and 57 nodules (11.2%) underwent segmentectomy. In addition, five of procedures (1.0%) were eventually converted from wedge or segmentectomy to lobectomy on account of an infiltrative lesion ratio (solid/GGO) >50% as determined by intraoperative frozen section. Pathological diagnosis included 426 primary lung malignancies (83.6%), 1 distant metastasis (0.2%), and 83 benign nodules (16.2%). All cases undergoing operation received negative resection margins (*Table 2*).

Localization and operative procedure outcomes

The procedure was performed without major complications or deaths. There were, however, cases of significant asymptomatic pneumothorax (n=63, 12.4%), parenchymal hemorrhage (n=46, 9.0%), and hemothorax (n=1, 0.2%) (*Figure 3*). There were two cases (0.4%) of pleural reaction observed with the requirement of further medical treatment. The median distance between the claw and the nodule was 0.2 cm (ranging from 0 to 3 cm) (*Table 3*). In addition, a notable correlation was found between the depth of the pulmonary nodules and the incidence of parenchymal

Table 1 Clinical characteristics of patients with solitary pulmonary nodules for localization (N=490)

Variable	Value
Sex, n (%)	
Male	152 (31.0)
Female	338 (69.0)
Age (years), median (range)	53 (15–82)
Smoking history, n (%)	
Yes	137 (28.0)
No	353 (72.0)
Time between localization and surgery (hours)	
Immediately* (n=193)	1.0
Not immediately (n=297), median (range)	20 (2–24)
Patient comfort (pain), n	
Normal	488
Mild pain	2
Moderate-to-severe pain	0

*, the time interval immediately after localization was assessed as 1.0 hours.

hemorrhage (P<0.001) (*Table 4*). Two patients had mild chest pain requiring no treatment during the waiting period (*Table 1*).

The localization success rate was 97.1% (495/510 lesions). Nineteen patients had multiple nodules that were localized simultaneously. Eighteen cases experienced double localization procedures, with six being conducted in the same lobe and twelve in two different lobes. Three nodules were localized in two different lobes in one patient. Visualization of all the sutures and claws was completed at the beginning before resection, and the entire lesions were retrieved (*Table 3*).

In 12 of the 15 cases where localization was unsuccessful, claws were distant from the nodules (1.1 to 3.0 cm), exceeding the target data (1.0 cm). The 3 cases of failure were caused by displacement since the lesions were on the surface lesions and did not penetrate through the pleura but were still attached to it (*Figure 3*). All of these lesions were successfully resected in the area of localization. Throughout the entire procedure, there were no instances of dislodgment or device fracture (*Table 3*).

The median length of time for the localization process

Table 2 Clinical and pathologic characteristics of solitary pulmonary nodules for localization (N=510)

Variable	Value
Diameter (cm), median (range)	0.7 (0.4–2.0)
Nodule characteristics, n (%)	
GGO	408 (80.0)
Solid	45 (8.8)
Mixed-solid GGO	57 (11.2)
Location, n (%)	
Right upper lobe	162 (31.8)
Right middle lobe	33 (6.5)
Right lower lobe	114 (22.3)
Left upper lobe	123 (24.1)
Left lower lobe	78 (15.3)
Depth of nodule from visceral pleura (cm), median (range)	0.9 (0–4.6)
Resection, n (%)	
Wedge resection	448 (87.8)
Segmentectomy	57 (11.2)
Lobectomy	5 (1.0)
Pathological diagnosis, n (%)	
Adenocarcinoma of the lung	
Adenocarcinoma *in situ*	82 (16.1)
Minimally invasive adenocarcinoma	293 (57.5)
Invasive adenocarcinoma	43 (8.4)
Mucinous adenocarcinoma	4 (0.8)
Squamous cell carcinoma	2 (0.4)
Primary lung carcinoid	1 (0.2)
Lymphoepithelioma-like carcinoma	1 (0.2)
Metastatic lesions	1 (0.2)
Benign lesions	
Fibrosis scar tissue	40 (7.8)
Granuloma	22 (4.3)
Hamartoma	3 (0.6)
Lymphoid hyperplasia	9 (1.8)
Atypical adenomatous hyperplasia	8 (1.6)
Sclerosing hemangioma	1 (0.2)

GGO, ground-glass opacity.

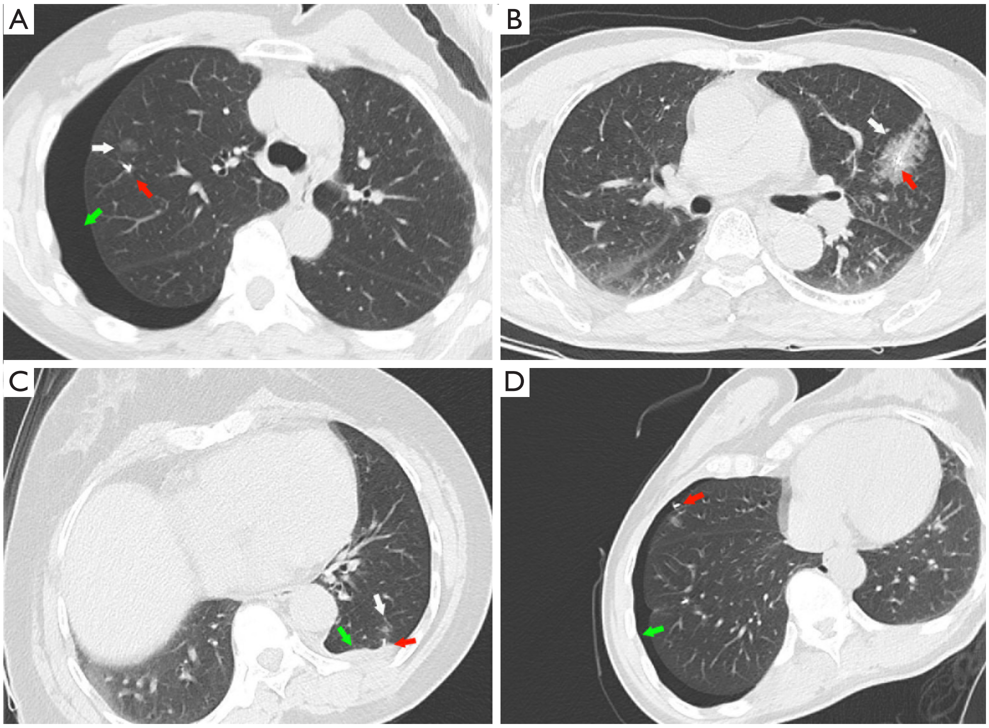

Figure 3 Complications and unsuccessful localization. (A) CT image showing asymptomatic pneumothorax (green arrow), with the claw (red arrow) and nodule (white arrow) in the right upper lobe. (B) CT image showing asymptomatic parenchymal hemorrhage (white arrow), with the claw (red arrow) in the left upper lobe. (C) CT image showing hemothorax (green arrow) with the claw (red arrow) and nodule (white arrow) in the left lower lobe. (D) CT image showing pneumothorax (green arrow) and displacement of the claw (red arrow) pushing against the lung tissue in right middle lobe. CT, computed tomography.

was 12 minutes (7–25 minutes) Additionally, 193 patients (39.4%) underwent resection immediately after preoperative localization of SPNs. The median interval time between localization process and surgical procedure was 1.0 hours, and the median interval time of 20 hours (2–24 hours) was observed in 297 patients (60.6%) (*Table 3*). Complications, complex surgery, and a large array of surgical arrangements contributed to the delay.

Discussion

It is becoming increasingly important to perform VATS resections of SPNs for diagnosis and therapy, but the impalpability and nonvisibility make the first VATS exploration difficult (17). Our study showed that the claw-suture technique had a high success rate and could provide a safe, effective, and viable method for localizing SPNs.

For the localization of SPNs, most surgeons rely on three fundamental techniques: (I) image-guided percutaneous fiducial placement, (II) ENB fiducial placement or dye marking, and (III) intraoperative US (18).

The hookwire localization technique is the most commonly used procedure for placement of percutaneous fiducials. Pneumothorax is the most common complication, with an incidence of 7.5% to 40%. (19). The incidence of parenchymal hemorrhage is also high, at 16%, while dislodgment of wires or needles occurs in 2.4–15% of cases (20). Meanwhile, air embolism is rarer, with an incidence of 0.6% reported in a large study (21). It is also worth noting that the device with hook-wires was initially designed for the localization of breast nodes but may not be the best method for the localization of lung nodules.

An increase in the popularity of ENB-guided dye marking has been seen in recent years (22). ENB-guided localization is more effective and reduces the risk of pneumothorax and dye diffusion significantly compared to traditional percutaneous marking methods (23). In a study by Song *et al.*, 94.5% of 164 pulmonary lesions were successfully localized, and no ENB-related complications were observed (24). However, intraoperative CT scans still

Table 3 Characteristics of the localization procedure (N=510)

Variable	Value
Time of localization procedure (min), median (range)	12 (7–25)
Location of the anchor claw, n (%)	
Inside of nodules	198 (38.8)
Around nodules	312 (61.2)
Distance between claw and lesion (cm), median (range)	0.2 (0–3.0)
Length of claw-suture in the parenchyma (cm), median (range)	1.2 (0–6.0)
Successful localization, n (%)	495 (97.1)
Unsuccessful localization, n (%)	15 (2.9)
Distance between the claw and lesion >1.0 cm	12 (2.4)
Displacement	3 (0.6)
Dislodgment	0 (0.0)
Device fracture	0 (0.0)
Complications, n (%)	
Pneumothorax	
Asymptomatic	63 (12.4)
Symptomatic	0 (0.0)
Parenchymal hemorrhage	
Asymptomatic	46 (9.0)
Symptomatic	0 (0.0)
Hemothorax	
Asymptomatic	1 (0.2)
Symptomatic	0 (0.0)
Pleural reaction	2 (0.4)
Retrieve of device after resection, n (%)	510 (100.0)

Table 4 Pearson correlation analysis of the localization procedure and complications

Variable	Pneumothorax	Parenchymal hemorrhage
Depth of nodule from visceral pleura		
Rs	0.082	0.182
P value	0.07	<0.001
Length of claw-suture in the parenchyma		
Rs	0.071	0.163
P value	0.11	<0.001

Rs, Pearson correlation coefficient.

expose patients to small amounts of radiation, and there are limitations to the availability of ENB-guided dye marking equipment and training in hospitals in remote or low-income areas.

Since the 1990s, the intraoperative US method has been widely used for the localization of lung nodules and has a rate of successful intraoperative localization of about 92% (25,26). However, identifying nodules with a GGO appearance is difficult (27-30). Furthermore, since US procedures require complete deflation of the lung, it is much more difficult to safely target these nodules in patients with emphysema. Finally, US procedures are highly operator-dependent, and only well-experienced radiologists are capable of performing them effectively and safely (31).

This study represents one of the largest studies on localizations completed with the claw-suture method. We have been performing SPN localizations for over 10 years and hope that our cumulative experience will be helpful to others. Some key points regarding the procedure are listed below:

(I) As opposed to hookwire procedures, we place three-colored sutures into the thorax after localization so that position changes and respiratory movements do not increase the amount of force applied to the claws, as more dislodgement of wire occurs when the hookwires are firmly attached to the skin.
(II) The anchor claw with four hooks is the most critical unit of this system. After the anchor claw is loosed, the surrounding parenchyma can be held without damaging it, decreasing the risk of parenchymal hemorrhage and pneumothorax.
(III) Since the anchor claw can withstand significant traction, it is convenient to pull the suture upward during the operation to create a maximum field of vision, thereby limiting parenchymal resection.
(IV) The coaxial needle with a scale assists in terms of precise localization. Another key step is that to pull the pusher out, we then pull the needle out until the tip is within 1–1.5 cm from the chest wall. Leaving the needle end in the pleural space is a good reminder to treat the nodules carefully if they are close to the surface of the lung. Having the needle end slightly exceed the nodule ensures penetration into the visceral pleura.
(V) The tricolor sutures appear to be an effective means to assess the nodule depth, ensuring sufficient margins in wedge resections, and facilitating

segmentectomy. In addition, our study found that the occurrence of parenchymal hemorrhage was significantly associated with the length of the suture in the tissue and the depth of pulmonary nodules. The surgeon should be conscious of the possibility of parenchymal hemorrhage if deep nodules are found.

(VI) Coaxial needles are often located in the visceral pleura at an acute angle when this claw-suture device is positioned in the diaphragm or apex of the lung. In these cases, it is more likely that the claws are shifted toward the surface of tissue, making resection even more challenging. Furthermore, if a lobectomy or segmentectomy is not performed, the insertion site of the dislodged claw must be removed to prevent ongoing air leakage.

(VII) It is recommended that the claw be placed near the nodule. Placement further than the inner side of the nodule within the parenchyma can lead to deeper resections that may cause deformation of the lung lobe, making further operation difficult.

The main limitation of our study is the use of a single-center, nonrandomized, retrospective design with a small sample size. A prospective randomized trial with a large sample size is required to confirm the efficacy and safety of this new method. Our claw-suture technique using the claw-suture system enables VATS-assisted resection of SPNs with high accuracy and safety and provides advantages over the other localization methods (7,9,10). However, it is well known that some nodules are difficult to perform a marking through CT-guided peripheral marking technique because of the location of the nodules, for example, nodules behind the scapula and on the mediastinal side. In addition to being able to move freely as a patient during the waiting time, the claw-suture system may be able to remain within the lung tissue for a longer period without causing significant discomfort (13). Additionally, unlike image-guided video-assisted thoracoscopic surgery (iVATS), a core comparison technique that uses intra-op fluoroscopy for depth and 3-dimensional (3D) assessment (32), most hospitals have this readily available device, and the procedure is easy to perform. In almost all cases, surgeons can operate on the entire lung without the need for radiation exposure.

Conclusions

This claw-suture localization method is reliable, effective, and practical, making it suitable for indicating SPNs that are challenging to identify prior to VATS surgery.

Acknowledgments

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1876/rc

Data Sharing Statement: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1876/dss

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1876/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 Institutional Review Board of Ningbo Medical Center Lihuili Hospital approved this clinical study (No. QT2023PJ036). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Informed consent was taken from the patients or legal guardians.

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