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Microcoil localization as an effective adjunct to thoracoscopic resection of pulmonary nodules in children

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ABSTRACT

Background/Purpose: Thoracoscopic excision of pulmonary nodules is often required for diagnostic or therapeutic purposes, however subpleural and sub-centimeter nodules can be difficult to visualize. Various CT-guided localization techniques have been described, though there is minimal published pediatric data regarding the use of microcoils. We hypothesize that microcoil localization facilitates thoracoscopic resection of pulmonary nodules in children.
Methods: A multi-institutional retrospective review of children who underwent preoperative CT-guided localization of lung nodules was conducted from 2012 to 2019. A combination of methylene blue dye (MBD), wires, and microcoils were utilized for CT-guided localization. When microcoils were utilized, fluoroscopy assisted in lesion identification and resection.
Results: Eighteen patients (mean age 13 years, range 2–21 years) underwent thoracoscopic resection of 24 preoperatively localized pulmonary nodules. Mean size and depth of the lesions were 5.5 mm and 10 mm, respectively. Microcoil placement was successful 95% of the time and assisted in lesion localization in 88% of cases. Wire localization was not a durable technique, as 3 of 5 wires became dislodged upon lung isolation.
Conclusions: Preoperative CT-guided localization with microcoils can assist in fluoroscopic-guided resection of pulmonary nodules in children. This technique avoids the pitfall of wire dislodgement, and provides surgeons an additional technique to localize sub-centimeter, subpleural nodules.
Type of Study: Retrospective Review.
Level of Evidence: Level III.

Indeterminant pulmonary nodules in children can have various benign, infectious and malignant etiologies. It is essential to obtain a pathologic diagnosis in order to guide treatment and prognosis, especially in children with extra-pulmonary malignancies. Complete excision of pulmonary nodules avoids the sampling error inherent in needle biopsy [1]. Additionally, in some childhood cancers, including osteosarcoma and hepatoblastoma, complete resection of pulmonary metastases is associated with a survival benefit [2].

Thoracoscopic resection has become a widely accepted and safe means of resecting pulmonary nodules in children [1,3,4]. In many cases, thoracoscopic surgery is the preferred method of resection over thoracotomy due to lower morbidity, decreased length of hospital stay, and improved cosmetic outcomes [1–6]. Additionally, thoracoscopy enhances intra-operative visualization of the pleural surface. However, sub-centimeter nodules discovered on high-resolution CT scans or nodules located deep to the pleural surface can be difficult to palpate or visualize during thoracoscopy [3,7]. Failure to localize subpleural and sub-centimeter nodules previously resulted in conversion to thoracotomy, therefore multiple preoperative localization techniques have been developed to more accurately resect these lesions [2,3].

Currently, there is no gold standard technique for preoperative localization of pulmonary nodules in children. The two techniques utilized most frequently in children include injection of methylene blue dye (MBD) and the placement of localization wires [1–5,8]. The reported experience with the use of microcoils is more limited in the pediatric population and the relative utility compared to other techniques is unknown [4,7]. We hypothesize that microcoil localization is an effective method to facilitate thoracoscopic resection of pulmonary nodules in children.

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1. Materials and methods

1.1. Patient selection

A retrospective review of children who underwent preoperative CT-guided localization of lung nodules from 2012 to 2019 was conducted in two tertiary children's hospitals after Institutional Review Board approval from both institutions. Patients 21 years old or younger who underwent preoperative CT-guided localization followed by thoracoscopic resection of pulmonary nodules were included in the study. Patient demographics, pulmonary nodule characteristics, and perioperative notes were reviewed in the selected patients. Pulmonary nodule size was measured in its longest axis and nodule depth from the middle of the nodule to the closest parietal pleural margin utilizing high-resolution CT images.

1.2. Preoperative CT-guided localization

Preoperative localization of the lung nodule was performed prior to thoracoscopic resection by a pediatric interventional radiologist. Following induction of general anesthesia and intubation, the patient was positioned for optimal nodule localization (i.e. supine, prone, lateral). Under CT guidance, the nodule was then localized with a micropuncture needle, and a microcoil was deployed adjacent to the nodule. The precise type of microcoils used were dependent on the interventional radiologist, but included Hilal, Tornado, and Nester embolization coils (Cook Medical, Bloomington, IN). In select patients, a small volume of MBD was injected into the subpleural space through the same needle while the needle was withdrawn from the parenchyma. Kopans wires (Cook Medical, Bloomington, IN) were also placed in some patients, employing a similar technique. The patients were then transferred to the operating room for resection.

1.3. Thoracoscopic resection

The patients were placed in the lateral decubitus position and single lung ventilation was established. Upon insertion of the thoracoscope, MBD and/or wires were visualized if present. When microcoils were utilized, they were identified under fluoroscopic guidance. After identifying the coil with fluoroscopy, a grasper was placed across the planned line of resection and the proposed resection specimen was rotated 90 degrees to obtain additional images in an orthogonal plane (Fig. 1). A standard stapled wedge resection was then performed, and the specimen was examined under fluoroscopy or specimen radiograph to confirm coil removal. All patients were then admitted to the hospital for postoperative care.

1.4. Efficacy of adjunctive techniques

The data was analyzed to determine the interventional radiologist's success rate in performing each adjunctive technique, as well as the surgeon's ability to localize and resect the lesions in the operating room. Finally, the operative reports were reviewed to determine if the surgeon found the preoperative localization technique helpful in finding the occult lesion. The technique was described as helpful if the surgeon mentioned that the dye, microcoil, and/or wire directed them to the lesion of interest and resulted in a successful resection.

2. Results

2.1. Patient demographics

Eighteen patients underwent preoperative CT-guided lung nodule localization for indeterminant pulmonary nodules between November 2012 and September 2019. Nine boys and nine girls aged 2 to 21 years

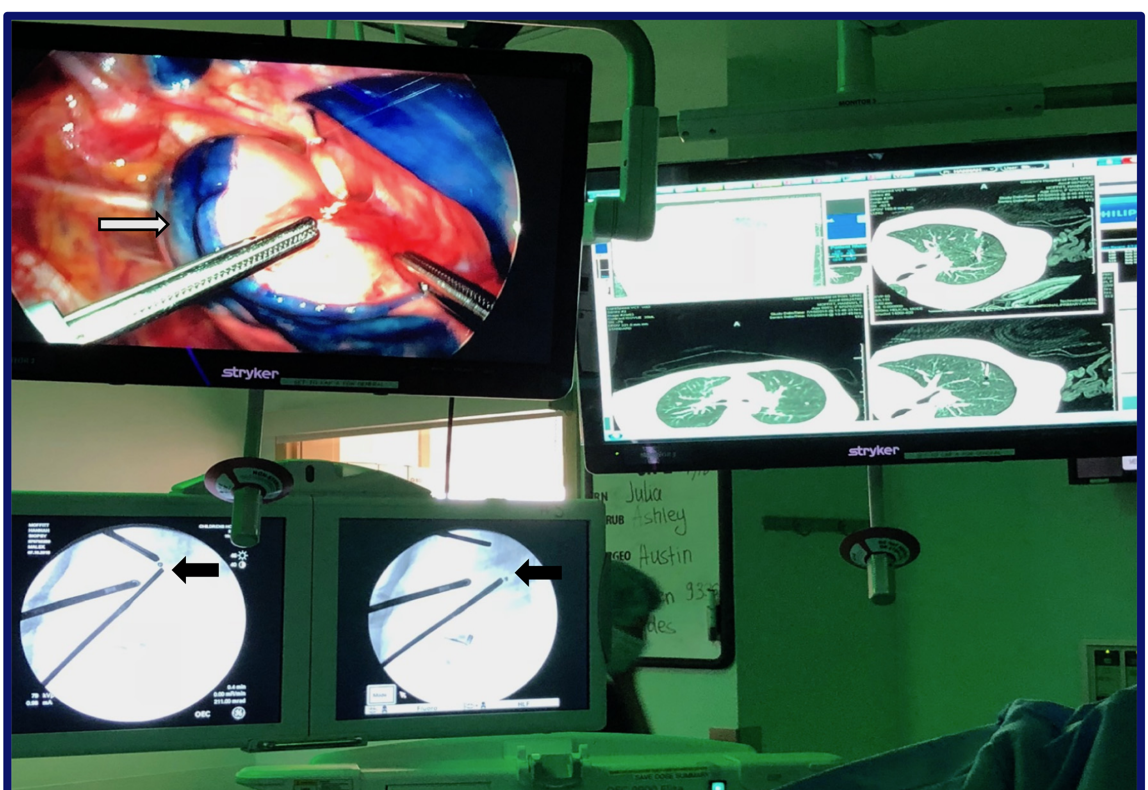

Fig. 1. Intraoperative localization utilizing methylene blue dye and microcoils The CT scan obtained during microcoil placement, thoracoscopy, and intraoperative fluoroscopy are all utilized during intraoperative lesion identification. Methylene blue dye (white arrow) directs the surgeon to the general area of the nodule. Two instruments are used to triangulate the microcoil, which is confirmed on fluoroscopy (black arrows).

Table 1
Patient and nodule characteristics.

Total number of patients = 18	
Age (years)	
Mean (range)	13 (2–21)
Gender, *n* (%)	
Male	9 (50)
Female	9 (50)
Total number of nodules = 24	
Nodule size (mm)	
Mean (range)	5.5 (3–15)
Nodule depth (mm)	
Mean (range)	10 (0–32)

Table 3
Pathology of resected pulmonary nodules.

Malignant, *n* (%)	10 (56)
Osteosarcoma	3 (17)
Hepatoblastoma	2 (11)
Wilms tumor	1 (6)
Malignant peripheral nerve sheath tumor	1 (6)
Synovial sarcoma	1 (6)
Ewing sarcoma	1 (6)
Alveolar soft part sarcoma	1 (6)
Benign, *n* (%)	8 (44)
Inflammation/atelectasis	4 (22)
Lymph node	3 (17)
Pneumonia	1 (6)

old (13 years old on average) were included. Of the 18 patients, 24 nodules were identified for preoperative localization (Table 1). The majority of patients with lung nodules had a malignancy as a primary diagnosis, except for one patient with chronic granulomatous disease.

2.2. Nodule characteristics and localization

Mean size and depth of the lesions were 5.5 mm (range 3–15 mm) and 10 mm (0–32 mm), respectively. Twenty-three of 24 nodules were localized preoperatively. Nineteen (79%) were localized by microcoil placement alone, three (13%) by a combination of microcoil and wire placement, and two (8%) with wire placement alone. MBD was also utilized for 14 nodules (58%), 12 of which were also localized with microcoils. Three of five wires became dislodged upon lung isolation, and one wire missed the targeted lesion. Microcoils were successfully placed by the interventional radiologist 95% of the time and assisted the surgeon in lesion localization 88% of the time (Table 2). Final pathology revealed metastatic disease in 56% of patients (Table 3).

2.3. Procedure times

The average interventional radiology (IR) procedural time was 73 min (range 20–173 min), operative time 95 min (46–168 min), and total time under anesthesia 319 min (193–503 min) (Table 4). The longest IR procedural time was in a patient who had two nodules and underwent microcoil, wire, and MBD placement. The longest operative time was in a patient who had two lesions in opposite hemithoraces, which required repositioning and re-draping the patient.

2.4. Complications and length of stay

During nodule localization, a pneumothorax was noted in four (22%) patients, with two patients requiring insertion of a chest tube in order to complete the localization. Three of these patients were having microcoils placed, one of which also had wire placement. One patient developed a pneumothorax during the placement of a wire alone. There were no reported complications during the operative procedures, and none of the procedures were converted to a thoracotomy. The median postoperative length of stay was 3 days (range 1–52 days).

Table 2
Comparison of localization techniques (18 patients, 24 nodules).

Technique, *n* (%)	
Microcoil and MBD	11 (46)
Microcoil alone	7 (29)
Microcoil and wire	2 (8)
Microcoil, wire, and MBD	2 (8)
Wire and MBD	2 (8)
Technical success (Yes), *n* (%)	
Microcoil	21 (95)
Wire	1 (20)
Microcoil localization helpful, *n* (%)	15 (88)

Table 4
Procedural times, complications, and length of stay.

Procedure time, *n* (range)	
Interventional radiology (min)	73 (20–173)
Operative (min)	95 (46–168)
Total anesthesia (min)	319 (193–503)
Complications, *n* (%)	
Pneumothorax	4 (22)
Length of stay, *n* (range)	
Median (days)	3 (1–52)

2.5. Long-term follow up

In patients who had a primary cancer diagnosis, seven patients (41%) developed recurrent pulmonary metastases. Two of these patients underwent additional thoracic surgery; one required two separate thoracoscopic wedge resections and the other underwent a thoracotomy. Five patients are now deceased; three from widely metastatic disease, one from pulmonary metastasis and superimposed pneumonia, and one from non-malignancy related causes. Eleven patients (65%) are alive with no evidence of disease, and one is alive with pulmonary metastases and still undergoing treatment.

3. Discussion

Reliable techniques for localizing and excising pulmonary nodules are critical to facilitate therapeutic clearance of metastatic disease, guide treatment, and determine prognosis for indeterminate nodules. A simple core needle biopsy is often not sufficient or feasible in children in many circumstances, especially in the case of osteosarcoma which requires a complete resection. Currently, occult pulmonary nodules are routinely resected via a thoracoscopic approach. In adults, Suzuki et al. reported a 46% conversion rate to thoracotomy due to inability to localize subpleural nodules during thoracoscopy, which prompted development of preoperative localization techniques [14]. CT-guided localization of pulmonary nodules has been shown to be useful in subpleural and sub-centimeter nodules that would otherwise be challenging to identify during thoracoscopic procedures [2,8]. Various localization techniques have been studied in the literature, including dyes, wires, radiotracers, and microcoils with varying utility.

Methylene blue dye can diffuse away from the site of injection and spread throughout the pleura, making localization with dye alone challenging [1,4,7,9]. Radiotracer placement appears to be an exciting new option, with a good reported success rate. A majority of patients that undergo localization with this technique, however, have required a thoracotomy for lesion localization and removal [10]. Additionally, in adult studies, the combined use of near-infrared (NIR) thoracoscopy and indocyanine green (ICG) fluorescence for image-guided localization has been developed with a 90–100% detection rate [6,11]. This technique has the benefit of eliminating intraoperative radiation exposure, ability to visualize fluorescence regardless of the background color of the lung, and ICG does not need to be resected (unlike radiotracers or other fiducial markers). However, NIR fluorescence is limited in its ability to detect nodules in lung that is inadequately desufflated and those deep to the pleural surface [6,11].

Meanwhile, wire localization, a procedure more thoroughly discussed in the literature, also has several limitations, including wire dislodgement and increased post-operative pain [1,7–9]. Several techniques to prevent wire dislodgement have been described, including avoidance of single-lung ventilation until the thoracoscope is placed and the wire can be stabilized, as well as maintaining the micropuncture catheter in the chest wall to allow the wire to slide through it with respirations. Despite these measures, dislodgement rates of up to 16% have been reported in the literature [2,8]. Additionally, Parida et al. reported an 11% conversion rate to thoracotomy, partially contributable to wire dislodgement [8]. Given the high rate of wire dislodgement in the literature, and even higher rate in our early experience, we transitioned to utilizing microcoils with or without MBD to localize occult lung lesions.

This is the first multi-institutional and largest study on the use of preoperative localization using microcoils in children. In adult studies, the reported benefits of microcoils include less frequent dislodgement rates, lower incidence of pneumothorax and intrapulmonary hemorrhage, decreased post-operative pain, and the ability to direct surgeons (via intraoperative fluoroscopy), as well as pathologists, to the precise location of the nodule [7,9,12]. In this study, microcoil placement was successful 95% of the time, and assisted in lesion localization in 88% of cases. This method facilitated lesion localization in nodules as small as 3 mm and up to 32 mm deep to the pleural surface. Additionally, none of our patients required conversion to a thoracotomy, and median post-operative stay was only 3 days.

Microcoils were determined to be unhelpful in localizing pulmonary nodules in two cases. One patient had a nodule abutting the inferior pulmonary vein. Due to concern for injuring the vein, the microcoil was place further from the lesion than usual (about 1 cm). However, the nodule was visible from the surface, so it was still successfully resected. The second patient had a lesion at the confluence of the fissures. While the microcoil was deployed into the right lower lobe, the lesion was in the middle lobe. Fortunately, MBD was utilized and directed the surgeon to the lesion.

A subset of our patients underwent both microcoil and MBD placement. This combination technique theoretically increases the chance of lesion localization if one method were to fail, for example, microcoil dislodgement or diffusion of MBD. Additionally, the use of MBD could decrease fluoroscopy and operative time, as the dye should direct the surgeon to the region of lung where the microcoil and lesion can be found. In our study, nodules localized with MBD and microcoil were successfully resected in all 12 patients.

One limitation of these techniques is the length of time the patients are under anesthesia (mean 319 min) and the amount of coordination required between surgeons, anesthesiologists, and interventional radiologists in order to safely transport patients and limit general anesthesia exposure. Additional reasons for prolonged procedural time includes resection of more than one nodule in different lobes of the lung, coordination between interventional radiology and the operating room, and transportation time. Since there is limited data on microcoil localization for thoracoscopic lung biopsy in children, it is difficult to compare our time under anesthesia with the literature. Comparing these data to adult literature on microcoil localization, as well as adult and pediatric literature on other lung lesion localization techniques, the times under anesthesia in this study are longer than expected [1,3,5,9,12,13]. There was, however, a significant difference in IR and total anesthesia time ($p = 0.006$ and 0.02, respectively) between the two institutions that contributed data to this study. This highlights the likelihood that a more efficient process can lead to much shorter times under anesthesia, which in combination with our localization success rates, may make this technique even more valuable over time. Additionally, these procedures could be performed in a hybrid operating room with an intraoperative CT scan, which may significantly decrease total time under anesthesia and improve safety.

Other limitations of this study include those inherent to a retrospective review, lack of technique standardization between institutions, and lack of randomization into different localization techniques, which limits the ability to compare outcomes between wire and coil localization. In addition, we relied on anesthesiology documentation for procedural and total anesthesiology times, and the documentation was not always clear on the exact start and end time for the interventional radiology procedure. This may have falsely lengthened the total time under anesthesia for our patients. We also recognize that the wire dislodgement rate (60%) in this study was significantly higher than what has been reported in the pediatric literature. Although this may have been the motivation to use an alternative method for localization, the results we have observed with microcoil use remain excellent, with no observed dislodgement and a high success rate of placement and lesion localization.

In conclusion, preoperative CT-guided localization of pulmonary nodules with microcoils is a safe technique to facilitate fluoroscopic-guided, thoracoscopic wedge resection. In our experience, placement of microcoils was reliable, with low risk for dislodgement, and led to a consistent pathologic diagnosis of subpleural and sub-centimeter pulmonary nodules.

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