Nonintubated versus intubated "one-stage" preoperative localization and thoracoscopic lung resection

Po-Kuei Hsu, MD, PhD,[a,b] Yi-Ying Lee, MD,[a] Lin-Chi Chuang, BS,[c] Chien-Kun Ting, MD, PhD,[b,d] and Mei-Yung Tsou, MD[b,d]

ABSTRACT

Objective: Nonintubated anesthesia, electromagnetic navigation (EMN)-guided preoperative localization, and uniportal video-assisted thoracic surgery (VATS) are recent innovations in minimally invasive thoracic surgery. This study aimed to explore the feasibility of applying nonintubated anesthesia in a "one-stage" localization and resection workflow.

Methods: Patients who underwent EMN-guided preoperative percutaneous localization with indocyanine green (ICG) and uniportal VATS were included. Perioperative data were compared between patients receiving nonintubated anesthesia and those receiving general anesthesia with endotracheal intubation.

Results: Forty-six patients with a total of 50 nodules were included in the study. Overall, finger palpation could be avoided in 94% of the nodules, whereas fluorescent green signals with a clear border on the pleural surface were noted in 91.3% (21 of 23) of nodules in the nonintubated group and 88.9% (24 of 27) of nodules in the intubated group. Intraoperatively, the nonintubated group had a lower median pH (7.33 [interquartile range (IQR), 7.28-7.40] vs 7.41 [IQR, 7.38-7.44]; $P = .003$), higher median arterial CO_2 (45.5 [IQR, 41.1-58.7] mm Hg vs 38.4 [IQR, 35.3-40.6] mm Hg; $P < .001$), and lower arterial oxygen (322 [IQR, 211-433] mm Hg vs 426 [IQR, 355-471] mm Hg; $P = .005$) levels compared with the intubated group. The nonintubated group also had a shorter median registration time (2.0 [IQR, 1.0-3.0] minutes vs 3.0 [IQR, 2.0-8.0] minutes; $P = .008$) and total time in the operating room (150 [IQR, 130-175] minutes vs 170 [IQR, 135-203] minutes; $P = .035$), whereas no between-group differences were seen in localization and operative time. The duration of chest drainage, postoperative complications, pathologic diagnosis, and margins were similar in the 2 groups.

Conclusions: Nonintubated "one-stage" EMN-guided percutaneous ICG localization and uniportal VATS can be an option for selected patients undergoing treatment for small peripheral nodules. (JTCVS Techniques 2021;10:517-25)

Nonintubated electromagnetic navigation-guided localization and uniportal video-assisted thoracic surgery.

CENTRAL MESSAGE

Nonintubated "one-stage" electromagnetic navigation–guided percutaneous indocyanine green localization and uniportal video-assisted thoracic surgery is a feasible workflow for small lung nodules and can be an option for selected patients.

PERSPECTIVE

Key innovations in minimally invasive thoracic surgery include nonintubated anesthesia, electromagnetic navigation-guided localization, and uniportal video-assisted thoracic surgery. Although patients in the nonintubated group were prone to CO_2 retention and respiratory acidosis, these intraoperative differences had no influence on postoperative outcomes.

See Commentary on page 526.

Video clip is available online.

The landmark National Lung Screening Trial showed that low-dose computed tomography (CT) screening for lung cancer significantly reduced the risk of cancer-associated death in high-risk patients by allowing for disease discovery

From the [a]Division of Thoracic Surgery, Department of Surgery, [c]Department of Nursing, and [d]Department of Anesthesiology, Taipei Veterans General Hospital, Taipei, Taiwan and [b]School of Medicine, National Yang Ming Chiao Tung University, Taipei, Taiwan.

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Address for reprints: Po-Kuei Hsu, MD, PhD, Division of Thoracic Surgery, Department of Surgery, Taipei Veterans General Hospital, No. 201, Sec. 2, Shih-Pai Rd, Taipei, Taiwan (E-mail: hsupokuei@yahoo.com.tw).

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Abbreviations and Acronyms

BIS = bispectral index
CT = computed tomography
EMN = electromagnetic navigation
ICG = indocyanine green
IQR = interquartile range
OR = operating room
VAL-MAP = virtual-assisted lung mapping
VATS = video-assisted thoracic surgery

at an earlier stage. There is a positive outlook for adopting low-dose CT in cancer screening and patient follow-up, which in turn leads to increased detection of small pulmonary nodules.[1] The management of these indeterminate nodules includes follow-up, biopsy, and surgical excision.[2] The surgical removal of nodules that show persistence, enlargement, and/or increased attenuation is both diagnostic and therapeutic; however, this can be challenging during minimally invasive thoracoscopic surgery, such as uniportal video-assisted thoracic surgery (VATS). This is more evident when these small-sized lesions generally are not visible under thoracoscopy and are hardly palpable with thoracoscopic instruments.[3,4]

To accurately locate and precisely resect the nodules, various techniques for preoperative nodule localization, such as CT-guided or bronchoscopy-guided dye injection or fiducial marker placement, have been developed, with promising results.[5-10] To optimize the workflow, "one-stage" intraoperative image-guided VATS, which includes the target nodule localization procedure in the operating room (OR) followed by immediate resection, has been proposed.[5,6] This "one-stage" workflow has been demonstrated to decrease the risks of localization marker dislodgement, as well as the impact of potential localization-related complications (eg, pneumothorax, hemorrhage), compared with the conventional "two-stage" workflow that involves a localization procedure performed by an interventional radiologist in the radiology suite, followed by patient transfer to the OR.[6] Our previous feasibility studies have also demonstrated that electromagnetic navigation (EMN)-guided percutaneous localization can identify small pulmonary nodules during thoracoscopic procedures and is a viable option for a "one-stage" workflow.[11-13]

Another recent advancement in minimally invasive thoracic surgery to enhance postoperative recovery is the nonintubated anesthetic technique, which attempts to avoid tracheal intubation and general anesthesia–associated complications.[14-16] Although nonintubated VATS has been applied in many thoracic procedures, including pneumothorax, empyema, and lung resection for malignancies, the application of nonintubated anesthesia in the "one-stage" localization and resection workflow has not been studied previously. To address the impact of nonintubated anesthesia on a EMN-guided "one-stage" workflow, we compared the perioperative outcomes between patients who underwent preoperative EMN-guided percutaneous localization followed by VATS resection under nonintubated anesthesia and those who did so under general anesthesia with endotracheal intubation.

METHODS

Patients who underwent "one-stage" EMN-guided localization and VATS resection from June 2019 to November 2020 were reviewed. To eliminate bias owing to different localization and resection procedures, only patients who underwent percutaneous localization with indocyanine green (ICG) as a localization marker and uniportal VATS for lung resection were included. Patients who underwent transbronchial localization and in whom localization markers other than ICG (eg, microcoils), intended multiport VATS, or mini thoracotomy were used were excluded. Clinical, radiographic, anesthetic, surgical, and pathologic parameters were obtained from the patient charts. The Institutional Review Board of the Taipei Veterans General Hospital approved this study and waived the requirement for informed consent (2019-01-023AC). For the central picture, Figure 2, and Video 1, patients provided informed written consent for publication.

Nonintubated Anesthesia

Standard monitors including electrocardiography, radial artery pressure monitoring, pulse oximetry, end-tidal CO_2 monitoring, and frontal bispectral index (BIS) monitoring (BIS Quatro; Aspect Medical System, Norwood, Mass) were applied to all patients. Patients were preoxygenated via a high-flow nasal cannula (Thrive; Fisher & Paykel Healthcare, Auckland, New Zealand) before anesthesia administration at an initial flow rate of 30 L/minute. They were then premedicated with 2 mg of intravenous midazolam and 200 μg of intravenous alfentanil. Somatosensory and motor block was achieved by either a thoracic epidural catheter inserted at the T7-T8 level with xylocaine or local infiltration of lidocaine at the intercostal space on entering the pleural cavity.

After preoxygenation and premedication, patients were sedated with intravenous propofol using target-controlled infusion to maintain a BIS value between 40 and 60 and a respiratory rate between 15 and 20 breaths/minute. Incremental intravenous injections of fentanyl and midazolam were administered as needed.

During the localization and VATS procedure, patients breathed spontaneously and were oxygenated via a high-flow nasal cannula, with an oxygen flow rate between 10 and 70 L/minute (fraction of inspired $O_2 = 1.0$) to avoid excessive hypercapnia and hypoxemia. Arterial blood gases were measured after completion of lung resection, before wound closure, for comparison with intraoperative arterial blood gas values.

The decision for nonintubated or intubated anesthesia was made through a shared decision making approach after discussing the benefits and risks of each method with the patient.

EMN-Guided Percutaneous Localization

Percutaneous localization was performed using the SPiN Thoracic Navigation System (Veran Medical Technologies, St Louis, Mo). A same-day inspiration/expiration chest CT with a navigational tracking pad equipped with electromagnetic sensors and providing a reference point on the chest was used to generate a dynamic 3-dimensional map of the lungs. The patient's position during the CT examination could be either supine or lateral decubitus but must be the same as that during the localization procedure.

During the planning step, the DICOM-formatted CT images were transferred to the planning software to provide the percutaneous navigational pathway to the target lesion. In the OR, the navigation procedure started with endobronchial registration in a process of matching CT images to spatial information collected within the magnetic field known as

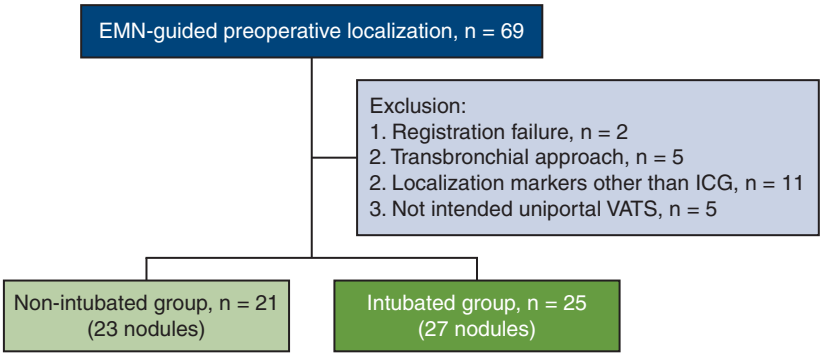


FIGURE 1. Flow chart of patient selection for this study. *EMN*, Electromagnetic navigation; *ICG*, indocyanine green; *VATS*, video-assisted thoracic surgery.

"image-patient alignment." During the localization procedure, the EMN allowed real-time tracking of the 19-gauge Chiba needle (19 gauge × 105 mm biopsy needle) by detecting the position of the electromagnetic tip-tracked needle stylet. The needle was placed on the planned chest wall entry point selected in the planning step and navigated to the target nodule along the trajectory path. Once the target nodule was reached, ICG injection (0.3 mL, 0.125 mg/mL; Diagnogreen; Daiichi-Sankyo Pharmaceutical, Tokyo, Japan) completed the localization procedure.

The entire bronchoscopy examination during the registration step was recorded as the registration time. The interval between skin preparation for the sterile localization procedure and completion of the ICG injection was defined as the localization time.

Uniportal VATS

A single 3- to 4-cm skin incision was made over the fifth intercostal space along the anterior axillary line, and a wound retractor (LapShield; Lagis, Taichung City, Taiwan) was applied without rib spreading. Given the low-level positive pressure generated by the high-flow nasal cannula, lung collapse could be obtained by iatrogenic pneumothorax and gentle compression with endoscopic sponges. The target position was identified through fluorescence signal detection with a near-infrared fluorescence imaging system (Olympus Visera Elite II; Olympus, Tokyo, Japan or 1688 AIM 4K platform; Stryker, San Jose, Calif). Ideally, the ICG will create a fluorescent green signal with a clear border on the pleural surface, which is defined as successful localization. Suboptimal localization is defined as a diffused fluorescent signal or the inability to identify any fluorescence, but with the target position still identifiable by the presence of a needle hole. When the target position could not be identified during VATS inspection and finger palpation was needed, the localization result was classified as a failure.

The operation time was defined as the interval from the creation of the skin incision to the completion of skin closure. The total time was defined as the duration of stay in the OR, including preparation, anesthesia induction, localization, and surgery.

Statistics

Continuous variables are expressed as median (interquartile range [IQR]) and were evaluated using Student's t test. Categorical variables are presented as number and frequency (%) and were compared using the χ^2 test. Statistical analyses were performed using SPSS for Windows version 25.0 (IBM, Armonk, NY). A P value <.05 was considered statistically significant.

RESULTS

During the study period, EMN-guided localization was planned for 69 patients. After exclusion (due to registration failure in 2 patients, transbronchial localization in 5, use of localization markers other than ICG in 11, and intended multiport VATS or mini-thoracotomy in 5), a total of 46 patients, including 21 patients in the nonintubated group and 25 patients in the intubated group, were included in the analysis. A flowchart of patient selection is shown in Figure 1.

Table 1 presents the patient characteristics of each group. There were no significant between-group differences in terms of age, sex, body mass index, pulmonary function, forced expiratory volume in 1 second, diffusing lung capacity for carbon monoxide, or American Society of Anesthesiologists physical status classification.

Localization and perioperative details are summarized in Table 2. Eighteen patients (39.1%) underwent EMN in the lateral decubitus position (Figure 2). The median registration and localization times were 3.0 (IQR, 1.0-4.8) minutes and 10.0 (IQR, 7.3-15.0) minutes, respectively. The nonintubated group had a shorter median registration time (2.0 [IQR, 1.0-3.0] minutes vs 3.0 [IQR, 2.0-8.0] minutes; $P = .008$). Intraoperatively, the nonintubated group had lower pH (7.33 [IQR, 7.28-7.40] vs 7.41 [IQR, 7.38-7.44]; $P = .003$), higher arterial CO_2 (45.5 [IQR, 41.1-58.7] mm Hg vs 38.4 [IQR, 35.3-40.6] mm Hg; $P < .001$), and lower arterial oxygen (322 [IQR, 211-433] mm Hg vs 426 [IQR, 355-471] mm Hg; $P = .005$) levels compared with the intubated group. Although patients in the nonintubated group were prone to CO_2 retention and respiratory acidosis, these intraoperative differences had no influence on postoperative outcomes. The duration of chest drainage and postoperative complications were comparable in the 2 groups.

The operation time was also comparable in the 2 groups. However, the median total time in the OR was shorter in the nonintubated group (150 [IQR, 130-175] minutes vs 170 [IQR, 135-203] minutes; $P = .035$). To allow for a fair comparison, we calculated time parameters in patients receiving EMN-guided localization for 1 nodule and 1 wedge resection (19 and 21 patients in the nonintubated and intubated groups, respectively). As shown in Figure 3, the nonintubated and intubated groups were comparable in terms of localization time, operation time, and total time, except for minor differences in registration time.

TABLE 1. Patient characteristics

Characteristic	Total cohort	Nonintubated group	Intubated group	*P* value
Number	46	21	25	
Age, y, median (IQR)	62.0 (51.5-66.3)	60.0 (49.5-68.5)	63.0 (54.0-64.5)	.589
Sex, n (%)				.938
Male	20 (43.5)	9 (42.9)	11 (44.0)	
Female	26 (56.6)	12 (57.1)	14 (56.0)	
BMI, median (IQR)	23.6 (20.9-25.0)	24.0 (21.3-25.4)	22.5 (20.9-25.0)	.646
FEV1, L, median (IQR)	2.42 (2.08-2.75)	2.53 (1.75-2.75)	2.32 (2.10-2.76)	.625
FEV1, %, median (IQR)	98.0 (88.0-111.0)	101.0 (85.5-107.5)	97.5 (88.5-113.3)	.200
FEV1/FVC, %, median (IQR)	82.0 (72.5-85.5)	83.0 (72.5-85.0)	81.5 (72.5-85.8)	.539
DLCO, %, median (IQR)	74.0 (63.0-81.0)	70.0 (62.0-75.8)	78.0 (64.0-86.0)	.057
ASA classification, n (%)				.573
I	7 (15.2)	4 (19.0)	3 (12.0)	
II	30 (65.2)	12 (57.1)	18 (72.0)	
III	9 (19.6)	5 (23.8)	4 (16.0)	
Number of nodules, n (%)				.855
1	42 (91.3)	19	23	
2	4 (8.7)	2	2	

IQR, Interquartile range; *BMI*, body mass index; *FEV1*, forced expiratory volume in 1 second; *FVC*, forced vital capacity; *DLCO*, diffusing lung capacity for CO_2; *ASA*, American Society of Anesthesiologists.

A total of 50 nodules, 23 in the nonintubated group and 27 in the intubated group, were resected (Table 3). There were no differences in nodular location, CT characteristics, or size between the 2 groups; however, the median pleural-to-target distance during the percutaneous approach was shorter in the nonintubated group (3.9 [IQR, 0.1-11.0] mm vs 9.6 [IQR, 5.0-25.0] mm; $P = .016$) (Figure 4). As for the localization results, fluorescent green signals with a clear border on the pleural surface were noted in 91.3% (21 of 23) of the nodules in the nonintubated group and in

TABLE 2. Localization and perioperative results

Variables	Total cohort	Nonintubated group	Intubated group	*P* value
Number	46	21	25	
Localization variables				
Patient position during localization, n (%)				.460
Supine	28 (60.8)	14 (66.7)	14 (56.0)	
Lateral	18 (39.1)	7 (33.3)	11 (44.0)	
Registration time, min, median (IQR)	3.0 (1.0-4.8)	2.0 (1.0-3.0)	3.0 (2.0-8.0)	.008
Localization time, min, median (IQR)	10.0 (7.3-15.0)	9.0 (7.0-15.0)	10.0 (8.5-15.5)	.698
Intraoperative variables				
Intraoperative arterial blood gases, median (IQR)				
pH	7.40 (7.34-7.42)	7.33 (7.28-7.40)	7.41 (7.38-7.44)	.003
$PaCO_2$, mm Hg	40.5 (37.4-46.1)	45.5 (41.1-58.7)	38.4 (35.3-40.6)	<.001
PaO_2, mm Hg	396 (317-463)	322 (211-433)	426 (355-471)	.005
Extent of resection, n (%)				.493
Wedge resection	44 (95.7)	21 (100)	23 (92.0)	
Segmentectomy	2 (4.3)	0 (0)	2 (8.0)	
Operative time, min, median (IQR)	55 (40-75)	55 (38-75)	55 (40-79)	.248
Total time, min, median (IQR)	163 (135-190)	150 (130-175)	170 (135-203)	.035
Postoperative variables				
Duration of chest drainage, d, median (IQR)	1 (0-1)	0 (0-1)	1 (0-1)	.245
Surgical complications, n (%)				
Persistent air leak for >3 d	3 (6.5)	1 (4.8)	2 (8.0)	1.000
Chylothorax	1 (2.2)	0 (0)	1 (4.0)	1.000

IQR, Interquartile range; *$PaCO_2$*, partial pressure of CO_2; *PaO_2*, partial pressure of O_2.

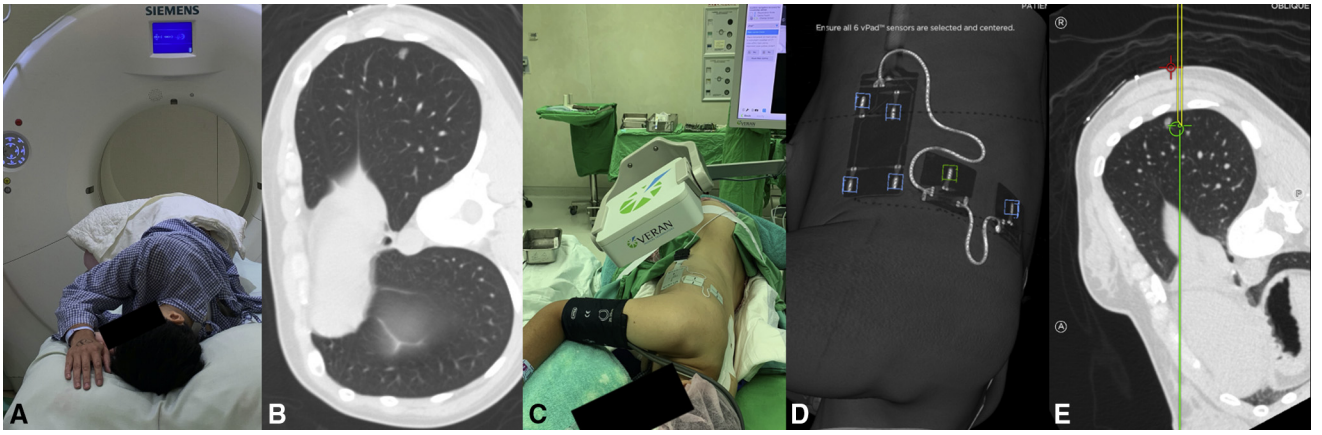


FIGURE 2. For a target lesion that we planned to approach from the dorsal side, we obtained a lateral decubitus computed tomography (CT) scan (A and B), With the patient in the same position during the localization procedure (C), the software indicated the optimal skin entry point, and navigation was based on lateral decubitus CT images (D and E).

88.9% (24 of 27) of the nodules in the intubated group. In each group, there was 1 nodule with suboptimal localization results. Overall, finger palpation could be avoided in 94% of nodules receiving EMN-guided percutaneous ICG localization before uniportal VATS (95.7% [23 of 24] in the nonintubated group and 92.6% [25 of 27] in the intubated group). Based on pathological examination, the most common diagnosis was adenocarcinoma in situ (34%), followed by minimally invasive adenocarcinoma (26%), metastatic tumor (16%), and invasive adenocarcinoma (14%), whereas only 5 nodules (10%) were benign. The distribution of pathologic results and margin distance were similar in the 2 groups.

DISCUSSION

For highly suspicious small pulmonary nodules seen on CT scan, surgical excision can be both diagnostic and therapeutic. Owing to the small size, a conventional bronchoscopic or CT-guided biopsy may be nondiagnostic or superfluous.[17] Furthermore, surgical resection is the most appropriate treatment for small early-stage lung cancer in many cases. A recent nationwide study suggested that sublobar resection may be associated with longer survival compared with radiation therapy or ablation in patients with early-stage lung cancer.[18] From the surgeon's perspective, it is mandatory to increase the efficacy and decrease the potential impact of surgical interventions on the patient's physical status. Our approach combines key innovations in minimally invasive thoracic surgery, including nonintubated anesthesia, optimized "one-stage" workflow, and uniportal VATS, to minimize overall surgical trauma and enhance postoperative recovery.

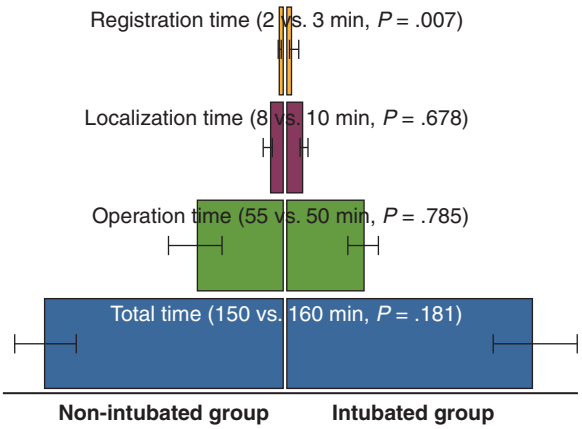


FIGURE 3. Comparison of time parameters between the nonintubated (n = 19) and intubated (n = 21) groups in patients undergoing electromagnetic navigation–guided localization for 1 nodule and only 1 wedge resection. Data are expressed as median and evaluated using Student's *t* test.

Uniportal VATS has been reported to be a safe and feasible approach for lung resection, with potential additional benefits of reduced surgical trauma and faster recovery.[19,20] In addition to uniportal VATS, nonintubated anesthesia is another method to reduce surgical stress and make minimally invasive thoracic surgery even less invasive. Since Pompeo and colleagues first proposed thoracoscopic resection of pulmonary nodules by awake VATS without endotracheal intubation in 2004, nonintubated VATS has been increasingly used in a wide range of thoracic procedures.[14] The major benefit of nonintubated anesthesia is the avoidance of intubation-related complications (eg, sore throat, airway injury) and side effects caused by general anesthesia with single-lung ventilation (eg, ventilation-related lung injury and postoperative vomiting and nausea).[15] In a recent meta-analysis, nonintubated VATS was associated with less anesthesia time, chest pain, and chest tube indwelling time. Moreover, the nonintubated VATS group also had a shorter hospital stay and lower perioperative morbidity than the intubated VATS group.[16]

TABLE 3. Nodule characteristics

Variables	Total cohort	Nonintubated group	Intubated group	*P* value
Number	50	23	27	
Location				.977
RUL	11 (22.0)	5 (21.7)	6 (22.2)	
RML	4 (8.0)	2 (8.7)	2 (7.4)	
RLL	10 (20.0)	5 (21.7)	5 (18.5)	
LUL	13 (26.0)	5 (21.7)	8 (29.6)	
LLL	12 (24.0)	6 (26.1)	6 (22.2)	
CT characteristics				.615
Pure GGO	12 (24.0)	5 (21.7)	7 (25.9)	
Part solid	24 (48.0)	10 (43.5)	14 (51.9)	
Solid	14 (28.0)	8 (34.8)	6 (22.2)	
Size, mm, median (IQR)	9.0 (7.4-12.2)	10.8 (7.9-16.1)	8.6 (6.6-10.4)	.109
Pleura-to-target distance, mm, median (IQR)	8.2 (2.7-13.2)	3.9 (0.1-11.0)	9.6 (5.0-25.0)	.016
Localization results				.898
Success	45 (90.0)	21 (91.3)	24 (88.9)	
Suboptimal	2 (4.0)	1 (4.3)	1 (3.7)	
Failure	3 (6.0)	1 (4.3)	2 (7.4)	
Diagnosis				.087
AIS	17 (34.0)	5 (21.7)	12 (44.4)	
MIA	13 (26.0)	4 (17.4)	9 (33.3)	
Invasive adenocarcinoma	7 (14.0)	5 (21.7)	2 (7.4)	
Metastatic lung tumors	8 (16.0)	5 (21.7)	3 (11.1)	
Benign lesions	5 (10.0)	4 (17.4)	1 (3.7)	
Margin, cm, median (IQR)	1.3 (1.0-1.7)	1.2 (1.0-1.8)	1.3 (1.0-1.7)	.585

RUL, Right upper lobe; *RML*, right middle lobe; *RLL*, right lower lobe; *LUL*, left upper lobe; *LLL*, left lower lobe; *CT*, computed tomography; *GGO*, ground glass opacity; *IQR*, interquartile range; *AIS*, adenocarcinoma in situ; *MIA*, minimally invasive adenocarcinoma.

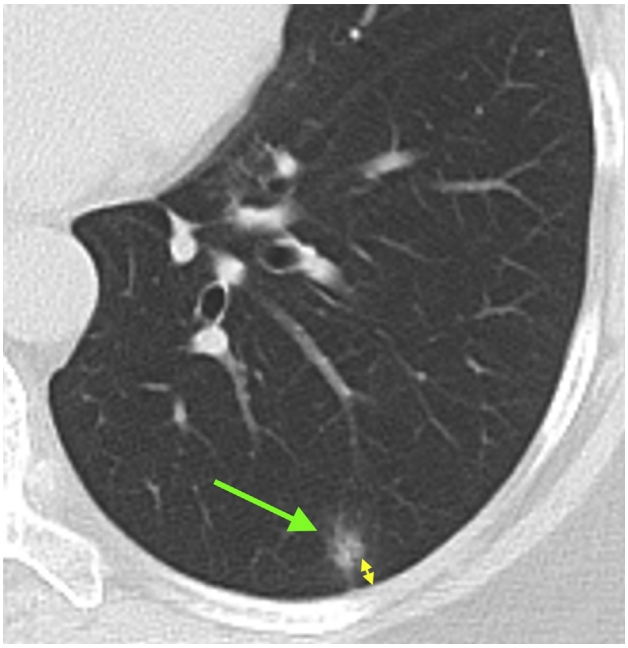


FIGURE 4. The pleural-to-target distance was based on measurements on lung window computed tomography. In this case, the distance (*yellow arrows*) between the target (*green arrow*) and pleura was 3.6 mm, and the pathological diagnosis was minimally invasive adenocarcinoma.

In minimally invasive thoracic surgery, the use of effective localization techniques before thoracoscopy makes the surgical procedure more efficient, because these small lung nodules are sometimes not visible and nonpalpable thoracoscopically.[3-10] Various preoperative localization techniques that use different guidance systems and localization materials have been developed. These so-called image-guided VATS techniques include 3 mainstream platforms: CT scan, bronchoscopy, and an EMN system.[10] For instance, Fang and colleagues[7] reported that a hybrid OR equipped with a C-arm cone-beam CT scanner and integrated software offers great potential as a safe and effective tool to localize small pulmonary nodules intraoperatively. The major advantages of this "intraoperative localization with hybrid OR" technique include a shorter time at risk (defined as the interval from completion of localization to skin incision) and a reduced need for patient mobilization. However, the surgical table in most hybrid ORs is not specific for thoracic procedures and lacks a hinge joint for bending. Moreover, surgical table collisions with the C-arm CT scanner may occur.[7]

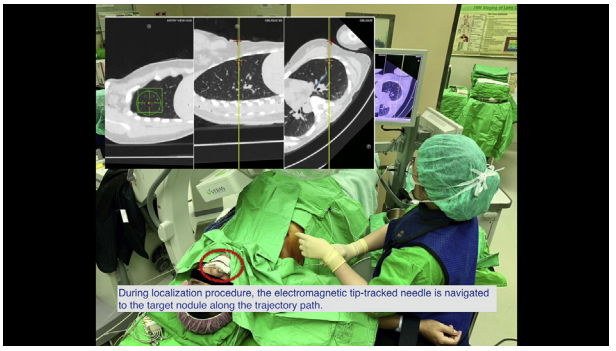
An example of a bronchoscopic method for preoperative localization is the virtual-assisted lung mapping (VAL-MAP) technique developed by Japanese thoracic surgeons.[8]

VAL-MAP has been demonstrated to be safe and effective for obtaining good surgical margins in pulmonary sublobar resection; however, it is a "mapping" rather than a "marking" technique. In VAL-MAP, post-mapping CT is also necessary to confirm the actual locations of the dye marks.

Another platform for preoperative localization is the EMN system. Although a description of EMN bronchoscopy-guided thoracoscopic resection of small lung nodules was published a decade ago,[21] the recently introduced novel thoracic navigation system allows for both transbronchial (endobronchial) and transthoracic (percutaneous) approaches, making this technique applicable for the entire lung field. Our initial report on the technique demonstrated the feasibility and accuracy of EMN-guided percutaneous preoperative localization of small pulmonary nodules.[11] Subsequent case reports published by our group[12] and Long and colleagues[22] also showed that EMN-guided transthoracic nodule localization is a safe and effective technique that minimizes the conversion to thoracotomy. Most importantly, it provides comparable results to conventional CT-guided localization methods, with a significantly reduced total operative time (localization and resection).[13]

Both the hybrid OR with a C-arm cone-beam CT and EMN-guided percutaneous localization protocols emphasize a streamlined workflow by performing localization and resection in the same room.[5,6] However, there are differences between the 2 platforms. One of the major differences is that most hybrid OR with a C-arm cone-beam CT protocols acquire images and perform localization procedures during the end-inspiratory hold phase, and thus require general anesthesia with endotracheal intubation, which conflicts with nonintubated VATS. In contrast, the navigation system used in the present study is characterized by respiratory gating technology, which tracks nodule movement during inspiration and expiration. This allows for the localization procedure without the need for endotracheal intubation, relying solely on spontaneous breathing. Moreover, the percutaneous approach is possible with this navigation system, which obviates the irritating stimulus to the trachea and bronchi. This also makes the localization procedure under nonintubated anesthesia possible. Our present results confirm the feasibility of a nonintubated "one-stage" workflow by demonstrating that EMN-guided percutaneous localization under nonintubated anesthesia does not jeopardize the localization results and perioperative outcomes compared with those achieved under intubated anesthesia.

Our protocol does have a potential disadvantage, however. Although the current "one-stage" protocol reduces the time at risk and decreases the impact of potential complications such as pneumothorax and hemorrhage, the percutaneous approach is associated with a risk of systemic air embolism. Anesthesia before localization limits the detection of any clinical manifestations that are suspicious for air embolism. Thus, measures to prevent air embolism should be instituted whenever possible.[23]



VIDEO 1. The navigation procedure started with endobronchial registration. During this procedure, the patient breathed spontaneously and was oxygenated via a high-flow nasal cannula. After registration, we proceeded with the localization procedure. During localization, the electromagnetic tip-tracked needle was navigated to the target nodule along the trajectory path. When the needle reached the target nodule, we injected contrast medium. A "cloudy sphere" diffusion pattern confirmed that the needle was in the lung parenchyma. We then started the indocyanine green injection. Patient oxygenation was maintained with a high-flow nasal cannula during nonintubated uniportal video-assisted thoracic surgery (VATS). Once the target position was identified by the fluorescence signal on the pleural surface, endostaplers were applied for wedge resection. In conclusion, we integrated nonintubated uniportal VATS with electromagnetic navigation-guided preoperative localization techniques. The "one-stage" workflow comprising nodule localization in the OR followed by immediate resection under spontaneous breathing is feasible. Video available at: https://www.jtcvs.org/article/S2666-2507(21)00663-5/fulltext.

This study has several limitations. First, owing to the study's retrospective design, the patients and nodules represent a highly selected group. Although the decision for nonintubated anesthesia was determined through a shared decision making approach, bias could not be completely avoided; for example, there was a trend toward larger nodular size and a shorter pleural-to-target distance in the nonintubated group. Second, this study describes our initial experience, and the sample size was small. The incidence of potential complications cannot be evaluated comprehensively. Studies with a larger number of patients are needed to determine the risk and potential side effects. Third, we only compared nonintubated and intubated patients on anesthesia in this study. Comparisons of uniport versus multiport VATS and of EMN-guided localization versus finger palpation were not performed. The additional value of each component in the workflow was not assessed.

In conclusion, owing to the novel EMN system, a "one-stage" workflow comprising nodule localization in the OR followed by immediate resection under spontaneous breathing is feasible (Video 1). The protocol described here, which combines minimally invasive anesthesia, precise

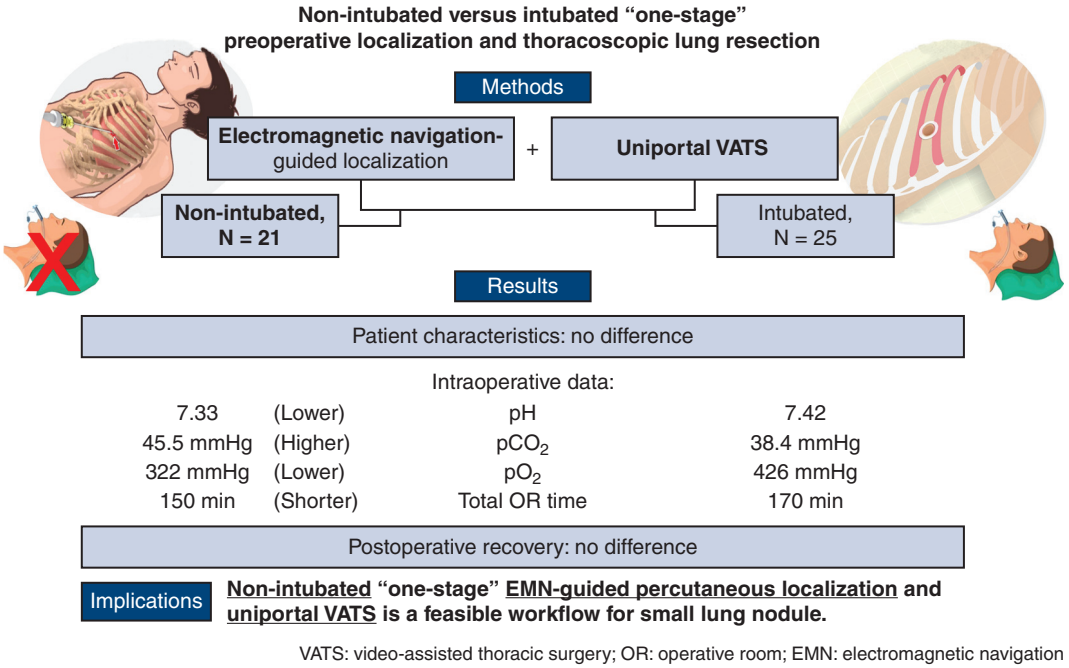


FIGURE 5. A summary of our study. Key innovations in minimally invasive thoracic surgery, including electromagnetic navigation (EMN)-guided localization and uniportal video-assisted thoracic surgery (VATS) were combined. Patients were divided into the nonintubated and intubated anesthesia groups. Although patients in the nonintubated group were prone to CO_2 retention and respiratory acidosis, these intraoperative differences had no influence on the postoperative outcome. Therefore, nonintubated "one-stage" preoperative localization and uniportal VATS is a feasible workflow.

preoperative percutaneous localization with ICG, and minimally invasive surgical technique, can further reduce surgical trauma. This protocol also can be recommended in selected patients (eg, nodular size ~10 mm, pleural-to-target distance <15 mm, and body mass index <25), with the aim of enhancing postoperative recovery after thoracoscopic resection (Figure 5).

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: nonintubated anesthesia, electromagnetic navigation, uniportal video-assisted thoracic surgery