Original Article

# Intraprocedural computed tomography-guided navigation with ventilatory strategy for atelectasis (ICNVA): a modified electromagnetic navigation bronchoscopy

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**Background:** Computed tomography (CT)-body divergence limits the accuracy of electromagnetic navigation bronchoscopy (ENB) in peripheral lung lesions diagnosis. We developed intraprocedural CT-guided navigation with ventilatory strategy for atelectasis (ICNVA) ENB for patients with peripheral lung lesions.

**Methods:** Retrospective observational study in which ten consecutive patients with pulmonary lesions (without bronchial direct connection) underwent ICNVA-ENB was conducted. During ICNVA-ENB, intraoperative CT data were used for ENB path planning, and a new ventilation strategy were employed to help maintain the pulmonary region in a static and inflation state which reduce CT to body divergence. We collected three sets of CT data: preENB CT, post-anesthesia intubation CT, and postENB CT. To evaluate the accuracy of ICNVA-ENB, we measured the distance between the ENB probe and the actual lesion location, but also recorded the results of rapid on-site evaluation (ROSE), and postoperative pathology. To evaluate the impact of CT-body divergence induced by atelectasis, we calculated the mutual position distance of target lesions in preENB CT, post-anesthesia intubation CT and postENB CT. Furthermore, ENB operation time and operative complications were recorded.

**Results:** Our analysis revealed that the distance between the navigation probe with the actual location of lesion center was 4–10 (5.90±1.73) mm. The ROSE results were consistent with the postoperative pathological diagnosis in 9 out of 10 patients (90%). The ICNVA-ENB atelectasis CT-body divergence was smaller than traditional ENB (12.10±3.67 *vs.* 6.60±2.59 mm, P<0.01). The ENB operation time was 20–53 (29.30±10.14) minutes and one patient developed slight intrapulmonary hemorrhage.

**Conclusions:** ICNVA-ENB can reduce the CT-body divergence and appears to be safe and accurate for patients with peripheral lung lesions.

**Keywords:** Electromagnetic navigation bronchoscopy (ENB); atelectasis; computed tomography-body divergence (CT-body divergence); intraprocedural computed tomography (intraprocedural CT); ventilatory strategy

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## Introduction

Electromagnetic navigation bronchoscopy (ENB) is a commonly used technique in respiratory interventional therapy and diagnosis. It has shown an accuracy of around 70% in diagnosing peripheral lung lesions (1). However, there are limitations to its accuracy due to computed tomography (CT)-body divergence, which is caused by atelectasis and CT data mismatch (2).

Atelectasis is one of the main factors contributing to CT-body divergence and is frequently observed in ENB procedures. General anesthesia, endotracheal intubation, and bronchoscopy operation are associated with the development of atelectasis. Sagar *et al.* revealed that the incidence of atelectasis was as high as 89% in patients who underwent anesthesia tracheoscopy, leading to a deviation in the location of the target lesion (3).

To minimize the impact of atelectasis, some research teams, such as Salahuddin *et al.* (4) and Pritchett *et al.* (5,6), have explored ventilation strategies to prevent atelectasis during anesthetic bronchoscopy. However, there is limited research on the topic, and no consensus has been reached regarding the optimal ventilation strategies. The accuracy of the proposed strategies is also limited, indicating a need for further improvement in this area.

Another important reason for CT-body divergence in the context of ENB is CT data mismatch. Currently, all research studies utilize preoperative CT data for navigation path planning in ENB. These scans are typically taken when patients are conscious and in a deep inspiration state. However, during ENB procedures, patients are under anesthesia and mechanical ventilation, which can result in a different distribution of lung volumes. As a result, there may be inevitable differences in the actual lung volume compared to the pre-procedural CT data, leading to CT-body divergence.

To address this issue, we propose using CT data obtained after general anesthesia and bronchoscope implantation for navigation path planning. By considering the patient's condition during ENB, such as being under anesthesia and mechanical ventilation, we can account for the differences in lung volume distribution. Additionally, we implement a new ventilation strategy that helps maintain the pulmonary region in a static and inflation state during ENB. This strategy eliminates atelectasis and reduces the deviation distance between the actual target lesion location and the navigation target. By incorporating these measures, we aim to minimize CT-body divergence and improve the accuracy of ENB procedures.

We name this method as ICNVA-ENB which means intraprocedural CT-guided navigation with ventilatory strategy for atelectasis. The purpose of this study is to evaluate the safety and effectiveness of ICNVA-ENB. We present this article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-82/rc).

### Highlight box

**Key findings**

- Intraprocedural computed tomography (CT)-guided navigation with ventilatory strategy for atelectasis-electromagnetic navigation bronchoscopy (ICNVA-ENB) appears to be safe and accurate for patients with pulmonary nodules without bronchial direct connection, and ICNVA-ENB can reduce the CT-body divergence.

**What is known and what is new?**

- CT-body divergence limits the accuracy of ENB, which is caused by atelectasis and CT data mismatch. Prior studies on ventilation protocols to minimize atelectasis, like ventilatory strategy to prevent atelectasis (VESPA) and lung navigation ventilation protocol, showed accuracy improvement, but limitedly.
- We proposed a modified ENB, which employed intraoperative CT data for navigation path planning and modified ventilatory method. In this way, we can eliminate CT data mismatch and minimize atelectasis, thereby improve the accuracy of ENB arrival by minimizing CT-body divergence.

**What is the implication, and what should change now?**

- ICNVA-ENB reduce CT to body divergence from a mechanistic perspective, and improve the accuracy of ENB effectively. ICNVA-ENB may be a safe and effective strategy for the diagnosis and treatment of pulmonary lesions, particularly in cases where there is no endobronchial connection to the lesions.

## Methods

### *Study setting and subjects*

This retrospective observational study was conducted in the Department of Thoracic Surgery, The First Affiliated Hospital, Jiangxi Medical College, Nanchang University. The study adhered to the guidelines of the Declaration of Helsinki (as revised in 2013) and was approved by the Ethics Committee of The First Affiliated Hospital, Jiangxi Medical College, Nanchang University (approval No. 2023028). Written informed consent was obtained from patients and/or their immediate family members.

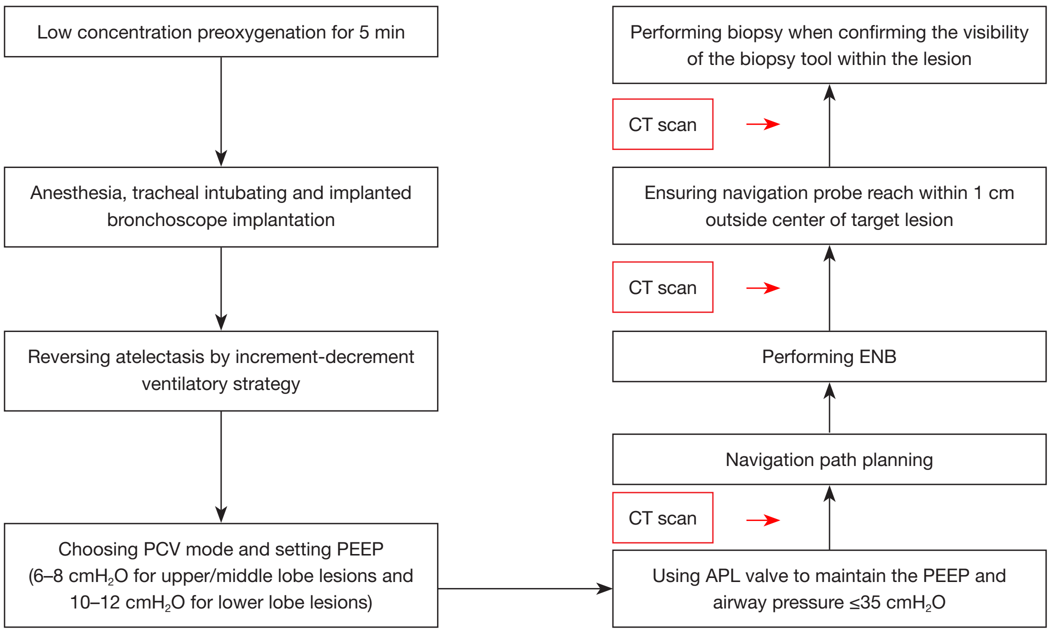


**Figure 1** ICNVA-ENB and biopsy procedures. min, minute; PCV, pressure-controlled ventilation; PEEP, positive end-expiratory pressure; CT, computed tomography; ENB, electromagnetic navigation bronchoscopy; ICVNA, intraprocedural CT-guided navigation with ventilatory strategy for atelectasis; APL, adjustable pressure limiting.

**Video 1** ICNVA-ENB procedure and result of one patient. ICNVA-ENB, intraprocedural computed tomography-guided navigation with ventilatory strategy for atelectasis-electromagnetic navigation bronchoscopy.

The study included patients with pulmonary nodules who required peripheral bronchoscopy with ENB and rapid on-site evaluation (ROSE) between May 1, 2023 to August 30, 2023.

Prior to the procedure, all patients underwent a chest CT scan which revealed that their pulmonary lesions were located in the outer third of the lungs. All lesions had undergone over a year of follow-up and the lesions had increased in size or solid components. The patients rejected percutaneous biopsy or surgical resection for some reasons, like percutaneous biopsy failure, requirement of pathologic diagnosis, etc.

Patients with lesion diameter ≤6 mm or >3 cm, lesions directly connected to the bronchial tree, pregnant patients, those with a history of bronchial asthma, severe pneumothorax, rib fractures, severe abdominal or thoracic aortic aneurysm, pleural effusions, ascites, or diaphragmatic paralysis were excluded from the study.

### *Operating procedures (Figure 1, Video 1)*

#### ICNVA-ENB procedures

(I) Patients received preoxygenation with the lowest oxygen concentration [it was usually 60%≤ fraction of inspiration $O_2$ ($FiO_2$) ≤80%] to keep blood oxygen saturation >92%. This process lasted for 5 minutes.

(II) After deep general anesthesia with non-depolarizing muscle relaxants and tracheal intubating with an 8.5-mm endotracheal tube, we implanted the bronchoscope (BF290, Olympus, Tokyo, Japan).

(III) Increment-decrement ventilatory strategy was performed to reverse atelectasis induced by anesthesia and intubation. We selected the pressure-controlled ventilation (PCV) mode. Meanwhile, we set inspiratory pressure at 10–15 $cmH_2O$ and positive end-expiratory pressure (PEEP) at 5 $cmH_2O$. Then we increased the PEEP by 5 $cmH_2O$ each time until it reached 35 $cmH_2O$, and then decreased the PEEP by 5 $cmH_2O$ each time until it reached 5 $cmH_2O$. Every PEEP changing sustained for five complete respiratory processes.

(IV) The optimally lowest $FiO_2$ level was kept to maintain the blood oxygen saturation >92%. And the PEEP was kept at desired level (it was usually 6–8 and 10–12 $cmH_2O$ when lesion located in upper/middle lobe and lower lobe respectively).

(V) Patients were maintained at the end of inspiratory state to minimize lung movement during breathing by using adjustable pressure limiting (APL). The APL valve (also referred to as an expiratory valve, relief valve or spill valve) is a type of flow control valve that will ensure the circuit will maintain airway pressure during breath-holding maneuvers (6). Manually APL valve was used at the end of inspiration to maintain the PEEP at desired level (airway pressure ≤35 $cmH_2O$), following a protective lung ventilation strategy. After setting the APL valve to auto mode and setting a constant pressure, the anesthesia machine would maintain the pressure inside the tracheal intubation at the preset pressure level.

(VI) After holding breathing for 7 seconds, CT scan (O-arm CT, Siemens Somatom Confidence 64 sliding gantry, Siemens Healthcare, Forchheim, Germany) was performed with a layer of 1-mm thickness. Then, patients were restored at normal breathing state and the Digital Imaging and Communications in Medicine (DICOM) format file was exported to Medtronic Version 7 ENB system for navigation path planning.

(VII) Patients were kept in breath hold state as in step 5. Then following preset navigation path, we completed ENB operation when navigation probe reached the target lesions.

(VIII) CT was reviewed to confirm the location of navigation probe, and to confirm whether there is pneumothorax, bleeding, etc.

**Biopsy procedures**

After successfully completing the ICNVA-ENB procedures and aligning the navigation catheter, our next step involved inserting and advancing a biopsy tool towards the targeted lesion. To ensure accurate positioning, a CT scan was performed on the patient to confirm the visibility of the biopsy tool within the lesion.

Following the CT scan, we utilized ROSE in all cases when they were kept in breath hold state. ROSE involved a quick assessment of the obtained tissue samples by a pathologist during the procedure. This real-time evaluation help in confirming the adequacy and quality of the collected samples, allowing for quick adjustments or additional biopsies if required.

### *Statistical analysis*

The statistical analysis involved the calculation of several measurements to evaluate the accuracy and effectiveness of the ENB procedure and the impact of the specific ventilatory strategy on atelectasis.

First, to assess the accuracy of ENB arrival, the distance between the navigation probe center and the target lesion center in the CT data after ENB operation was calculated. This distance served as the accuracy index.

Next, the time from endotracheal intubation completion to bronchoscope removal was recorded as the ENB operation time. Complications, ROSE results, and postoperative pathological results were also recorded.

To evaluate the impact of the specific ventilatory strategy on CT-body divergence induced by CT-body divergence, the relative distance of the target lesion between the CT data before ENB and the CT data after anesthesia intubation was calculated. For specific methods, we referred to the research of Chen *et al.* (7). This was done by aligning preENB-anesthesia CT scan pairs using the main carina as a common point of translation. The physical three-dimensional (3D) motion was then calculated, considering the X, Y, and Z directions of motion. Motion in the X direction equated to medial and lateral movement, motion in the Y direction equated to anterior and posterior movement, and motion in the Z direction equated to cranial and caudal movement within each patient. This deviation was represented by the vector formula atelectasis deviation (m) = $\sqrt{(x^2 + y^2 + z^2)}$, providing the physical 3D of traditional ENB CT-body divergence. Anesthesia-postENB CT scan

**Table 1** Clinical data of patients

| No. | Sex | Age (years) | BMI (kg/m$^2$) | Merger of underlying diseases | Lesion location | The longest diameter of the lesion (mm) | The shortest diameter of the lesion (mm) | The longest diameter of solid component (mm) |
|---|---|---|---|---|---|---|---|---|
| 1 | F | 36 | 21.33 | None | $LS_{1+2}$ | 7 | 7 | 0 |
| 2 | F | 44 | 24.45 | None | $RS_1$ | 11 | 7 | 0 |
| 3 | M | 54 | 20.81 | None | $RS_2$ | 9.7 | 8.2 | 1.2 |
| 4 | M | 60 | 23.14 | Diabetes mellitus | $RS_2$ | 8 | 6.5 | 0 |
| 5 | F | 81 | 17.11 | Hypertension | $LS_3$ | 15 | 10.4 | 5 |
| 6 | F | 33 | 20.31 | None | $RS_4$ | 8 | 4 | 0 |
| 7 | F | 46 | 18.43 | None | $RS_1$ | 8 | 5 | 3 |
| 8 | F | 25 | 20.96 | None | $LS_{1+2}$ | 10 | 9 | 0 |
| 9 | F | 54 | 18.00 | None | $RS_6$ | 4.1 | 3.1 | 0 |
| 10 | F | 34 | 20.55 | None | $LS_{1+2}$ | 7 | 6 | 0 |

No., number; F, female; M, male; BMI, body mass index; LS, left segment; RS, right segment.

pairs were applied with the same method to calculated the physical 3D total ICNVA-ENB atelectasis deviation of target lesion (ICNVA-ENB CT-body divergence).

The quantitative data were expressed as a number, median, and range, while categorical variables were described as a number and percentage. All statistical analyses were performed using SPSS 20 software (IBM Corp., Armonk, NY, USA).

## Results

The results of the study conducted between May 2023 and August 2023 on ten lesions of ten patients who underwent ICNVA-ENB are summarized in the following paragraphs.

*Table 1* provides information on the characteristics of the patients and lesions. All ten lesions were located in the outer third of the pulmonary region, none of them were visible endobronchially, and all were located beyond the segmental bronchus.

Based on the final CT data, the navigation probe successfully reached within 1 cm outside the center of the target lesion in all cases. The average distance between the navigation probe and the actual location of the lesion center was 4–10 (5.90±1.73) mm. The traditional ENB atelectasis CT-body divergence was 7–17 (12.10±3.67) mm, and ICNVA-ENB atelectasis CT-body divergence was 4–12 (6.60±2.59) mm. The difference is statistically significant.

The ENB operation time was 20–53 (29.30±10.14) minutes. Out of the ten patients, one developed intrapulmonary hemorrhage, as observed by localized patchy shadows on CT imaging. No other complications were reported during the procedure. The results of ROSE showed that all lesions were malignant, and every patient then underwent video-assisted thoracic surgery. The ROSE results were consistent with the postoperative pathological diagnosis in 9 out of 10 patients (90%) (*Table 2*; *Figure 2* shows the ENB results of one patient).

## Discussion

Over the past few decades, bronchoscopy technology has advanced significantly, but its diagnostic yield is still limited to around 70% (8-11). Despite the introduction of various technologies such as ultrathin-bronchoscopy, radial-probe endobronchial ultrasound, electromagnetic navigation, and robotic-bronchoscopy, the diagnostic yield has not been significantly improved.

One of the new bronchoscopy tools, ENB combines electromagnetic navigation, virtual bronchoscopy, and 3D CT imaging technology to achieve real-time navigation and precise positioning of lung lesions. However, this technology relies on CT data for virtual map reconstruction, which can result in deviations in the localization of lesions. CT-body divergence may be one of the important reasons limiting the accuracy of navigation technology (12). During the ENB process, patients often experience atelectasis due to factors like anesthesia, endotracheal intubation,

 

**Table 2** ENB data of patients

| No. | Probe-lesion distance (mm) | Traditional ENB atelectasis CT-body divergence (mm) | ICNVA-ENB atelectasis CT-body divergence (mm) | ENB operation time (min) | ROSE | Postoperative pathological diagnosis | Radiation dose (mSV) | Complication |
|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 8 | 5 | 26 | Malignant | MIA | 6.37 | None |
| 2 | 6 | 7 | 6 | 23 | Malignant | MIA | 5.17 | None |
| 3 | 4 | 12 | 10 | 22 | Malignant | AAH | 3.99 | None |
| 4 | 7 | 15 | 12 | 40 | Malignant | AIS | 4.77 | None |
| 5 | 6 | 13 | 6 | 26 | Malignant | MIA | 6.26 | None |
| 6 | 4 | 17 | 7 | 53 | Malignant | AIS | 3.64 | Intrapulmonary hemorrhage |
| 7 | 6 | 15 | 7 | 32 | Malignant | AIS | 4.77 | None |
| 8 | 5 | 16 | 5 | 20 | Malignant | MIA | 4.38 | None |
| 9 | 6 | 8 | 4 | 28 | Malignant | MIA | 7.20 | None |
| 10 | 5 | 10 | 4 | 23 | Malignant | AIS | 4.23 | None |

ENB, electromagnetic navigation bronchoscopy; No., number; CT, computed tomography; ICVNA, intraprocedural CT-guided navigation with ventilatory strategy for atelectasis; ROSE, rapid on-site evaluation; MIA, microinvasive adenocarcinoma; AAH, adenomatous atypical hyperplasia; AIS, adenocarcinoma in situ; mSV, millisievert.

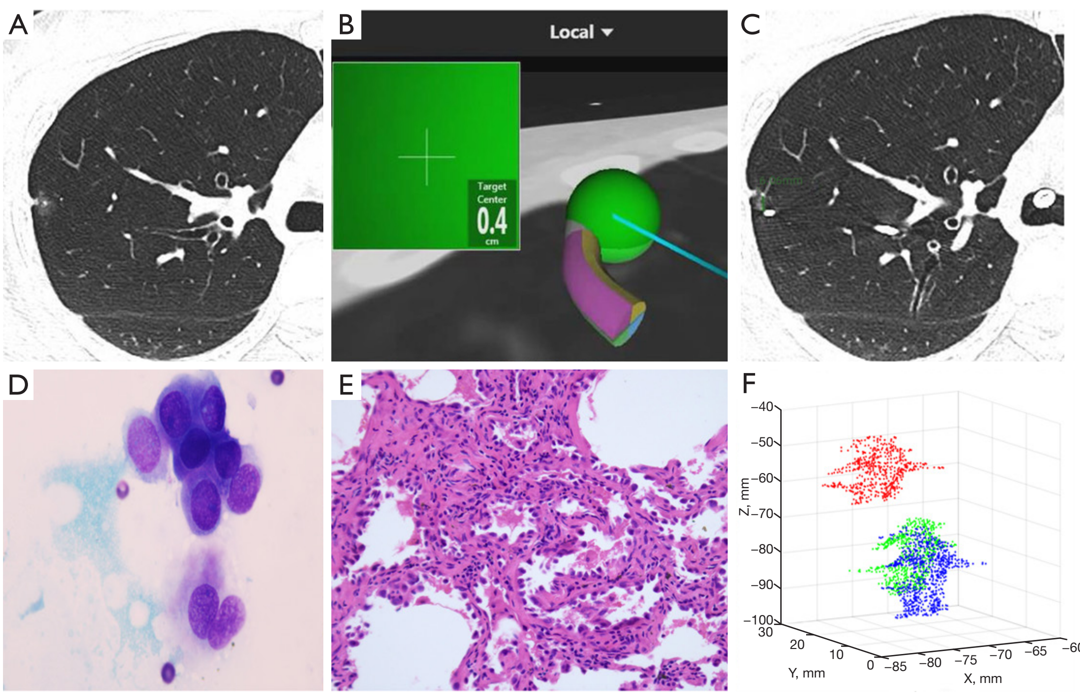


**Figure 2** ICNVA-ENB data of one patient. (A) Chest CT showed mGGO in right upper lobe. (B) ENB probe reached 4 mm outside target lesion (virtual green ball) in ENB system. (C) Chest CT showed ENB probe reached 6 mm outside target lesion. (D) ROSE result showed malignant cell (Diff-Quik stain, ×1,000). (E) Postoperative pathological section showed AIS (hematoxylin and eosin stain, ×20). (F) The physical 3D motion of lesion by using the main carina as a common point of translation (red, green and blue dots represent the position of target lesion in preENB CT, anesthesia CT and postENB CT respectively). ICVNA, intraprocedural CT-guided navigation with ventilatory strategy for atelectasis; ENB, electromagnetic navigation bronchoscopy; CT, computed tomography; mGGO, mixed ground glass opacity; ROSE, rapid on-site evaluation; AIS, adenocarcinoma in situ; 3D, three-dimensional.

 

bronchoscopy operation, and ventilation mode. Anesthesia is particularly significant in causing CT-body divergence, leading to deviations in the location of the target lesion. In the study of Sagar *et al.*, the incidence of atelectasis was 89% in patients underwent anesthesia tracheoscopy (3). Optimizing the ventilation mode may be a crucial factor in improving atelectasis.

Researchers have suggested various ventilation strategies to improve atelectasis during bronchoscopy. For example, the ventilatory strategy to prevent atelectasis (VESPA) (4) includes large-diameter tracheal intubation, lower inhaled oxygen concentration, and PEEP of 8–10 $cmH_2O$, while the lung navigation ventilation protocol (LNVP) (5,6) includes sustained inflation, higher PEEP, and peak pressure threshold. However, the accuracy of these strategies is limited, and further improvement is needed.

In clinical practice, there are two common methods for lung recruitment: sustained inflation and stepwise inflation. The stepwise method using slow-low pressure can achieve lung recruitment while reducing impact on the circulatory system (13,14). LNVP strategy used sustained inflation, higher PEEP, and peak pressure threshold, but this setting violated the protective lung ventilation strategy and may lead to ventilator-related lung injury (5,6,15-17). In our early cases, we followed the LNVP strategy and found that patients were prone to intraoperative bleeding and hypotension and decreased oxygenation index.

Therefore, we changed to choose stepwise method to improve atelectasis. We utilized an optimized ventilation strategy with individualized adjustments, lower initial PEEP values, individualized suction pressure, and a lower pressure peak threshold to reduce the risk of ventilator-related lung injury. We followed the VESPA strategy to choose a large-diameter tracheal intubation and reduce inspiratory oxygen concentration. In terms of PEEP, we did not completely follow the VESPA strategy to set it at 8–10 $cmH_2O$, but instead of personalized PEEP level. We referred to the lung recruitment strategy in LNVP. Differently, in order to reduce the impact of lung recruitment on the cardiovascular circulation system, the increment-decrement ventilatory strategy was used for lung recruitment, rather than the method of maintaining a constant high pressure of 40 $cmH_2O$ for 40 seconds in the LNVP strategy. Moreover, in the PEEP level setting, the setting of 10–15 $cmH_2O$ for upper and middle lobe nodules and 15–20 $cmH_2O$ for lower lobe nodules in LNVP were abandoned. Because this level of PEEP was found too high and can easily affect the cardiovascular circulation system, leading to hypotension. Therefore, a PEEP of 6–8 $cmH_2O$ for the upper and middle lobe nodules was set. For lower lobe nodules, PEEP was usually set at 10–12 $cmH_2O$. In our study, we found that optimized ventilation strategy (ICNVA-ENB) reduced the CT-body divergence induced by atelectasis compared to traditional ENB strategy (12.10±3.67 *vs.* 6.60±2.59 mm, $P<0.01$). Furthermore, there were no complications related to ventilator-induced lung injury. This study is the first to apply this optimized ventilation strategy to minimize atelectasis in ENB examination.

In addition to atelectasis, the mismatch between preoperative and intraoperative CT data, known as CT bias, is another factor affecting the accuracy of ENB. Traditional ENB navigation paths planning use preoperative CT data, which may not accurately reflect intraoperative lung volume changes and anatomical position shift due to sedation, mechanical ventilation, and bronchoscope placement (5). Therefore, the key to improve ENB accuracy should be how to match the navigation location with the actual lesion location, rather than simply solving atelectasis. So far, no research has proposed a solution to this point. Benefiting from the intraoperative CT equipment in our center, we propose using CT data after bronchoscope placement under anesthesia to plan the navigation path, for reducing CT bias.

Currently, the largest report on the accurate rate of ENB diagnosis is the NAVIGATE study, which had a diagnostic accuracy of 67.8%. In NAVIGATE (Clinical Evaluation of superDimension$^{TM}$ Navigation System for Electromagnetic Navigation Bronchoscopy) study, the presence of bronchial direct connection to lesion is a key factor determining its diagnostic accuracy (18). In comparison, we achieved a 100% arrival rate confirmed by CT and a 90% pathological diagnosis accuracy in our study. We believe that this was mainly due to the optimization of ventilation strategy and using of intraoperative CT data under general anesthesia intubation and placement of bronchoscopy for ENB path planning. ICNVA-ENB can reduce CT to body divergence from a mechanistic perspective, which improve the accuracy of ENB effectively.

However, there are still some shortcomings in this study, including the small sample size and the situations that most of the lesions were located in the upper lobe. The operator's experience may affect ENB accuracy. Further research is needed to validate our findings.

## Conclusions

The ICNVA-ENB technique described herein is a novel approach that utilizes intraoperative CT data for path planning in ENB. This technique also incorporates a modified ventilatory method to prevent atelectasis and reduce CT-body divergence. The ICNVA-ENB technique significantly improves the accuracy of ENB arrival. This study suggests that this technology has higher accuracy compared to traditional ENB and has shown no significant complications in our early experience. ICNVA-ENB may be a safe and effective strategy for the diagnosis and treatment of pulmonary lesions, particularly in cases where there is no endobronchial connection to the lesion.

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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-24-82/rc

*Data Sharing Statement:* Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-82/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-24-82/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. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the ethics committee of The First Affiliated Hospital, Jiangxi Medical College, Nanchang University (approval No. 2023028). Written informed consent was obtained from patients and/or their immediate family members.



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