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The Korean Academy of Tuberculosis and Respiratory Diseases

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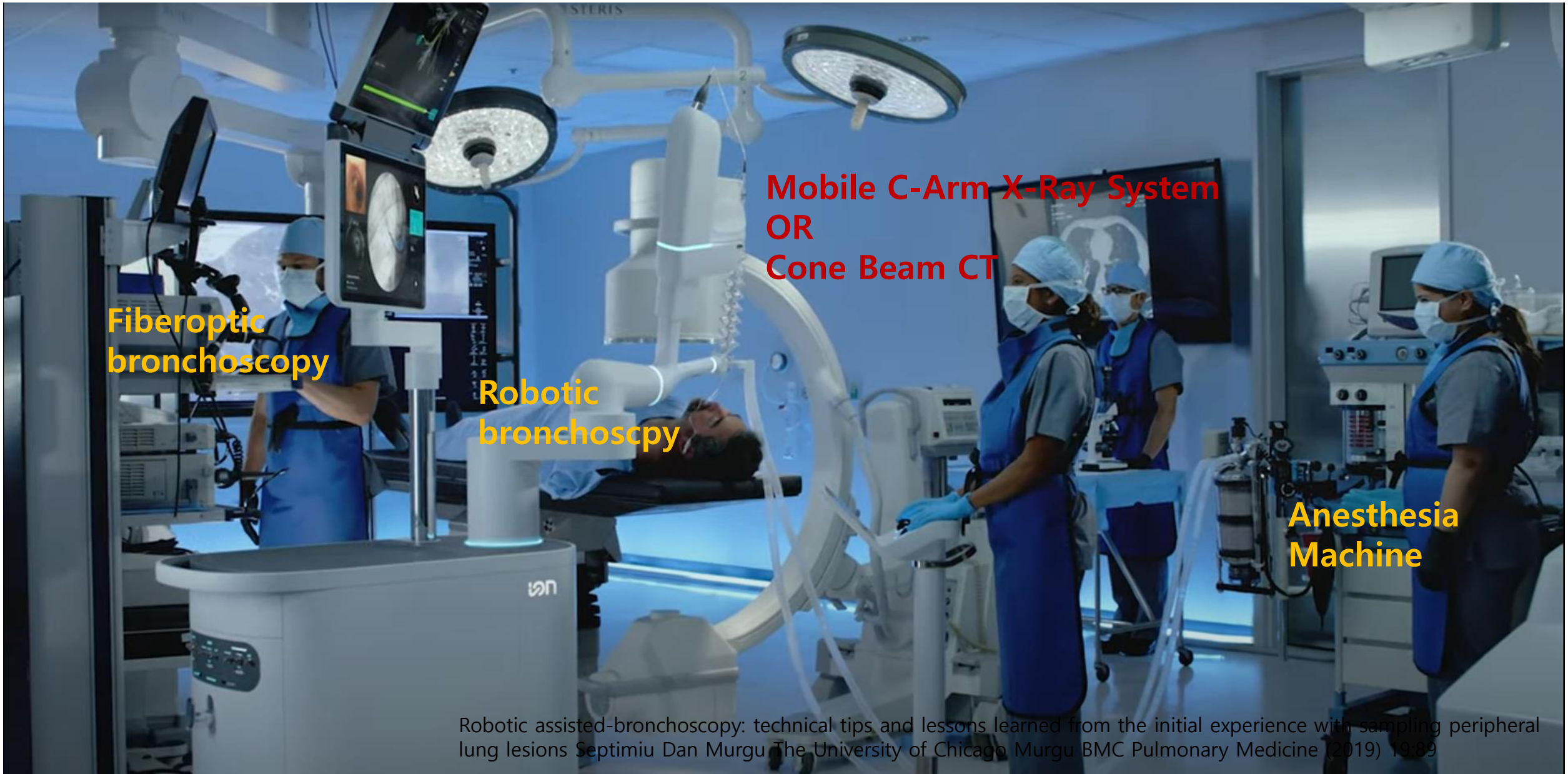
The Role of Image Guidance in The Era of Robotic Assisted Bronchoscopy

PNUYH
HEE YUN SEOL

The Korean Study Group for Bronchology and Interventional Pulmonology
2024.11.18



Robotic assisted-bronchoscopy: technical tips and lessons learned from the initial experience with sampling peripheral lung lesions Septimiu Dan Murgu The University of Chicago Murgu BMC Pulmonary Medicine (2019) 19:89

Usefulness of CT-guided percutaneous transthoracic needle biopsy with additional laser-guidance system
Dong Il Park, Ju Ock Kim, Sung Soo Jung, Hee Sun Park, Chae Uk Chung, Yeon Hee Park, Min Cheol Jeon
European Respiratory Journal Sep 2016, 48 (suppl 60)

The Role of Image Guidance in The Era of Robotic Assisted Bronchoscopy

- Planning and Navigation to the target

- Confirmation of arrival at the target

Image-guided bronchoscopy for biopsy of peripheral pulmonary lesions

1. preprocedural Thin slice Chest CT : 0.6mm, axial, coronal, sagittal
2. Fiberoptic bronchoscope with/without Catheter OR Robotic bronchoscope Optic
3. Planning and Navigation to the target VBN, ENB, Augmented Fluoroscopy Cone Beam CT
4. Confirmation of arrival at the target Radial probe EBUS Cone Beam CT
5. Biopsy tools
6. Sufficient tissue acquisition Rapid on-site evaluation (ROSE)

Meta-Analysis > J Bronchology Interv Pulmonol. 2024 Jan 1;31(1):70-81.
doi: 10.1097/LBR.0000000000000942.

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Robotic-assisted Navigation Bronchoscopy: A Meta Analysis of Diagnostic Yield and Complications

Fahim F Pyarali [1], Niv Hakami-Majd [2], Wesam Sabbahi [2], George Chaux [2]

References	Patients (n)	Augmented fluoro or CBCT	Robotic platform	Age	% Women	% Patients with current or previous smoking history	Nodule size	Diagnostic nodules/ total nodules (n)	% Nodules with bronchus sign
Bajwa et al[29]	76	No	Ion	68.4 (mean)	54.0	—	17.0 mm (median)	—	—
Benn et al[30]	52	Yes	Ion	68.0 (mean)	65.0	54.0	21.9 mm (mean)	46/59	46.0
Chadda et al[14]	165	No	Monarch	66.5 (mean)	45.5	78.2	25.0 mm (mean)	100/167	63.5
Chen et al[13]	54	No							
Cumbo-Nacheli et al[31]	32	—							
Ekeke et al[32]	25	No							
Fielding et al[12]	29	No							
Ghosh et al[33]	95	No							
Grier et al[34]	6	Yes							
Hammad Al Taq et al[34]	20	—							
Kalchiem-Dekel et al[34]	131	Yes							
Manley et al[37]	17	No							
Monterroso et al[37]	3	Yes							
Oberg et al[39]	10	No							
Ost et al[40]	69	—	Ion	—	—	—	17.0 mm (mean)	57/69	25.0
Pritchett et al[40]	192	Yes	Ion	—	56.0	—	15 mm (median)	207/230	38.0
Pritchett and Schirmer[40]	34	Yes	Ion	—	—	—	17.5 mm (median)	—	30.0
Reddy et al[43]	3	No	Monarch	—	—	—	5.9 mm (mean)	3/3	—
Reisenauer et al[44]	241	No	Ion	66.9 (mean)	59.3	80.5	18.8 mm (mean)	—	34.5
Reisenauer et al[45]	30	Yes	Ion	69.3 (mean)	43.3	70.0	19.5 mm (mean)	28/30	40.0
Rojas-Solano et al[11]	15	No	Monarch	67.0 (median)	40.0	—	26 mm (median)	14/15	—
Ross et al[46]	45	Yes	Ion	—	—	—	14 mm (median)	—	—
Tavakoli et al[47]	65	No	Ion	68.3 (mean)	53.0	—	21.2 mm (mean)	—	70.7

CBCT indicates cone beam computed tomography.

- Robotic platform with/without
- **Augmented Fluoro or CBCT**

Review > Diagnostics (Basel). 2023 Mar 5;13(5):990. doi: 10.3390/diagnostics13050990.

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Advanced Imaging for Robotic Bronchoscopy: A Review

Nakul Ravikumar [1], Elliot Ho [2], Ajay Wagh [1], Septimiu Murgu [1]

Additional imaging devices

1. SuperDimension™ : ENB
2. Illumisite™ : Digital Tomosynthesis-assisted fluoroscopic Electromagnetic navigational bronchoscopy (DT-ENB)
3. LungVision™ : Augmented Fluoroscopy
4. CBCT : Fixed Cone Beam CT
5. Cios Spin™ : Mobile Cone Beam CT

Table 1. Description of studies utilizing additional imaging with robotic bronchoscopy and electromagnetic navigation bronchoscopy.

Publication	Device	Description	Sample Size	Diagnostic Yield	Adverse Events
Aboudara et al. [15]	SuperDimension, Medtronic	Comparison of Standard ENB to Fluoroscopic ENB.	90 lesions (S-ENB) vs. 59 lesions (F-ENB)	79% (F-ENB) vs. 54% (S-ENB). $p < 0.005$. Mean divergence of 12 mm	Pneumothorax (1.9% vs 1.5%)
Avasarala et al. [17]	Illumisite™; Medtronic	Real-time guidance with digital tomosynthesis	100 lesions	83% overall yield with 71% sensitivity for malignancy (52/73)	Pneumothorax—3%. Bleeding requiring intervention—2%
				93% nodule localization success; DYi: 75% yield on ROSE	No adverse events
				Localization success: 96%, DYi 78%, and DA: 88%. Average divergence of 14.5 mm	No adverse events
				DYi: 84% DA: 91%	Pneumothorax: 8% (4/45)
				Tool in lesion: 90%. Tool correction in 30% lesions with real-time imaging. DY not reported	-
				DYi: 93%. Average divergence: 10 mm in upper lobe 20 mm in lower lobe	No adverse events
				DY: 83% DA: 93%	Pneumothorax: 4%
				DY: 74% (ENB-CBCT) vs. 51% (ENB)	Total adverse events (6.5%)—no difference between groups
				DY: 83% DA: 86%	Pneumothorax: 3.8%
Styrvoky et al. [30]	CBCT	intra-operative CBCT for biopsy tool guidance	209 lesions	DA: 91%	Pneumothorax: 1%
Cumbo-Nacheli et al. [31]	Monarch™ robotic platform with CBCT	Robotic platform for navigation with intra-operative CBCT for biopsy tool guidance	20 lesions	Sensitivity for malignancy: 86%	-

Abbreviation: 3D: 3-dimensionsal, CABT: C-arm-based tomosynthesis, CBCT: cone-beam CT, DA: diagnostic accuracy at 12 months, DY: diagnostic yield, DYi: diagnostic yield at index procedure, ENB: electromagnetic navigation bronchoscopy, ROSE: rapid onsite pathology, rEBUS: radial endobronchial ultrasound.

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Advanced fluoroscopic imaging modalities during peripheral bronchoscopy OR Robotic Assisted Bronchoscopy

(use of ancillary technology to accommodate for CT-to-body divergence)

Agenda

- **Limitation of virtual guidance and fluoroscopy using Mobile C-Arm X-Ray System in the peripheral lung lesions**

- **CT-to-Body Divergence (CTBD)**

- **Advanced fluoroscopic imaging modalities**
  - **Digital Tomosynthesis-assisted** fluoroscopic electromagnetic navigational bronchoscopy (DT-ENB) : ILLUMISITE™ Fluoroscopic Navigation Platform

  - **Augmented Fluoroscopy**
    - **LungVision**™ (Body Vision Medical Ltd., Ramat Ha Sharon, Israel)
  - **Cone-Beam CT** with Fluoroscopy or Augmented Fluoroscopy
    - **Fixed Cone-Beam CT with Augmented Fluoroscopy**
    - **Mobile Cone-Beam CT** : CIOS 3D Spin Mobile (Siemens Healthineers)

Limitation of virtual guidance in the peripheral lung lesions

Asano et al. BMC Pulmonary Medicine (2017) 17:184
DOI 10.1186/s12890-017-0531-2

BMC Pulmonary Medicine

RESEARCH ARTICLE Open Access

Virtual bronchoscopic navigation without X-ray fluoroscopy to diagnose peripheral pulmonary lesions: a randomized trial

Fumihiro Asano[1*], Takashi Ishida[2], Naofumi Shinagawa[3], Noriaki Sukoh[4], Masaki Anzai[5], Kenya Kanazawa[2], Akifumi Tsuzuku[1] and Satoshi Morita[6]

Table 2 Diagnostic yield according to each parameter

	VBNA	XRFA	*P*- value	*Odds ratio*	*95% Confidence interval*	
Total	50/65 (76.9)	55/64 (85.9)	0.258	1.8	0.7	4.6
Forceps	48/65 (73.8)	54/64 (84.4)	0.142	1.9	0.8	4.6
Brush	40/65 (61.5)	47/64 (73.4)	0.149	1.7	0.8	3.6
Lesion size						
≤ 50 mm	36/49 (73.5)	46/55 (83.6)	0.236	1.8	0.7	4.8
> 50 mm	14/16 (87.5)	9/9 (100)	0.400	1.1	1.0	1.4
Lobe						
Right upper	15/19 (78.9)	13/14 (92.9)	0.278	3.5	0.3	35.1
Right middle	4/5 (80.0)	2/2 (100)	0.714	N/A		
Right lower	12/13 (92.3)	14/19 (73.7)	0.197	0.2	0.02	2.3
Left upper	14/21 (66.7)	15/17 (88.2)	0.120	3.8	0.7	21.2
						60.6
						4.2
						4.3
						19.6
						20.5
						5.1
						5.2
Primary lung cancer	43/56 (76.8)	53/60 (88.3)	0.140	2.3	0.8	6.2
Metastatic lung tumor	2/3 (66.7)	1/2 (50.0)	0.700	0.5	0.01	19.6
Benign	5/6 (83.3)	1/2 (50.0)	0.464	0.2	0.01	6.6

Data are shown as numbers of lesions/total lesions (%)

- The diagnostic yield was 76.9% (50/65) in the VBN-assisted group and 85.9% (55/64) in the X-ray fluoroscopy (XRF)-assisted groups.
- The non-inferiority of the VBN-assisted group could not be confirmed.
- X-ray fluoroscopy is necessary to improve the accuracy of sample collection from lesions

Limitation of virtual guidance in the peripheral lung lesions

IASLC
ORIGINAL ARTICLE

NAVIGATE 24-Month Results: Electromagnetic Navigation Bronchoscopy for Pulmonary Lesions at 37 Centers in Europe and the United States

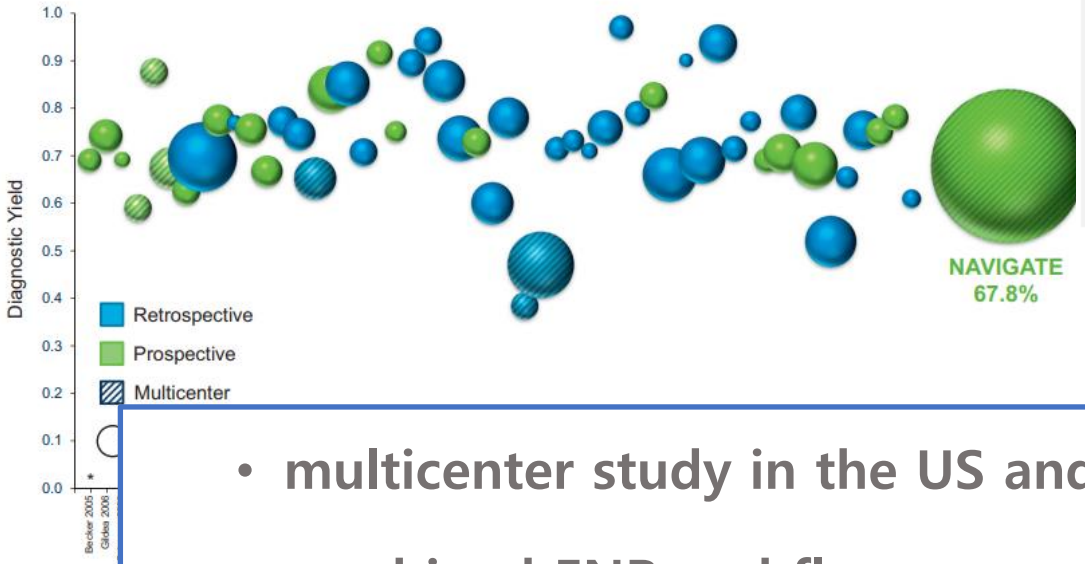


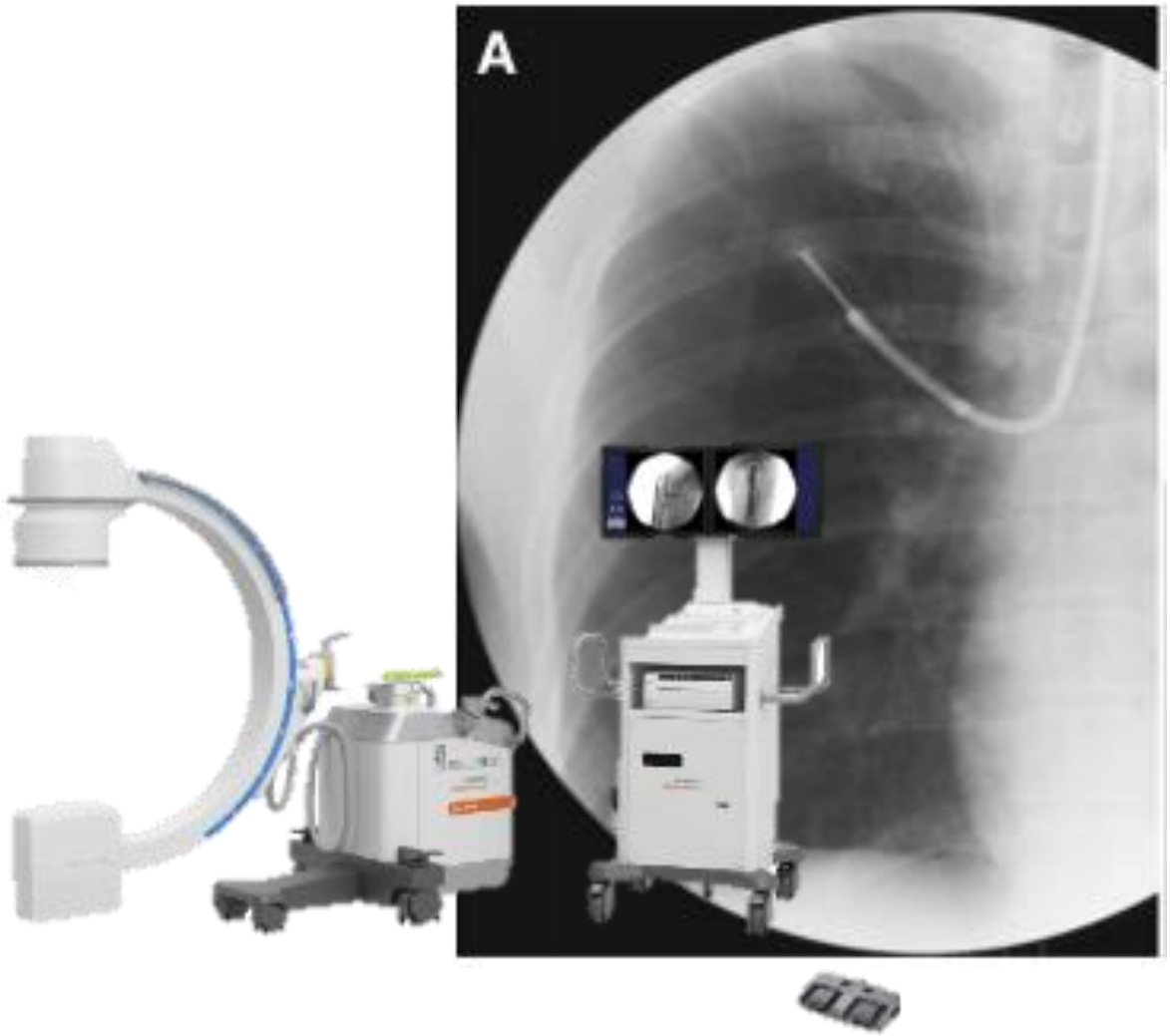
Table 1. Demographics, Procedural, and Lesion Characteristics

Baseline Variables	Global 67.8%	EU Only 55.2%	U.S. Only 69.8%
Subject demographics	1388 subjects	175 subjects	1213 subjects
Age at consent (y)	69.0 (61.0-76.0)	69.0 (61.0-77.0)	69.0 (60.0-76.0)
Subject age ≥ 65 y	64.4 (894/1388)	63.4 (111/175)	64.6 (783/1213)
Female/male	50.3/49.7	46.9/53.1	50.8/49.2
Tobacco history (current or former)	79.8 (1107/1388)	81.1 (142/175)	79.6 (965/1213)
COPD	43.3 (601/1388)	34.3 (60/175)	44.6 (541/1213)
Personal history of cancer	48.1 (667/1388)	43.4 (76/175)	48.7 (591/1213)
Family history of cancer	58.8 (816/1388)	38.3 (67/175)	61.7 (749/1213)
Procedural characteristics	1388 procedures	175 procedures	1213 procedures
General anesthesia	78.2 (1086/1388)	56.6 (99/175)	81.4 (987/1213)
Radial EBUS used during ENB	50.6 (703/1388)	4.0 (7/175)	57.4 (696/1213)
Cone-beam CT used during ENB	5.5 (77/1388)	9.7 (17/175)	4.9 (60/1213)
Fluoroscopy used during ENB[a]	85.0 (1299/1529)	41.7 (78/187)	91.0 (1221/1342)
Lesion visible on fluoroscopy[a]	59.1 (768/1299)	50.0 (39/78)	59.7 (729/1221)

Figure 1. Dia
basis of clinic
defined diagn
†Cone-beam

- multicenter study in the US and Europe
- combined ENB and fluoroscopy was far more frequently used in the US than Europe (91.0% vs. 41.7%), possibly contributing to the higher diagnostic yield (69.8% vs. 55.2%)

Limitation of fluoroscopy using Mobile C-Arm X-Ray System in the peripheral lung lesions



- Identification of tumor depth
- Check the distance to the pleura
- Make sure the forceps are open

"Fluoroscopy provides real-time imaging, but it has the disadvantage of not showing the pathway to the target and the target itself."

CT-to-Body Divergence (CTBD)

- The discrepancy between the **static preprocedural CT scans** and the **dynamic lung anatomy during bronchoscopy**

- **Lung Volume Variance**: Differences in lung volume between spontaneous breathing during CT and mechanical ventilation during bronchoscopy.
- **Patient Position**: Changes in patient positioning can alter thoracic and lung anatomy.
- **Time Gap**: Variations in lung anatomy due to the time elapsed between the preprocedural CT and the bronchoscopy.

- **Localization Accuracy**: Divergence can lead to inaccurate localization of the target lesion, especially in the lower lobes. Navigation systems may show successful localization, but actual bronchoscope position may be off-target.

CT-to-Body Divergence (CTBD)
The Effect of Respiratory Motion on Pulmonary Nodule

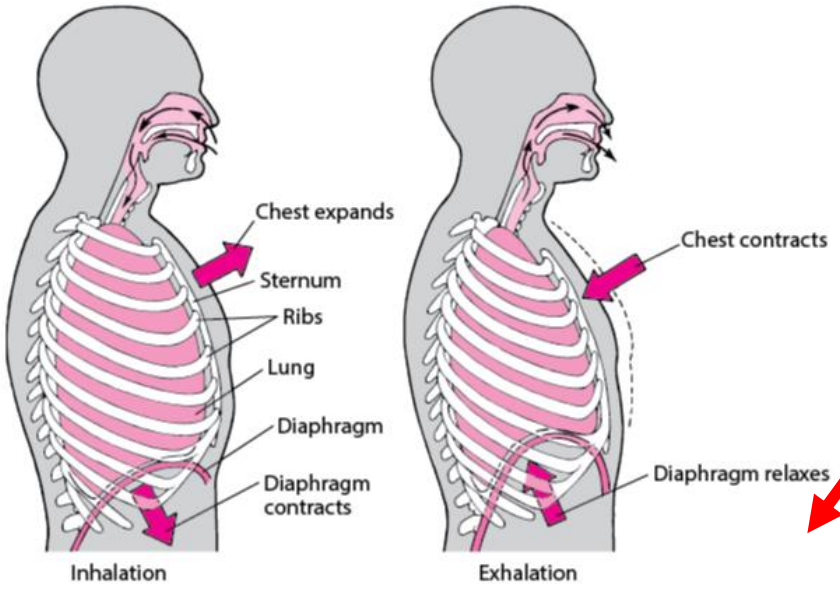


Figure 3 – *Inspiratory and expiratory chest CT scan. Tracheobronchial tree on full inspiration in gray and on end-exhalation from tidal volume in blue.*

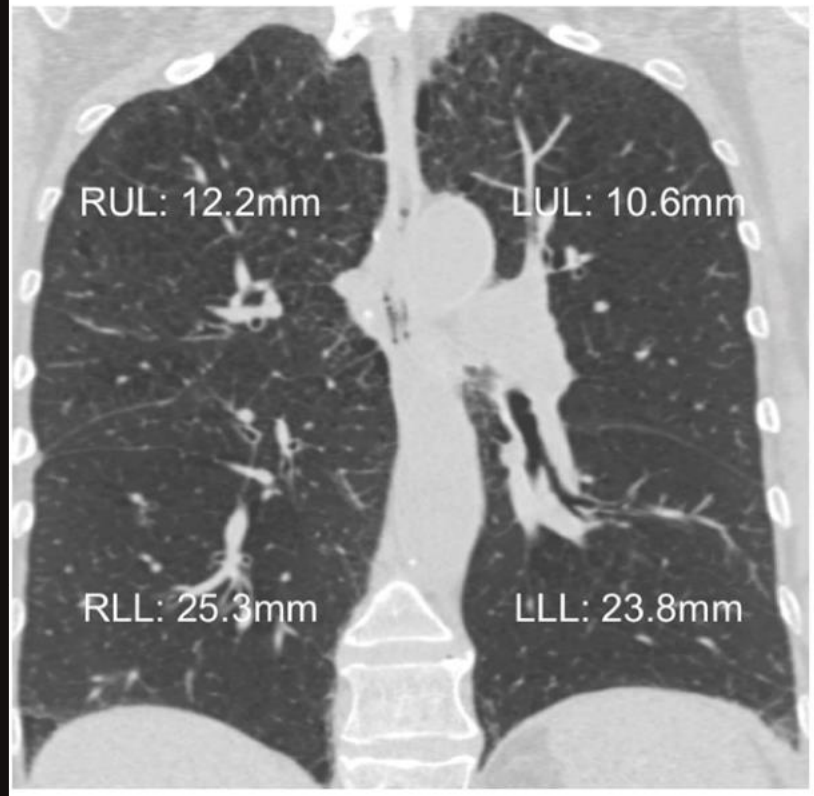


Figure 2 – *Nodule movement by lobe. Average nodule movement per lobe. LLL = left lower lobe; LUL = left upper lobe; RLL = right lower lobe; RUL = right upper lobe.*

Chen A, Pastis N, Furukawa B, Silvestri GA. The effect of respiratory motion on pulmonary nodule location during electromagnetic navigation bronchoscopy. Chest. 2015 May;147(5):1275-1281

CT-to-Body Divergence (CTBD)

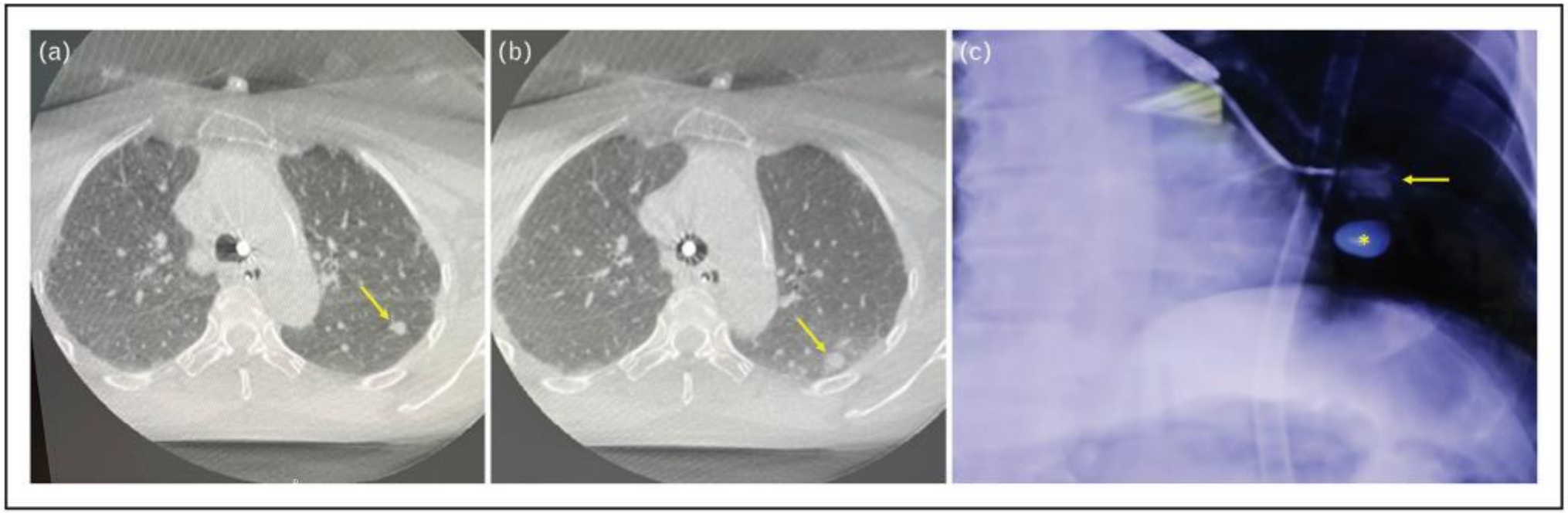


FIGURE 1. CT-body divergence. (a) Right lower lobe nodule (arrow) on cone beam CT imaging immediately after intubation. (b) Cone beam CT imaging after approximately 6 min of bronchoscopic navigation showed significant posterior displacement of the right lower lobe nodule (arrow) due to dependent atelectasis despite high-pressure ventilation to combat lung-derecruitment. (c) Augmented fluoroscopy demonstrating a radio-opaque target lesion (arrow) to be in a significantly different location as compared to where it was demarcated (asterisk) on cone beam CT images just a few minutes prior. *Images courtesy of Brian D. Shaller.*

Shaller BD, Sethi S, Cicenia J. Imaging in peripheral bronchoscopy. Curr Opin Pulm Med. 2024 Jan 1;30(1):17-24

CT-to-Body Divergence (CTBD) : atelectasis during general anesthesia

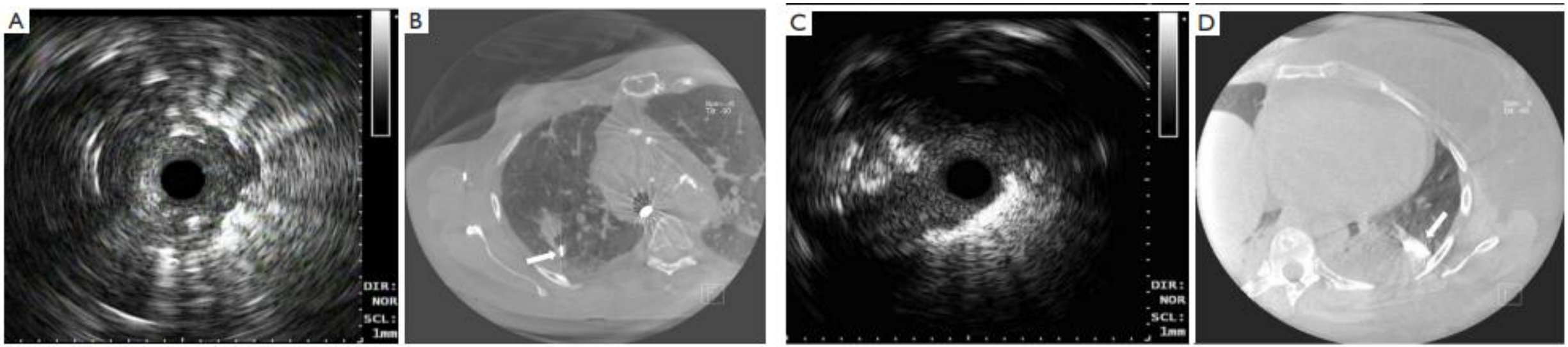
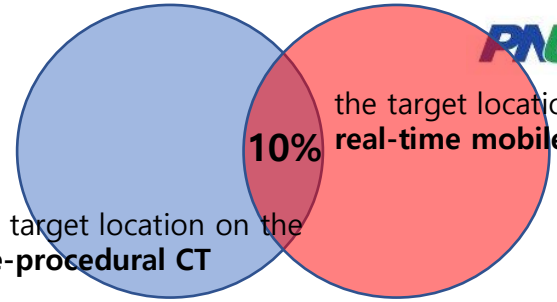


Figure 3 CBCT demonstrating unsuccessful navigation and atelectasis obscuring target. (A) RP-EBUS showing a falsely "positive" image finding; (B) CBCT correlation of image "A", showing that the RP-EBUS is not in contact with the target (unsuccessful navigation); (C) RP-EBUS showing a "positive" image finding; (D) CBCT correlation of image "C", showing the RP-EBUS surrounded by atelectasis which are obscuring the target. CBCT, cone beam computed tomography; RP-EBUS, radial-probe endobronchial ultrasound.

Casal RF, Sarkiss M, Jones AK, Stewart J, Tam A, Grosu HB, Ost DE, Jimenez CA, Eapen GA. Cone beam computed tomography-guided thin/ultrathin bronchoscopy for diagnosis of peripheral lung nodules: a prospective pilot study. J Thorac Dis. 2018 Dec;10(12):6950-6959.

CT-to-Body Divergence (CTBD)



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Mayo Clin Proc Innov Qual Outcomes. 2022 Apr 23;6(3):177-185.
doi: 10.1016/j.mayocpiqo.2022.02.004. eCollection 2022 Jun.

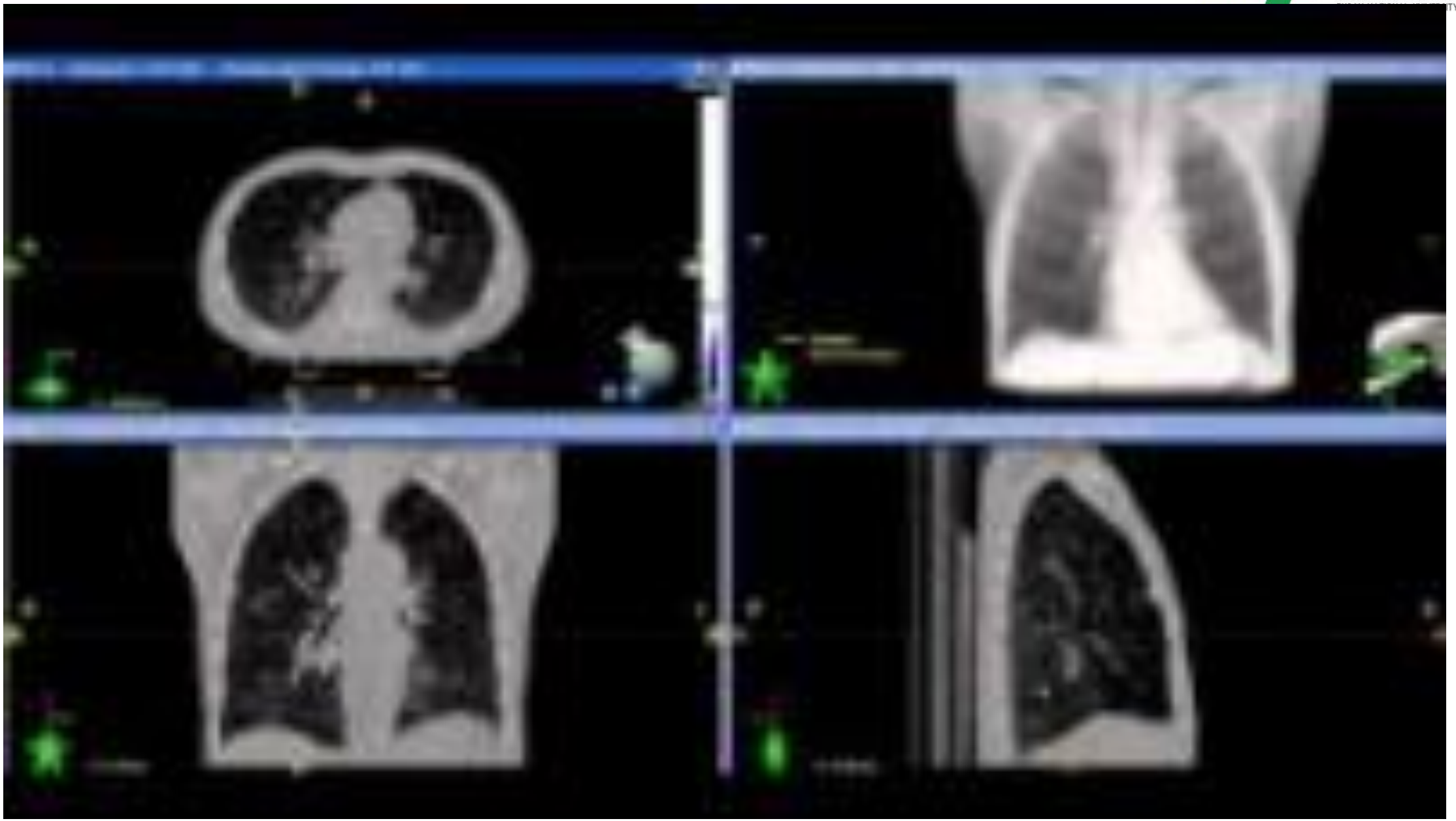
Combining Shape-Sensing Robotic Bronchoscopy With Mobile Three-Dimensional Imaging to Verify Tool-in-Lesion and Overcome Divergence: A Pilot Study

Janani Reisenauer [1,2], Jennifer D Duke [2], Ryan Kern [2], Sebastian Fernandez-Bussy [3], Eric Edell [2]

TABLE 2. Cases of Divergence[a]

Target lesion from preprocedural and intraoperative CT with less than 10% overlap or less[b]	
Upper lobes (17)	Lower lobes (11)
Average lesion size: 16.5 mm	Average lesion size: 16.8 mm
Median divergence: 10 mm	Median divergence: 21 mm
Cases with divergence, 6 (35%)	Cases with divergence, 8 (73%)
Average lesion size: 18.5 mm	Average lesion size: 14.2 mm
Median divergence: 17.8 mm	Median divergence: 21.5 mm
Target centers from preprocedural CT and intraoperative 3D images divergent >10 mm[c]	
Upper lobes (17)	Lower lobes (11)

- **Divergence was defined as an overlap less than 10% between the target location on the pre-procedural CT and the target location during real-time mobile 3D imaging**
- **Divergence was identified in 50% of nodules**



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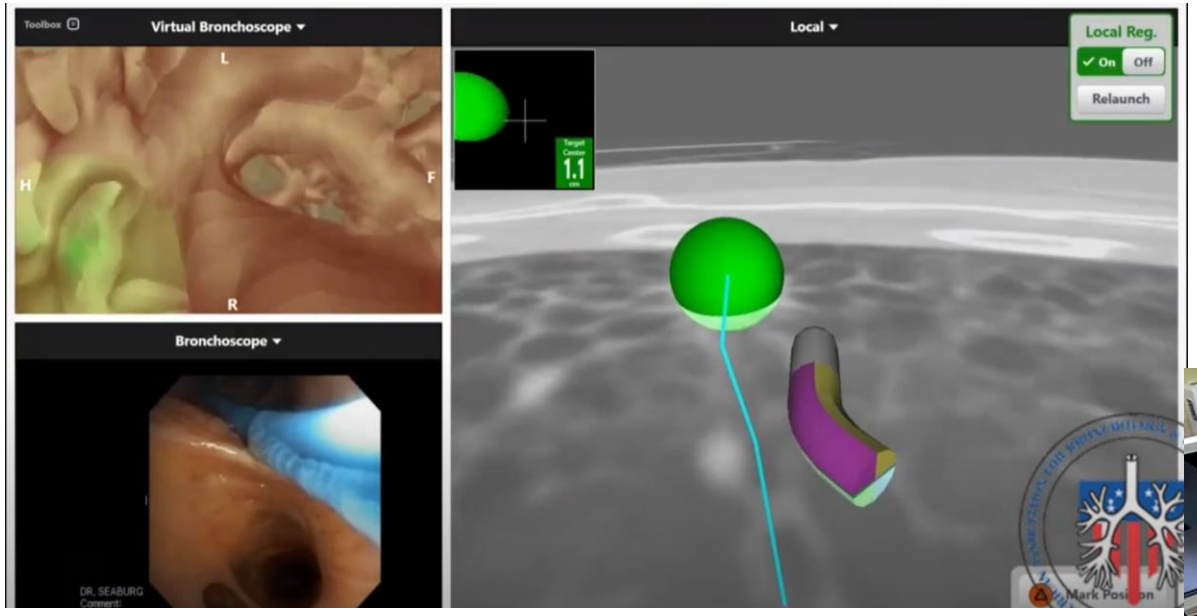
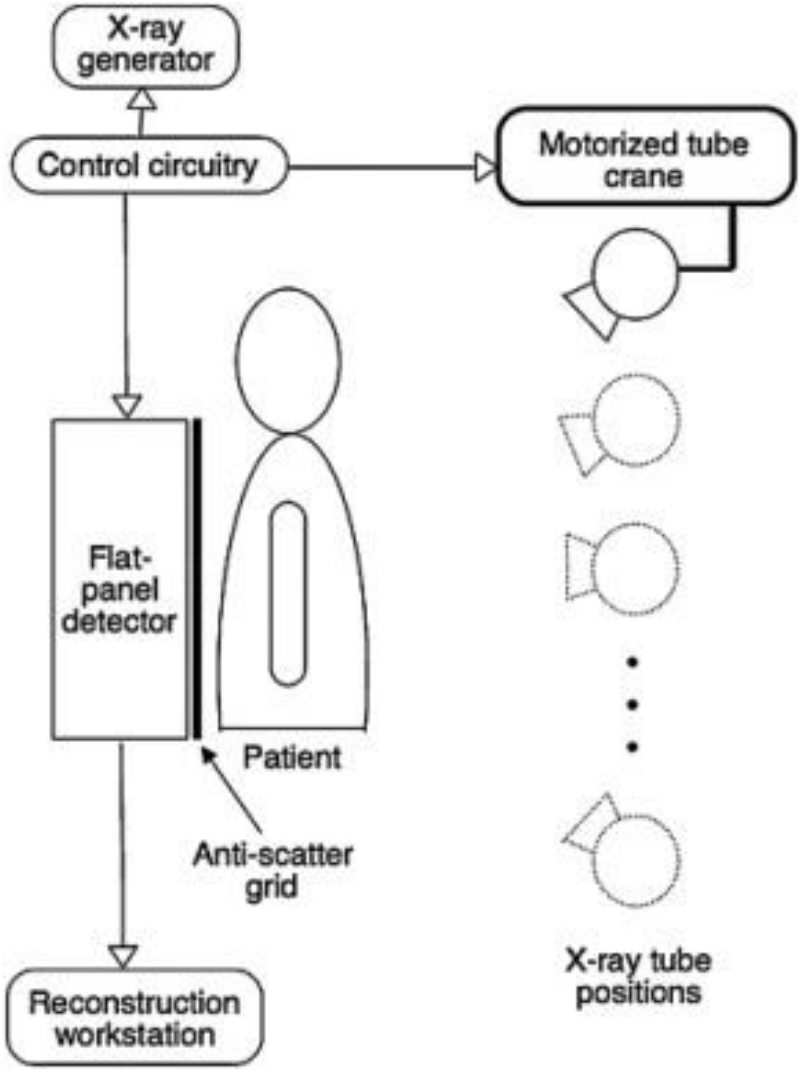
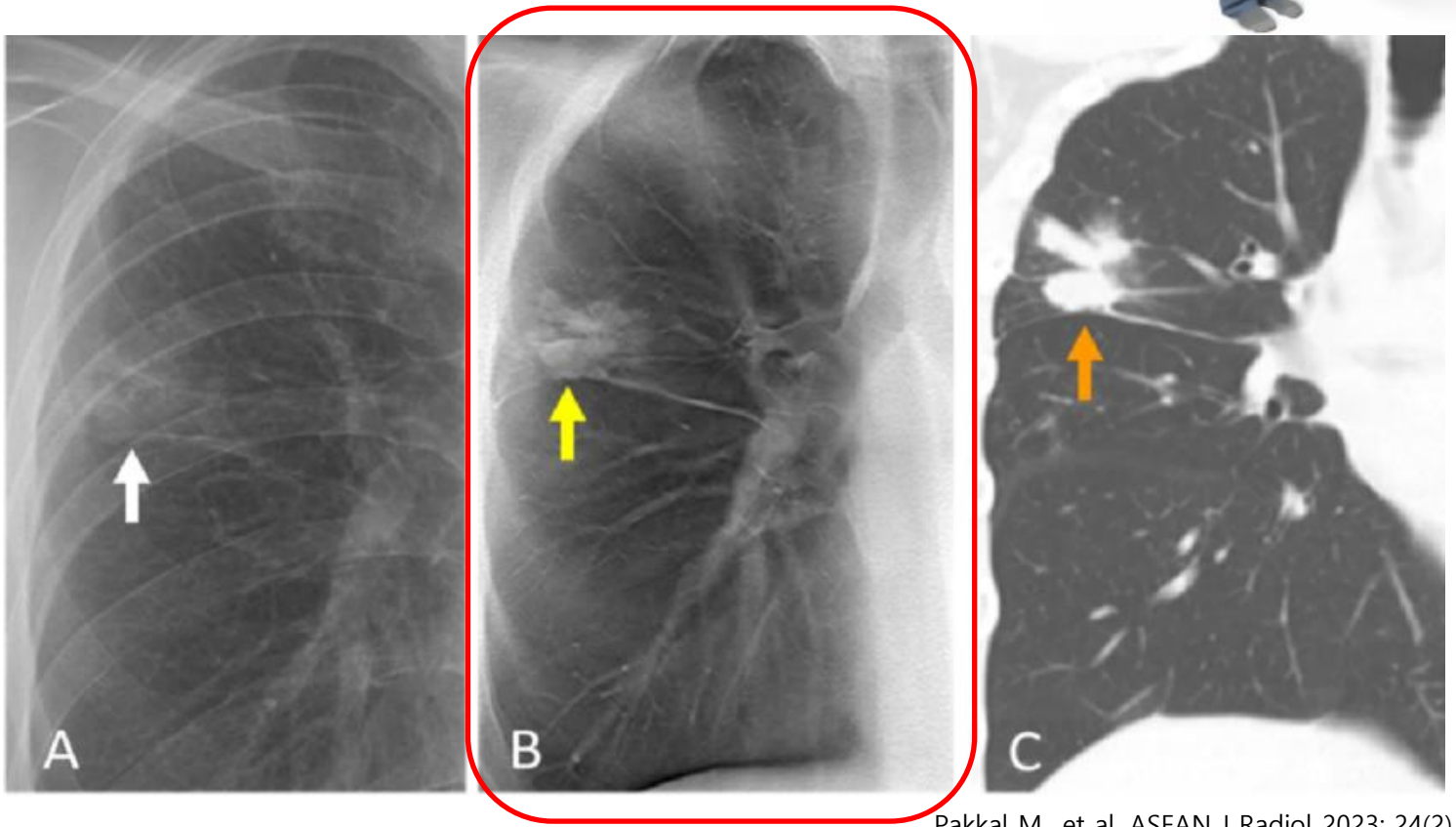
Digital Tomosynthesis-assisted fluoroscopic Electromagnetic navigational bronchoscopy (DT-ENB) Illumisite™



Digital Tomosynthesis of the Chest





Pakkal M., et al. ASEAN J Radiol 2023; 24(2) : 180-198

Digital Tomosynthesis-assisted fluoroscopic Electromagnetic navigational bronchoscopy (DT-ENB) Illumisite™

- the virtual pathway from the preprocedural CT imaging

- Once the bronchoscope reaches the nodule, local registration using Digital Tomosynthesis(DT) is performed to address CT to body divergence

- The software can accommodate conventional C-arm hardware which made the device easily adopted

Respirology. 2020 Feb;25(2):206-213. doi: 10.1111/resp.13609. Epub 2019 Jul 2.

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Improved diagnostic yield for lung nodules with digital tomosynthesis-corrected navigational bronchoscopy: Initial experience with a novel adjunct

Matt Aboudara [1], Lance Roller [1], Otis Rickman [1], Robert J Lentz [1], Jasleen Pannu [2], Heidi Chen [3], Fabien Maldonado [1]

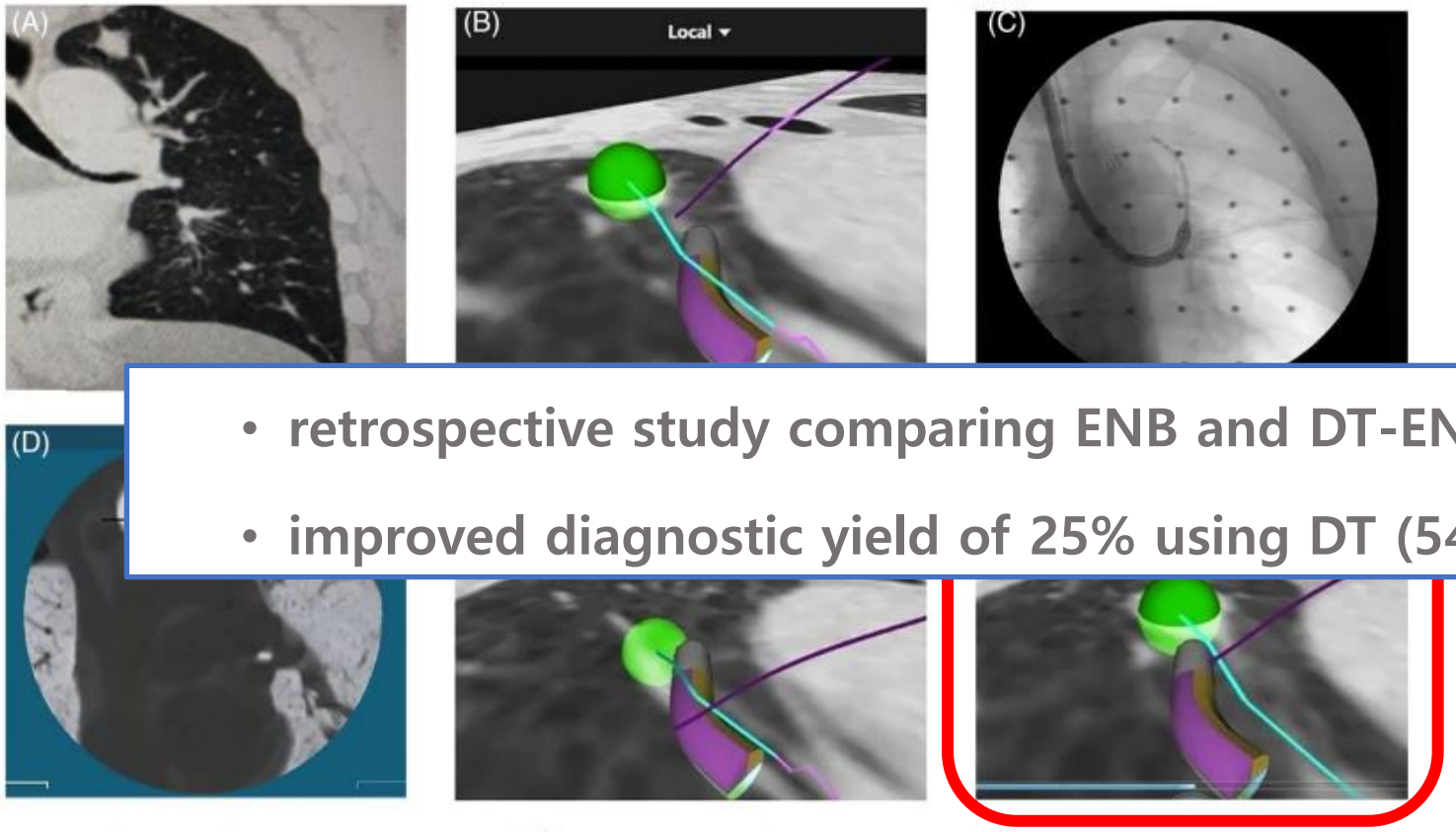

Figure 1 Correction for divergence with F-ENB. (A) Small, peripheral left upper lobe nodule. (B) Navigation to nodule based on original pre-procedure planning. Green ball is target nodule. (C) Fluoroscopic image showing EWC with locatable guide before fluoroscopy sweep. (D) Previously invisible nodule is now visible following a fluoroscopy sweep (arrow). (E) Corrected intra-procedural position of target nodule. Note lack of central target alignment between EWC and nodule. (F) EWC position has been corrected and central target alignment has been achieved. EWC, extended working channel; F-ENB, fluoroscopic electromagnetic navigation bronchoscopy.

- retrospective study comparing ENB and DT-ENB
- improved diagnostic yield of 25% using DT (54% ENB vs 79% DT-ENB)

Table 1 Demographic data and diagnostic yield

Variable	S-ENB (n = 101†)	F-ENB (n = 67†)	P-value
Number of patients, n	90	59	
Patient demographics			
Sex			0.06
Male, n (%)	38 (41.2)	16 (27.1)	
Female, n (%)	52 (57.7)	43 (72.8)	
Age, mean (SD)	64.4 (11.8)	62.2 (11.33)	0.25
Smoking status			
Current, n (%)	14 (15.3)	10 (1.7)	0.05
Former, n (%)	54 (60)	31 (52.5)	
Size of nodule			
Overall size, mm, median (IQR)	15 (12–24)	16 (12–24)	0.56
<20 mm, n (%)	64 (63.3)	43 (64.1)	
Median size, mm (IQR)	13 (11–15)	14 (11–16)	0.74
≥20 mm, n (%)	37 (36.6)	24 (35.8)	
Median size, mm (IQR)	28 (23–38)	30 (23–35)	0.33
Diagnostic yield, total n (%)	55 (54.4)	53 (79.1)	0.0019
Malignant, n (%)	39 (38.6)	36 (53.7)	0.07
Benign, n (%)	16 (15.8)	17 (25.3)	0.84

Digital Tomosynthesis-assisted fluoroscopic Electromagnetic navigational bronchoscopy (DT-ENB) Illumisite™

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Chest. 2023 Apr;163(4):977-984. doi: 10.1016/j.chest.2022.10.019. Epub 2022 Oct 29.

Shape-Sensing Robotic-Assisted Bronchoscopy vs Digital Tomosynthesis-Corrected Electromagnetic Navigation Bronchoscopy: A Comparative Cohort Study of Diagnostic Performance

See-Wei Low [1], Robert J Lentz [1], Heidi Chen [2], James Katsis [3], Matthew C Aboudara [4], Samuel Whatley [1], Rafael Paez [1], Otis B Rickman [1], Fabien Maldonado [5]

TABLE 3] Diagnostic Findings for DT-ENB and ssRAB Cohorts

Diagnostic Finding	DT-ENB (n = 197)	ssRAB (n = 143)
Diagnostic or lesional biopsy	158 (80)	110 (77)
Malignant	107 (54.3)	78 (54.5)
Specific benign diagnosis	51 (25.9)[a]	32 (22.4)
Nonspecific diagnosis	39 (19.8)	33 (23.1)
Malignant		
NSCLC adenocarcinoma	52 (48.6)	40 (51.3)
NSCLC squamous	18 (16.8)	10 (12.8)
NSCLC NOS	9 (8.4)	4 (5.1)
Small cell carcinoma	5 (4.7)	1 (1.3)
Carcinoid	3 (2.8)	4 (5.1)
Metastasis	13 (12.2)	18 (23.1)
Lymphoma	3 (2.8)	1 (1.3)
Poorly differentiated	3 (2.8)	. . .

- the diagnostic yield of Digital Tomosynthesis-assisted fluoroscopic Electromagnetic navigational bronchoscopy (DT-ENB) and shape sensing RAB (ssRAB).
- Both showed comparative diagnostic yield (DT-ENB 80% VS. ssRAB 77%)

NSCLC = non-

T-ENB cases).

with atypical

stromal cells consistent with radiation effect (n = 1), and hamartoma (n = 2). Additional specific benign diagnoses established by ssRAB: pericardial cyst (n = 1), organizing fibrin with atypical stromal cells consistent with radiation effect (n = 1) and hamartoma (n = 2).

Current evidence of DT-ENB

Table 1. Summary of studies of digital tomosynthesis with electromagnetic navigation bronchoscopy for peripheral pulmonary nodules.

Author (year)	Study design	Number of patients	Size of nodule	Sensitivity of malignancy	Diagnostic yield
Aboudara et al. (2019)	Retrospective comparative	59	16 mm (median)	–	79.1% (immediate)
Katsis et al. (2021)	Retrospective	324	19 mm (mean)	–	77.4% (at 6 months)
Katsis et al. (2021)	Prospective observational	29	13 mm (mean)	–	72.4% (tool in lesion)
Avasarala et al. (2022)	Prospective observational	100	20 mm (median)	71%	79% (immediate)
Low et al. (2023)	Retrospective comparative	170	19 mm (median)	–	80% (immediate)

Abdelghani R, Omballi M, Abia-Trujillo D, Casillas E Jr, Villalobos R, Badar F, Bansal S, Kheir F. Imaging modalities during navigational bronchoscopy. Expert Rev Respir Med. 2024 Mar-Apr;18(3-4):175-188.

Augmented Fluoroscopy (LungVision™)

J Bronchol Interv Pulmonol • Volume 28, Number 2, April 2021 Novel Navigation for Augmented Fluoroscopy

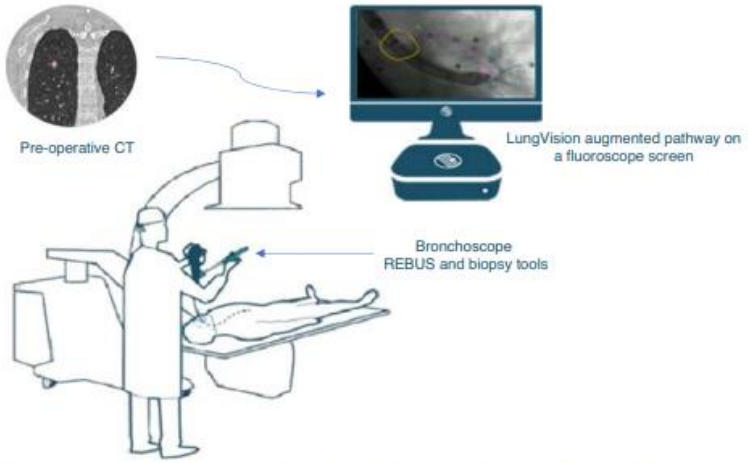
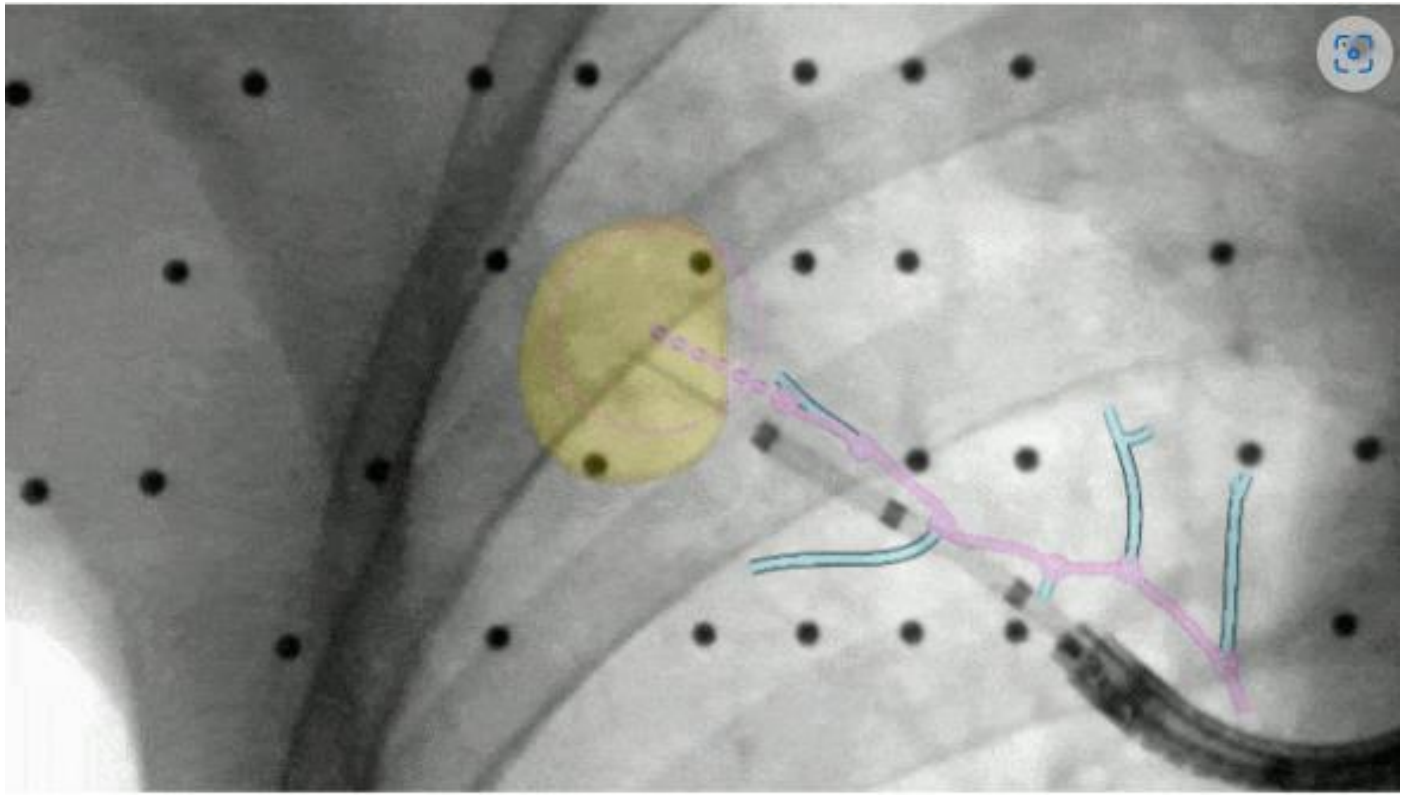


FIGURE 1. LungVision Platform. The platform integrates with available endobronchial modalities including bronchoscope, fluoroscope, and radial endobronchial ultrasound (REBUS) to present an augmented real-time pathway to a suspicious lung nodule. CT indicates computed tomography.



Cicenia J, Bhadra K, Sethi S, Nader DA, Whitten P, Hogarth DK. Augmented Fluoroscopy: A New and Novel Navigation Platform for Peripheral Bronchoscopy. J Bronchology Interv Pulmonol. 2021 Apr 1;28(2):116-123.

Augmented Fluoroscopy (LungVision™)

- system providing real time augmented fluoroscopic navigation and tool-in-lesion confirmation.

- Using the same principles of DT imaging, the system uses proprietary artificial intelligence in combination with conventional mobile C-arm X-ray system

Augmented Fluoroscopy (LungVisionTM)

Multicenter Study > J Bronchology Interv Pulmonol. 2021 Apr 1;28(2):116-123.
doi: 10.1097/LBR.0000000000000722.

Augmented Fluoroscopy: A New and Novel Navigation Platform for Peripheral Bronchoscopy

Joseph Cicenia [1], Krish Bhadra [2], Sonali Sethi [1], Daniel A Nader [3], Patrick Whitten [4], Douglas Kyle Hogarth [5]

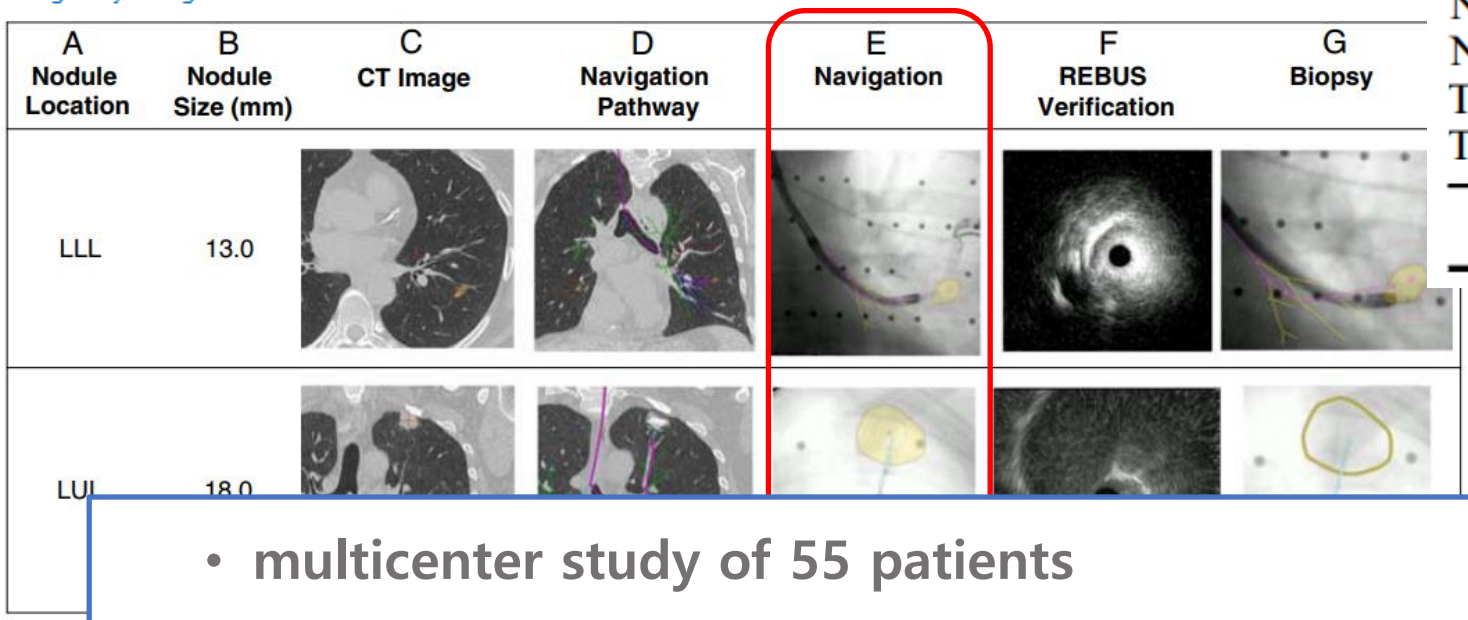


TABLE 2. Total Localization Success Verified With REBUS and Diagnostic Yield

	n (%)
No. patients	55 (100)
No. navigations	57 (100)
Total number of nodules localized	53 (93)
Total diagnostic yield	43 (75.4)

REBUS indicates radial endobronchial ultrasound.

- multicenter study of 55 patients
- a nodule localization success rate at 93% with an overall diagnostic yield of 75.4%

FIGURE 4
computed
screen, shown in purple, the nodule was marked in yellow (D). The physician navigated with a steerable catheter through the working channel of the bronchoscope to the nodule with real-time augmented visualization of the nodule (E). Once the catheter reached the proposed PN location, localization was confirmed by a radial endobronchial ultrasound (REBUS) (F) and then a biopsy was collected under real-time guidance (G).

Cicenia J, Bhadra K, Sethi S, Nader DA, Whitten P, Hogarth DK. Augmented Fluoroscopy: A New and Novel Navigation Platform for Peripheral Bronchoscopy. Bronchology Interv Pulmonol. 2021 Apr 1;28(2):116-123.

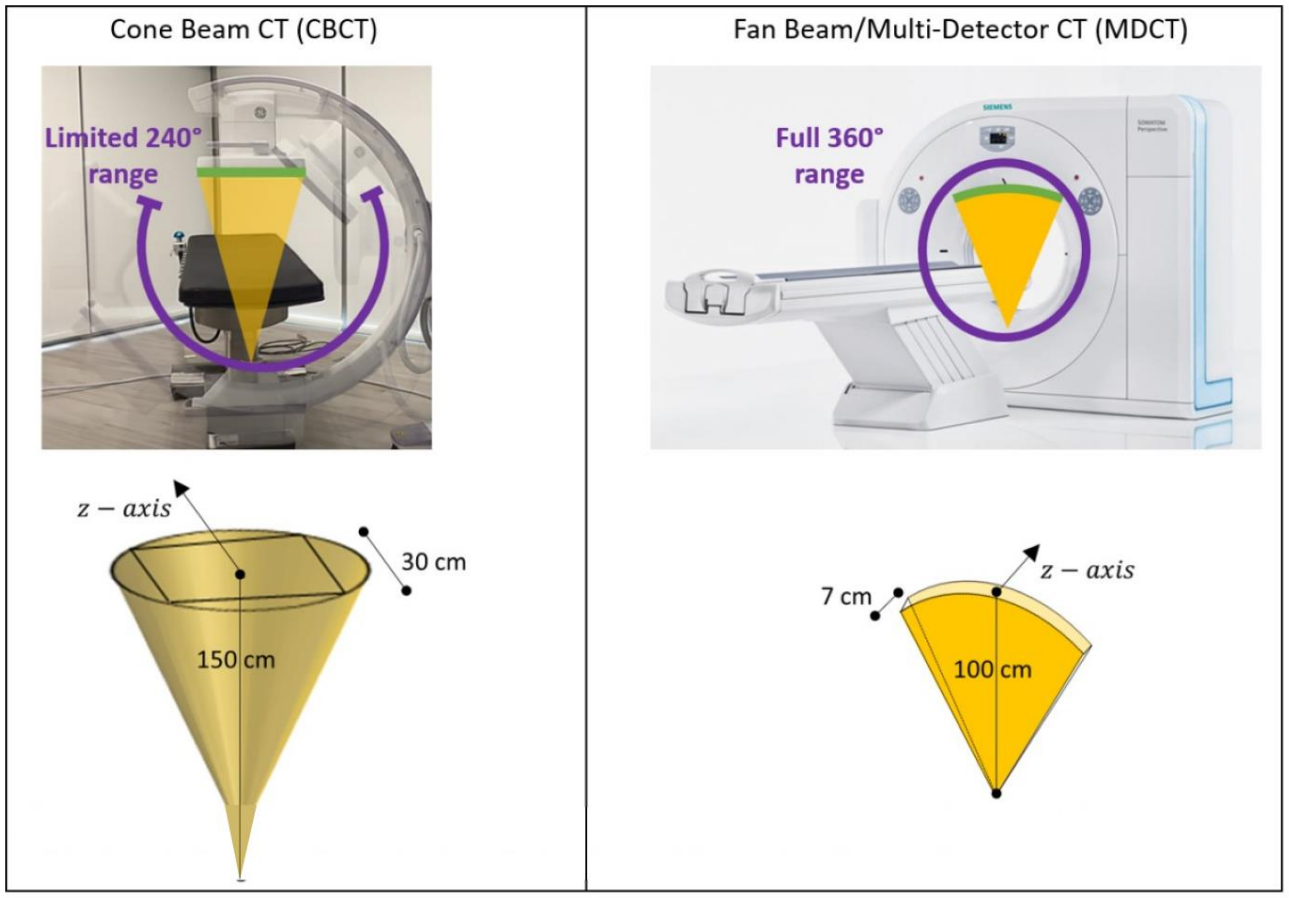
Current evidence of Augmented Fluoroscopy (LungVision™)

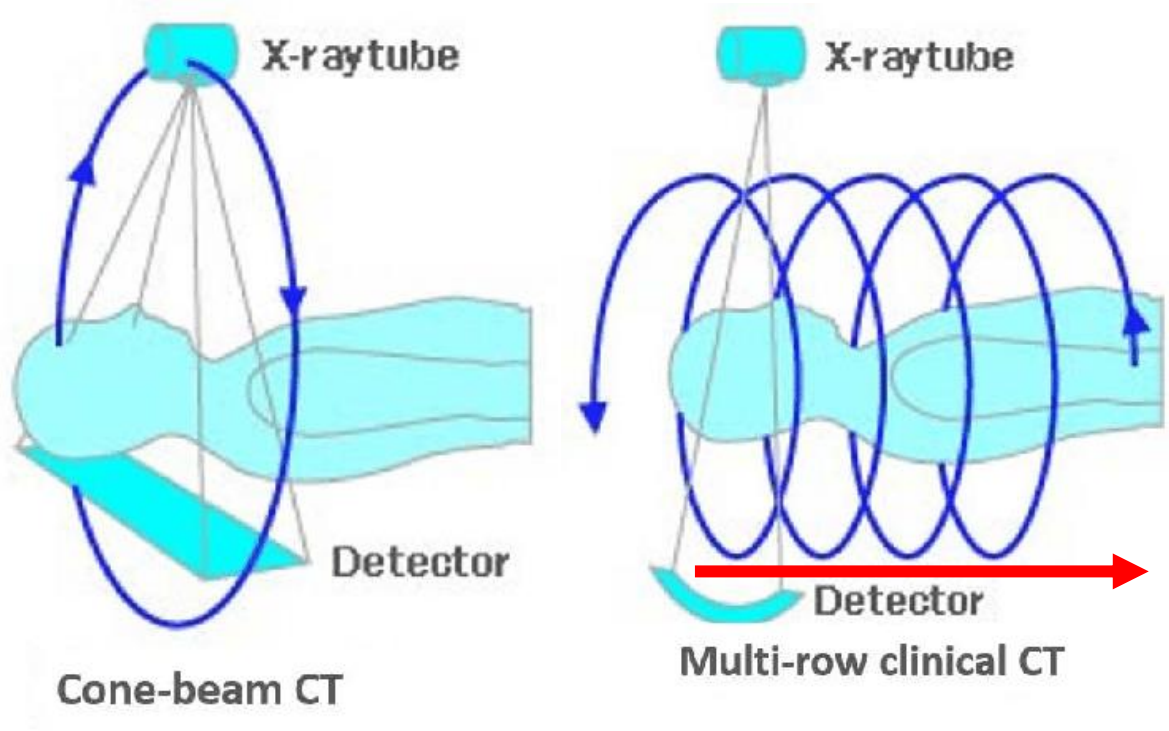
Table 2. Summary of studies of digital tomosynthesis body vision for peripheral pulmonary nodules.

Author (year)	Study design	Number of patients	Size of nodule	Sensitivity of malignancy	Diagnostic yield
Pritchett et al. (2021)	Prospective observational	51	18 mm (median)	86.7%	78.4%(immediate) 87.7% (at 12 months)
Cicenia et al. (2021)	Prospective observational	55	20 mm (median)	–	75.4% (immediate)
Pertzov et al. (2021)	Prospective observational	63	25 mm (median)	–	77.8%(immediate)

Abdelghani R, Omballi M, Abia-Trujillo D, Casillas E Jr, Villalobos R, Badar F, Bansal S, Kheir F. Imaging modalities during navigational bronchoscopy. Expert Rev Respir Med. 2024 Mar-Apr;18(3-4):175-188.

Cone-Beam computed tomography





https://perswww.kuleuven.be/~u0015224/publications/TaoSun_PhDthesis.pdf

Cone-Beam computed tomography : Fixed CBCT-AF and Mobile CBCT

https://www.siemens-healthineers.com/

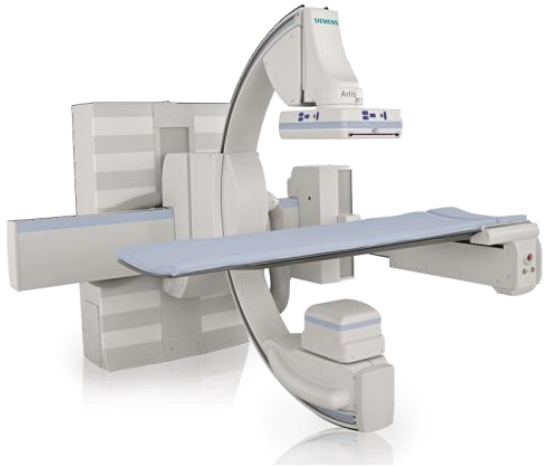
Fixed CBCT-AF

Bi - Plane

Biplane

Single - Plane

Ceiling-mounted



Multi-purpose

Floor-mounted

Fixed CBCT-AF

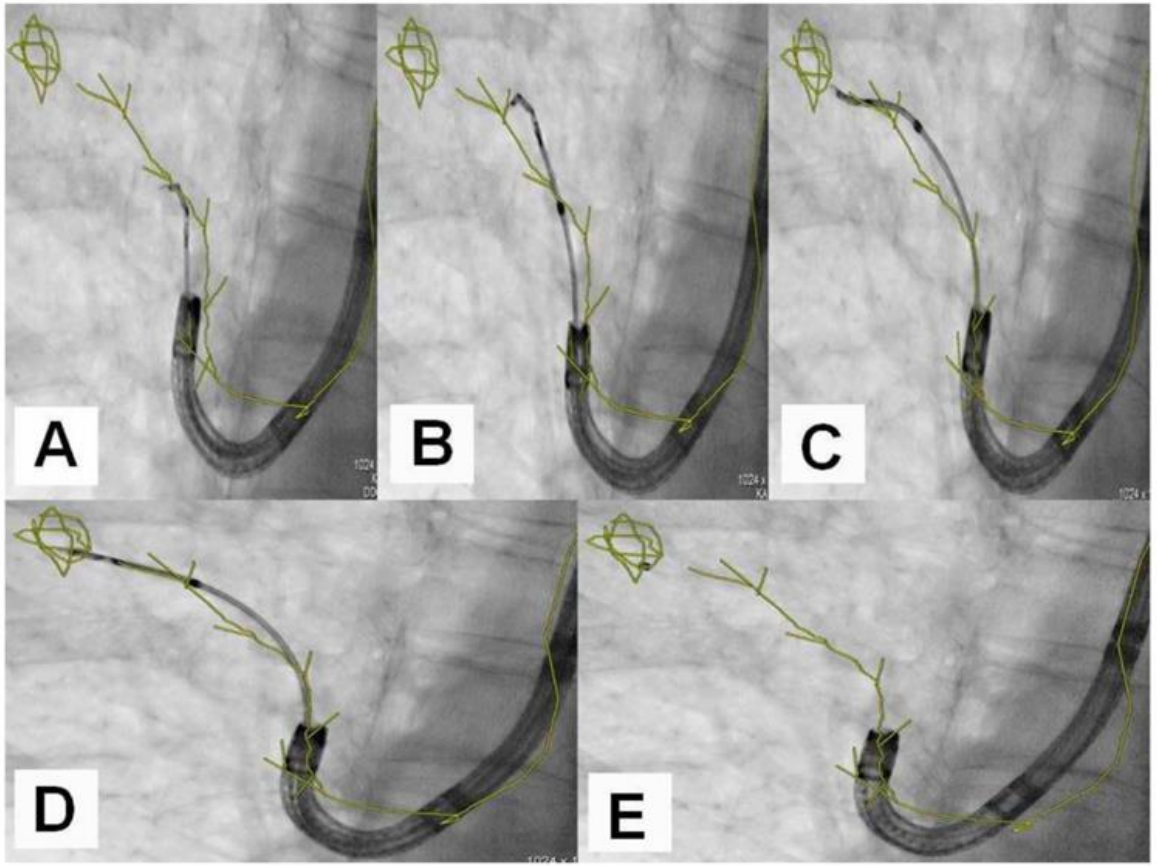


Figure 4. An example of navigation up to a SPN after the 8th segmentation (counted from the main carina).

Figure 6. CBCT (Philips Healthcare) imaging during Monarch® Robotic Bronchoscopy with real-time location of the lesion in blue. Reprinted with permission from AME publishing company [21].

Ravikumar, N.; Ho, E.; Wagh, A.; Murgu, S. Advanced Imaging for Robotic Bronchoscopy: A Review. Diagnostics 2023, 13, 990Ravikumar, N.; Ho, E.; Wagh, A.; Murgu, S. Advanced Imaging for Robotic Bronchoscopy: A Review. Diagnostics 2023, 13, 990

Fixed CBCT-AF

- Highlight target lesions using augmented fluoroscopy
- Two dimensional digital panel detector that receives X-rays in a cone-shaped distribution from the X-ray source.
- Captures images throughout the 5-10 second CBCT spin
- Spin is acquired during an inspiratory breath hold to decrease respiratory motion artifact.
- CBCT platforms employ augmented fluoroscopy

Current evidence of Fixed CBCT-AF

Table 5. Summary of studies of fixed cone-beam computed tomography for peripheral pulmonary nodules.

Study	Design	N	Lesion Size	Technology	Navigational platform	Navigational success	Diagnostic yield	Diagnostic yield definition	Radiation dose
Hohenforst-Schmidt et al. (2014)	Prospective	33	25 mm	Siemens (DynaCT) CBCT-AF	Bronchoscopy with Guide Sheath	91%	70%	Not specified	<2mSV
Park et al. (2017)	Retrospective	59	31 mm	Siemens (Artis Zee)	Flexible Bronchoscope	72.9%	71.2%	Immediate	N/A
Bowling et al. (2017)	Retrospective	14	23 mm	Siemens, (Artis Zeego) CBCT-AF	superDimension	N/A	71%	Up to 6-month follow-up	4.3 mSV
Pritchett et al. (2018)	Retrospective	93	16 mm	Philips (Allura Xper) CBCT-AF	superDimension	N/A	83.7%	Immediate	3 mSV
Sobieszczyk et al. (2018)	Retrospective	22	21 mm	N/A	superDimension	N/A	77.2%	Up to 6-month follow-up	N/A
Casal et al. (2018)	Prospective	20	21 mm	Siemens (Artis dTA)	Thin/Ultrathin Flexible Bronchoscope	75%	70	Up to 6-month follow-up	64.6 Gycm^2
Ali et al. (2019)	Prospective	40	20 mm	Siemens (Artis Zeego)	Ultrathin Bronchoscope	90%	90%	Up to 6-month follow-up	N/A
Kheir et al. (2021)	Retrospective	31	16 mm	Siemens (Artis Zeego) CBCT-AF	ENB and ENB + CBCT	N/A	74.2%	Immediate	N/A
Benn et al. (2021)	Prospective	59	21.9 mm	N/A	Ion Endoluminal System	85%	86%	Up to 12-month follow-up	1.69 mSV
Verhoeven et al. (2021)	Prospective	107	16.6 mm	Philips (Allura), Siemens (Artis Zeego) CBCT-AF	superDimension and CBCT-AF + R-EBUS	76.3% (EMN + CBCT-AF)	70.2% (Diagnostic Accuracy)	At least 12-month follow-up	N/A
Yu et al. (2021)	Retrospective	53	28 mm	Siemens (Artis Zee) CBCT-AF	Flexible Bronchoscope and AF	N/A	75.5%	Up to 12-month follow-up	19.6 Gycm^2
Verhoeven et al. (2021)	Prospective	238	13 mm	Philips (Allura Clarity and Azurion)	superDimension + R-EBUS vs R-EBUS	92.3%	90% (Diagnostic Accuracy)	Up to 6-month follow-up	25.4 Gycm^2
Cumbo-Nacheli et al. (2022)	Retrospective	20	22 mm	N/A	Monarch Platform	100%	65%	Up to 12-month follow-up	N/A
Styrvoky et al. (2022)	Retrospective	209	22.6 mm	Philips (Allura Clarity)	Ion Endoluminal System	N/A	91.4% (Diagnostic Accuracy)	Up to 14 month follow-up	N/A
Bondue et al. (2023)	Prospective	25	16.6 mm	Philips (Allura Clarity)	superDimension, CBCT-AF	92%	80%	At least 12-month follow-up	5.6 mSV
Abdelghani et al. (2023)	Retrospective	111	12 mm	Philips (Allura Clarity)	Ion Endoluminal System	83% (Tool within center of Lesion)	94.6%	Up to 12-month follow-up	2.97 mSV
Pritchett et al. (2023)	Prospective	58	19 mm	Philips (Allura)	CBCT-guided Navigation	98.3%	87.9%	Up to 24-month follow-up	56 Gycm^2
DiBardino et al. (2023)	Retrospective	30	19.5 mm	Siemens (Artis Zeego)	Ultrathin Bronchoscope and AF	N/A	85%	Up to 24-month follow-up	11.97 mSV
Huang et al. (2024)	Retrospective	32	15.8 mm	GE Discovery IGS 730	VBN and SuperDimension	N/A	71.9%	Immediate	N/A

CBCT, cone-beam computed tomography, AF. Augmented Fluoroscopy: CBCT-AF, cone-beam computed tomography scan with augmented fluoroscopy; R-EBUS, radial-probe endobronchial ultrasound.

Abdelghani R, Omballi M, Abia-Trujillo D, Casillas E Jr, Villalobos R, Badar F, Bansal S, Kheir F. Imaging modalities during navigational bronchoscopy. Expert Rev Respir Med. 2024 Mar-Apr;18(3-4):175-188.

Fixed CBCT-AF

Lung. 2022 Dec;200(6):755-761. doi: 10.1007/s00408-022-00590-7. Epub 2022 Nov 11.

Shape-Sensing Robotic-Assisted Bronchoscopy with Concurrent use of Radial Endobronchial Ultrasound and Cone Beam Computed Tomography in the Evaluation of Pulmonary Lesions

Kim Styrvoky [1], Audra Schwalk [2], David Pham [2], Hsienchang T Chiu [2], Anastasiia Rudkovskaia [2], Kristine Madsen [3], Stephen Carrio [4], Elizabeth M Kurian [5], Luis De Las Casas [5], Muhanned Abu-Hijleh [2]

Diagnostic test outcomes (disease prevalence of malignancy 64.1%)

Statistic	Value (%)	95% CI
Positive likelihood ratio	65.5	9.3 to 459.3
Negative likelihood ratio	0.13	0.08 to 0.20
Positive predictive value	99.2	94.3% to 99.9%
Negative predictive value	81.3	73.6% to 87.2%

- diagnostic accuracy of 91.04% in a cohort of 209 lung lesions

J Bronchology Interv Pulmonol. 2022 Oct 1;29(4):303-306. doi: 10.1097/LBR.0000000000000860. Epub 2022 Aug 2.

Robotic-assisted Bronchoscopy and Cone-beam CT: A Retrospective Series

Gustavo Cumbo-Nacheli [1], Ravi K Velagapudi, Mark Enter, John P Egan 3rd, Diego Conci

Affiliations – collapse

Affiliation

[1] Spectrum Health, Michigan State University School of Human Medicine, Grand Rapids, MI.

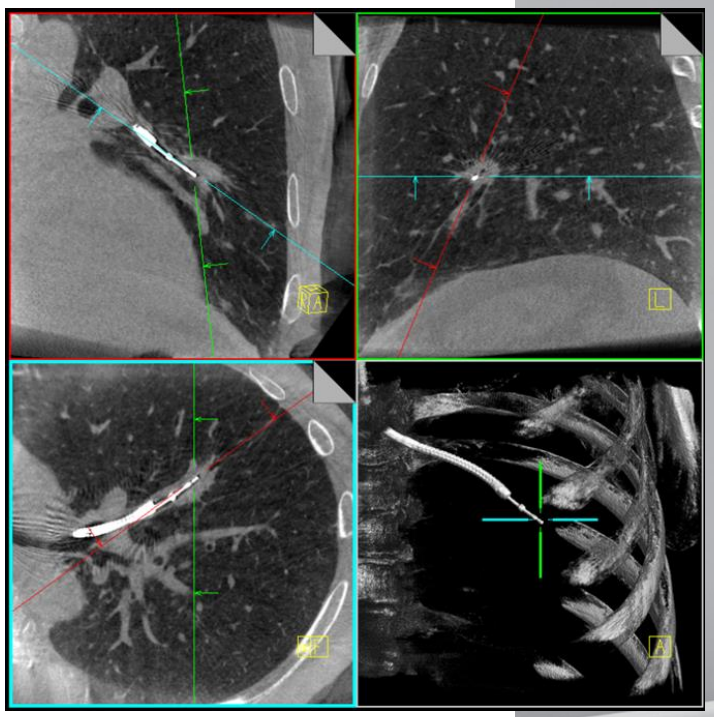
TABLE 2. Histopathologic Results of the Patients Who Underwent RAB With CBCT-guided Biopsies

Reactive cells	1/20
Nondiagnostic	4/20*
Atypical cells	1/20†
Non-necrotizing granulomatous inflammation	1/20

*One of these biopsies was a false negative with a positive finding for malignancy at 3 months' follow-up.
†Positive for malignancy on linear endobronchial ultrasound biopsies.
CBCT indicates cone-beam computed tomography; RAB, robotic-assisted bronchoscopy.

- 100% tool-in-lesion confirmation and an 86.6% sensitivity for malignancy

Mobile CBCT



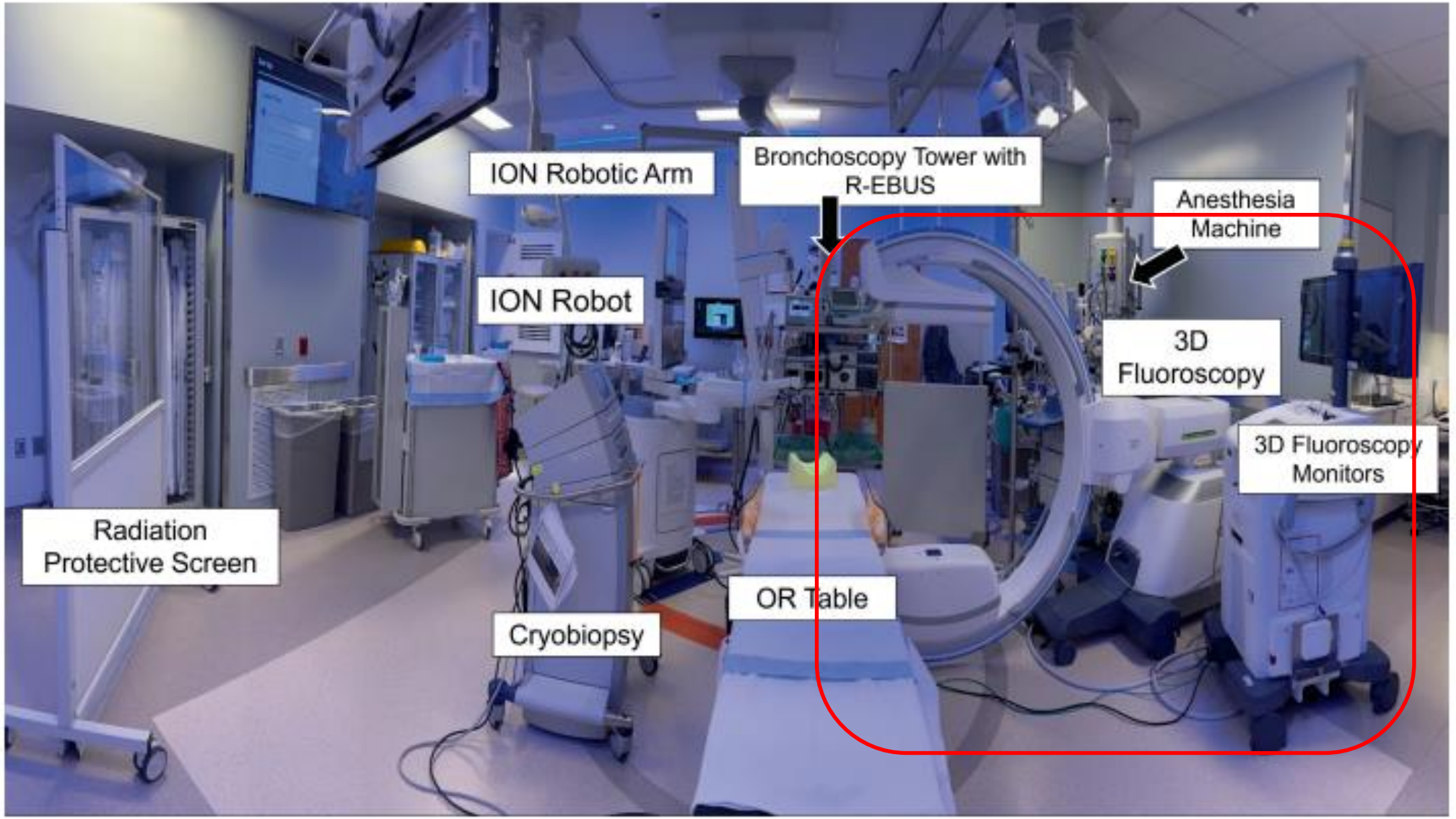


FIGURE 2 Bronchoscopy room set-up of Site 1 including shape-sensing robotic-assisted bronchoscopy, mobile cone-beam computed tomography and cryoprobe.

Abia-Trujillo D, Folch EE, Yu Lee-Mateus A, Balasubramanian P, Kheir F, Keyes CM, Villalobos R, Chadha RM, Hazelett BN, Fernandez-Bussy S. Mobile cone-beam computed tomography complementing shape-sensing robotic-assisted bronchoscopy in the small pulmonary nodule sampling: A multicentre experience. Respirology. 2024 Apr;29(4):324-332

Mobile CBCT with ssRAB

Mayo Clin Proc Innov Qual Outcomes. 2022 Apr 23;6(3):177-185.
doi: 10.1016/j.mayocpiqo.2022.02.004. eCollection 2022 Jun.

Combining Shape-Sensing Robotic Bronchoscopy With Mobile Three-Dimensional Imaging to Verify Tool-in-Lesion and Overcome Divergence: A Pilot Study

Janani Reisenauer [1] [2], Jennifer D Duke [2], Ryan Kern [2], Sebastian Fernandez-Bussy [3], Eric Edell [2]

TABLE 3. Results of Biopsy and Diagnostic Yield On the Basis of Nodule Characteristics[a]

Malignancy	N	Infection	N	Inflammation	N
Squamous cell	4	Chronic necrotizing aspergillosis	1	Organizing pneumonia	2
Metastatic leiomyosarcoma	1			Granuloma	2
Metastatic adenocarcinoma, not primary lung	2			Focal interstitial fibrosis	1
Carcinoid	1				
Adenocarcinoma, lung primary	8				
Non-small-cell	4				
Small-cell	2				
Total	22 (73.3)	Total	1 (3.6)	Total	5 (17.9)

stic yield[b]

- the CIOS 3D Mobile Spin system in conjunction with the Ion Endoluminal System
- the tool in lesion was achieved in 96.7%
- diagnostic yield of 93%,
- overall sensitivity for malignancy of 91%

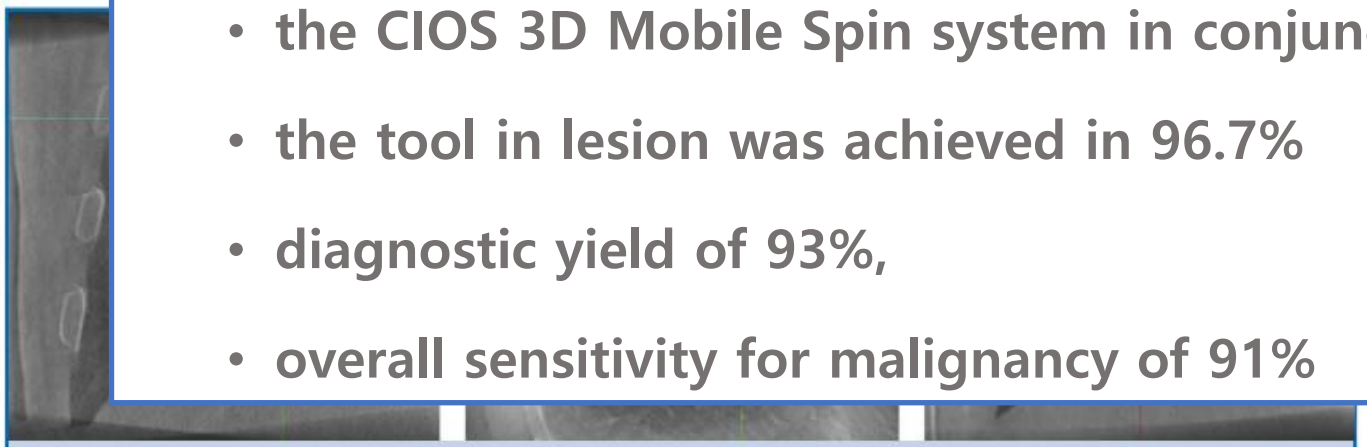


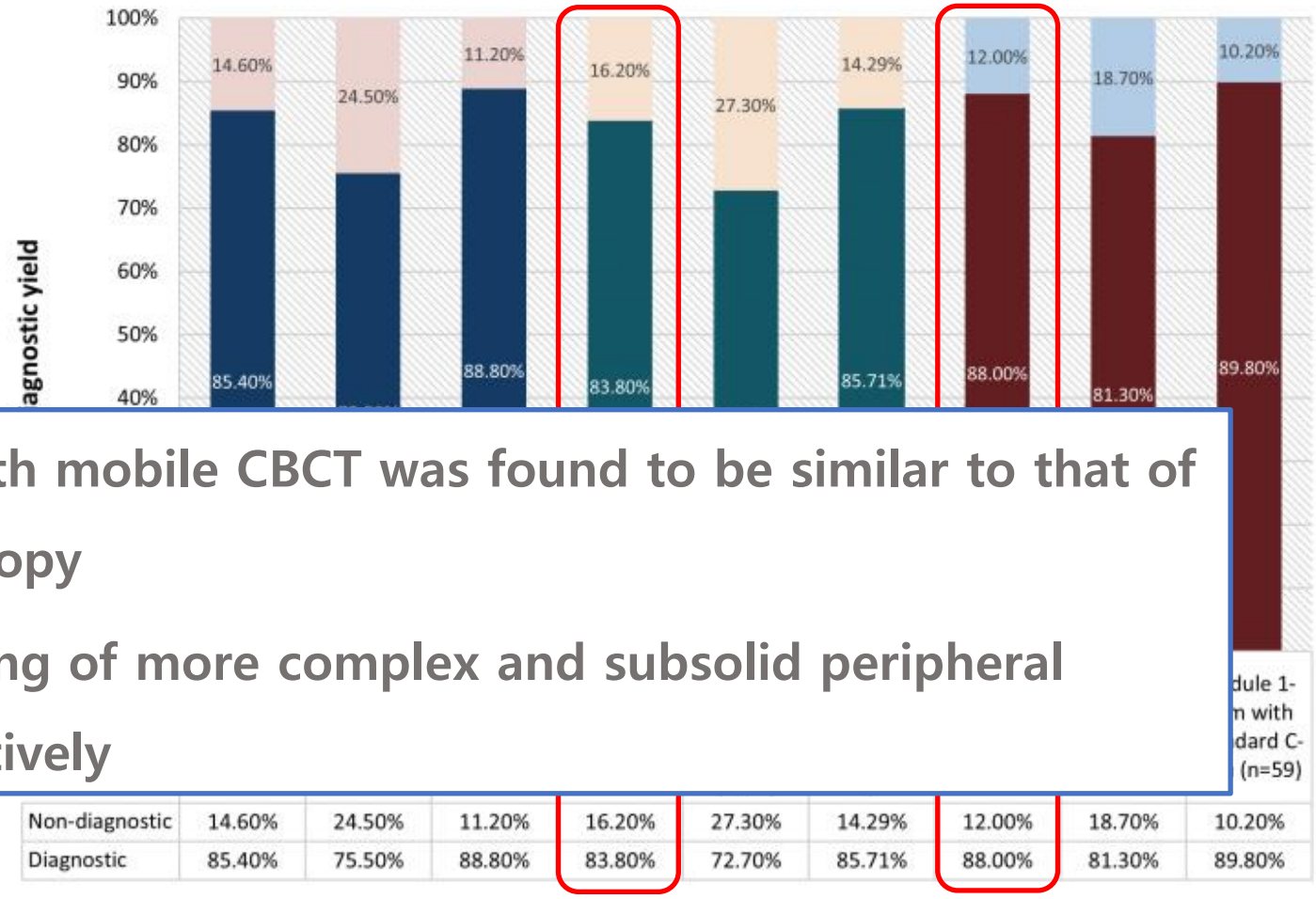
FIGURE 2. Intraprocedural cone-beam computed tomography scan with measurements in 3 axes demonstrating tool-in-lesion.

Mobile CBCT with ssRAB

Multicenter Study > Respirology. 2024 Apr;29(4):324-332. doi: 10.1111/resp.14626.
Epub 2023 Nov 28.

Mobile cone-beam computed tomography complementing shape-sensing robotic-assisted bronchoscopy in the small pulmonary nodule sampling: A multicentre experience

David Abia-Trujillo [1], Erik E Folch [2], Alejandra Yu Lee-Mateus [1], Prasanth Balasubramanian [3], Fayez Kheir [2], Colleen M Keyes [2], Regina Villalobos [2], Ryan M Chadha [4], Britney N Hazelett [1], Sebastian Fernandez-Bussy [1]



TABLE

- The diagnostic yield of ssRAB with mobile CBCT was found to be similar to that of ssRAB with standard 2D fluoroscopy
- mobile CBCT enabled the targeting of more complex and subsolid peripheral pulmonary nodules (PPNs) effectively

Non-diagnostic	14.60%	24.50%	11.20%	16.20%	27.30%	14.29%	12.00%	18.70%	10.20%
Diagnostic	85.40%	75.50%	88.80%	83.80%	72.70%	85.71%	88.00%	81.30%	89.80%

FIGURE 3 Diagnostic yield overall and by subgroups based on the use of mobile cone-beam computed tomography and nodule size.

Current evidence of Mobile CBCT

Table 4. Summary of studies of Cios for peripheral pulmonary nodules.

Author (year)	Study design	Number of patients	Size of nodule	Platform	Sensitivity of malignancy	Diagnostic yield
Avasarala et al. (2020)	Retrospective	8	26 mm (mean)	superDimension	–	100% (tool in lesion) 37.5% (immediate)
Reisenauer et al. (2022)	Prospective observational	30	17.5 mm (median)	Ion Endoluminal System	–	96.7% (tool in lesion) 93.3% (immediate)
Salahuddin et al. (2023)	Retrospective	51	26 mm (mean)	Thin/Ultrathin scope	77.4%	78.4% (immediate)
Abia-Trujilo et al. (2023)	Retrospective	105	12 mm (median)	Ion Endoluminal System	77.4%	83.8%(immediate)

CBCT with or without a robotic assisted bronchoscopy

Added Value of a Robotic-assisted Bronchoscopy Platform in Cone Beam Computed Tomography-guided Bronchoscopy for the Diagnosis of Pulmonary Parenchymal Lesions

Brian D. Shaller, MD, Duy K. Duong, DO,† Kai E. Swenson, MD,‡ Dwayne Free, RRT, RCP,§ and Harmeet Bedi, MD**

J Bronchol Intervent Pulmonol • Volume 31, Number 3, July 2024

- no significant differences in diagnostic yield (88% vs. 90% for RB-CBCT, P=0.822) or incidence of complications between the FB-CBCT and RB-CBCT.
- CBCT-guided bronchoscopy with or without a robotic assisted bronchoscopy platform is a safe and effective method for sampling PPLs
- the integration of a robotic-assisted plat form was associated with significantly shorter procedure times and significantly less radiation exposu

TABLE 3. Procedure Details

Variable	FB-CBCT (n = 100)	RB-CBCT (n = 100)	*P*
Navigation and access instruments	—	—	—
Robotic bronchoscope	—	100	—
Standard or slim bronchoscope	68	—	—
			—
			—
			—
			< 0.001
			0.003
			0.059
			—
			—
			—
			0.054
			< 0.001
			< 0.001
			< 0.001
			< 0.001
			0.170
			0.833
			—
			—
			—
			—
			—
			—

*In 2 RB-CBCT cases, a tool-in-lesion spin was performed but the result was not documented, and the CBCT images were no longer available for review.
†Other complications were one occurrence of pneumomediastinum without pneumothorax that was followed on an outpatient basis and resolved without intervention, and one occurrence of seizure with hemiplegia in the post-anesthesia care unit that was observed on an inpatient basis and resolved spontaneously.
EBUS indicates endobronchial ultrasound.

FIGURE 1. Cohort identification flow diagram. FB-CBCT indicates flexible bronchoscopy under CBCT guidance; RB-CBCT, robotic-assisted bronchoscopy under CBCT guidance.

Summary

- **CT-to-body divergence** occurs due to differences between **static** preprocedural CT scans and the **dynamic**, breathing lung during bronchoscopy.

- This divergence can lead to **inaccuracies in locating lesions**, which is critical for successful biopsies.

- To address this, several ancillary technologies have been developed
  - Digital Tomosynthesis-assisted fluoroscopic electromagnetic navigational bronchoscopy (F-ENB)
  - Augmented Fluoroscopy
  - Mobile Cone-Beam CT with Fluoroscopy or Augmented Fluoroscopy
  - Fixed Cone-Beam CT with Fluoroscopy or Augmented Fluoroscopy

Summary

- **Advanced fluoroscopic imaging modalities**
  - ENB : superDimension™ Navigation System
  - **Digital Tomosynthesis-assisted** fluoroscopic electromagnetic navigational bronchoscopy (DT-ENB) : ILLUMISITE™ Fluoroscopic Navigation Platform

  - ~~Fluoroscopy using Mobile C-Arm X-Ray System~~
  - **Augmented Fluoroscopy**
    - **LungVision**™ (Body Vision Medical Ltd., Ramat Ha Sharon, Israel)
  - **Cone-Beam CT** with Fluoroscopy or Augmented Fluoroscopy
    - **Fixed Cone-Beam CT with Augmented Fluoroscopy**
    - **Mobile Cone-Beam CT** : CIOS 3D Spin Mobile (Siemens Healthineers)

양산부산대학교병원
PUSAN NATIONAL UNIVERSITY YANGSAN HOSPITAL

Core message

- *Interventional pulmonologists must possess a comprehensive understanding of the characteristics, benefits, and limitations of diverse advanced fluoroscopic imaging modalities.*

- *Additionally, Interventional pulmonologists should be proficient in integrating these modalities with peripheral bronchoscopy or robotic-assisted bronchoscopy.*