Robotic Bronchoscopy:

A Review of Current Systems

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- **Emerging needs for approaching peripheral pulmonary lesions**
- **History of advanced image-guided bronchoscopy**
- **Robotic bronchoscopy: state-of-the-art**

Incidence of Incidentally Detected Nodules

- **Frequency of chest CT imaging and positive scans**

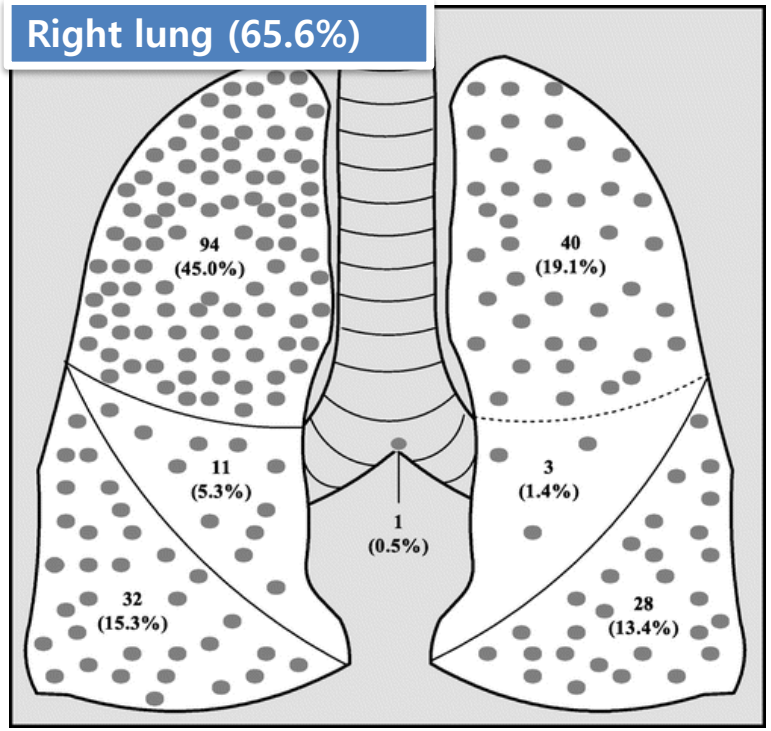
Year	Total Members (*N*)	Chest CT Scans Performed (*n*)	Positive Chest CT Scans [*n (% of Scans)*]	Time at Risk for Scanning* (*Person-Years*)	Chest CT Scans Performed† [*Rate per 1,000 Person-Years (95% CI)*]	Positive CT Scans† [*Rate per 1,000 Person-Years (95% CI)*]
2006	2,623,719	46,663	11,172 (23.9)	2,288,046	20.4 (20.2 –20.6)	4.9 (4.8–5.0)
2007	2,673,078	50,571	13,645 (27.0)	2,342,118	21.6 (21.4–21.8)	5.8 (5.7–5.9)
2008	2,672,351	55,264	15,171 (27.5)	2,369,685	23.3 (23.1–23.5)	6.4 (6.3–6.5)
2009	2,663,055	60,430	17,250 (28.5)	2,375,472	25.4 (25.2, 25.6)	7.3 (7.2–7.4)
2010	2,698,679	63,036	19,420 (30.8)	2,412,059	26.1 (25.9–26.3)	8.1 (7.9–8.2)
2011	2,822,145	68,411	20,346 (29.7)	2,540,580	26.9 (26.7–27.1)	8.0 (7.9–8.1)
2012	2,916,094	71,206	21,766 (30.6)	2,635,220	27.0 (26.8–27.2)	8.3 (8.2–8.4)
2006–2012 Total‡	19,069,121	415,581	118,770 (28.6)	16,963,179	24.5 (24.4–24.6)	7.0 (7.0–7.0)

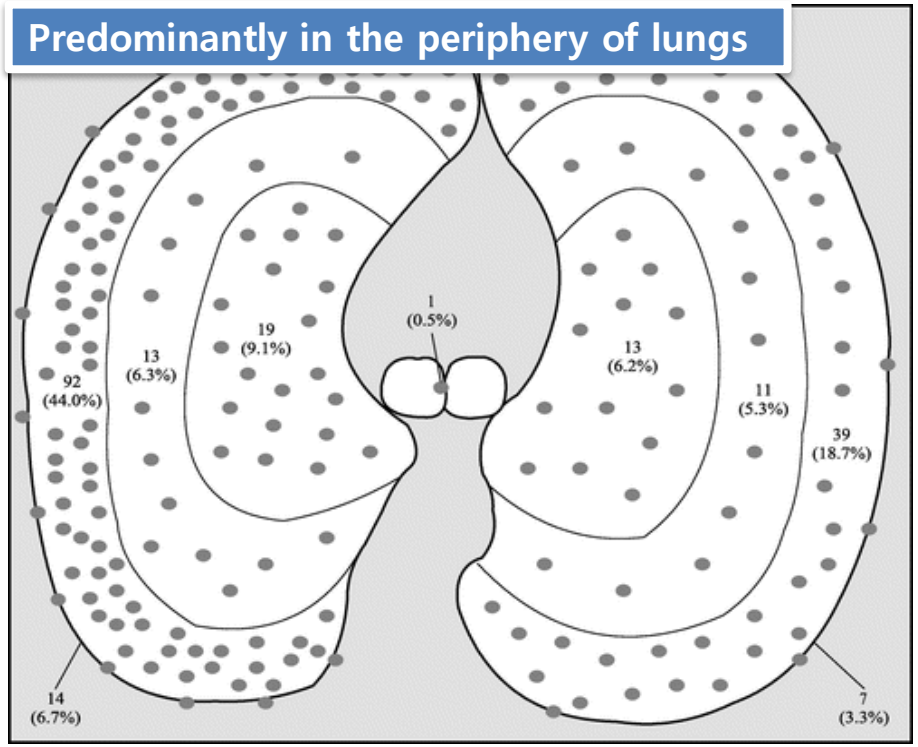
Gould et al. Am J Respir Crit Care Med. 2015

Wide Implementation of Lung Cancer Screening

- **Increasing early detection of peripheral lung cancer**

- Distribution of lung nodules detected from the NELSON trial





	Peripheral or pleural-attached	Central or middle one-third
Adenocarcinomas	82.2%	17.8%
Squamous cell carcinomas	62.9%	37.1%

Horeweg et al. AJRCCM. 2013.

Diagnostic Tissue Sampling for Pulmonary Nodules

- **Nonsurgical biopsy**
  - Transthoracic needle biopsy
  - Conventional bronchoscopy and EBUS -> **Not optimal for peripheral nodules**
  - Advanced image-guided bronchoscopy

- **Surgical biopsy**
  - Sublobar resection with VATS or RATS preferred

Sensitivity of flexible bronchoscopy for peripheral lung lesions

All Methods:		< 2 cm LESION				> 2 cm LESION			
First Author	Year	N	Pos	Neg	Sens	N	Pos	Neg	Sens
Gasparini[110]	1995	195	82	113	**42**	300	169	131	**56**
Hattori[76]	1971	17	13	4	**76**	182	150	32	**82**
Baaklini[88]	2000	16	4	12	**25**	135	93	42	**69**
Wallace[122]	1982	65	3	62	**5**	78	24	54	**31**
Bandoh[130]	2003	25	8	17	**32**	72	50	22	**69**
Radke[106]	1979	21	6	15	**29**	76	49	27	**64**
Naidich[121]	1988	15	4	11	**27**	46	26	20	**57**
Trkanjec[129]	2003	17	9	8	**53**	33	27	6	**82**
McDougall[105]	1981	9	1	8	**11**	36	21	15	**58**
Stringfield[107]	1977	3	1	2	**33**	26	13	13	**50**
Summary		383	131	252	**34**	984	622	362	**63**

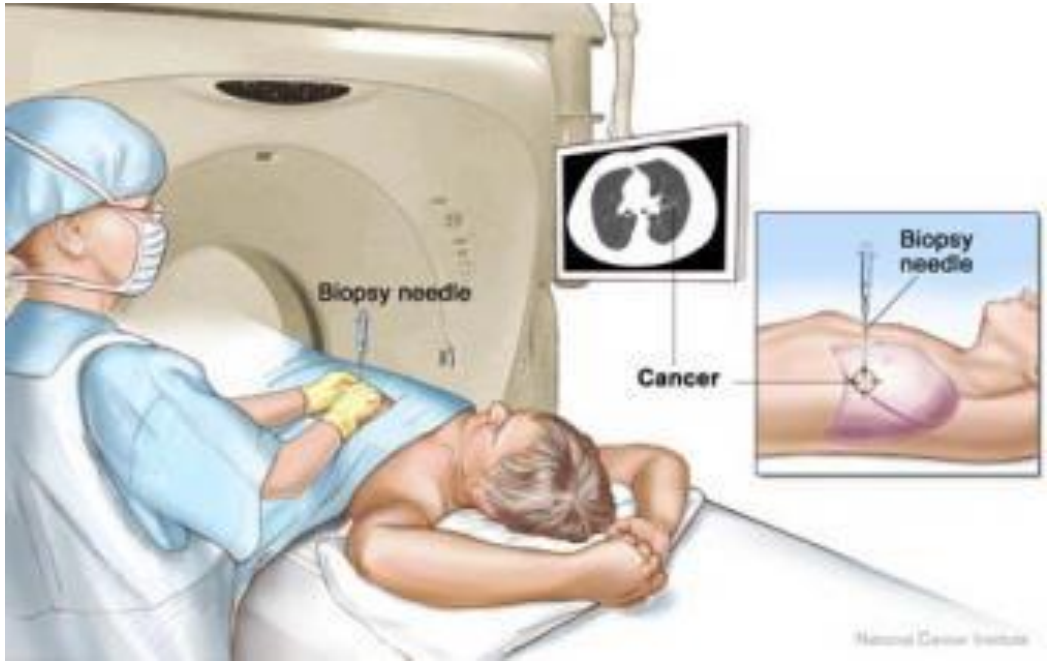
Rivera et al. Chest. 2013

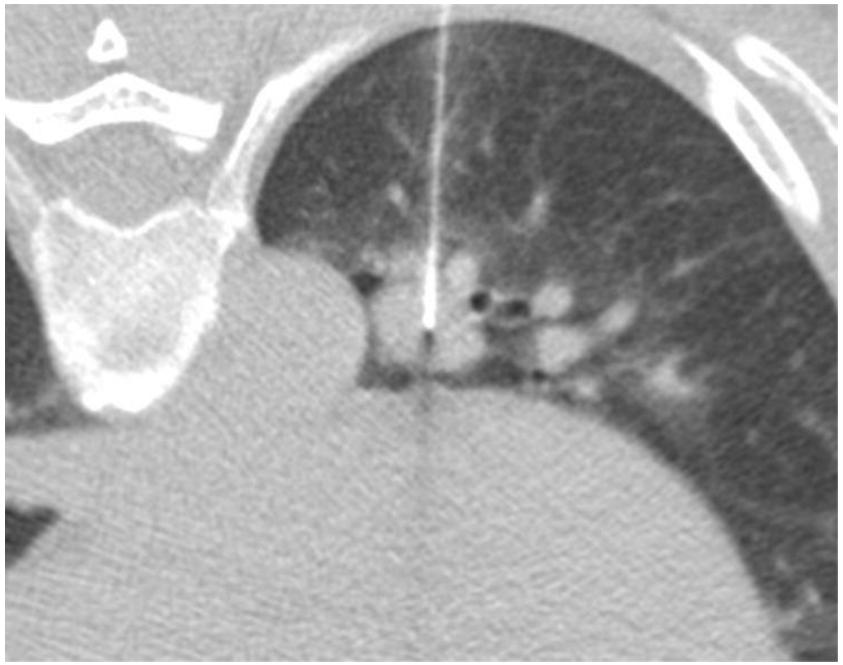
Transthoracic Needle Biopsy

- **Conducted under local anesthesia**
- **High diagnostic yield > 90%**
- **Lower diagnostic yield for smaller nodules**
- **Notable rate of complications (pneumothorax rate =~ 25%)**

-> Increased risk with <2cm, and distance from pleura

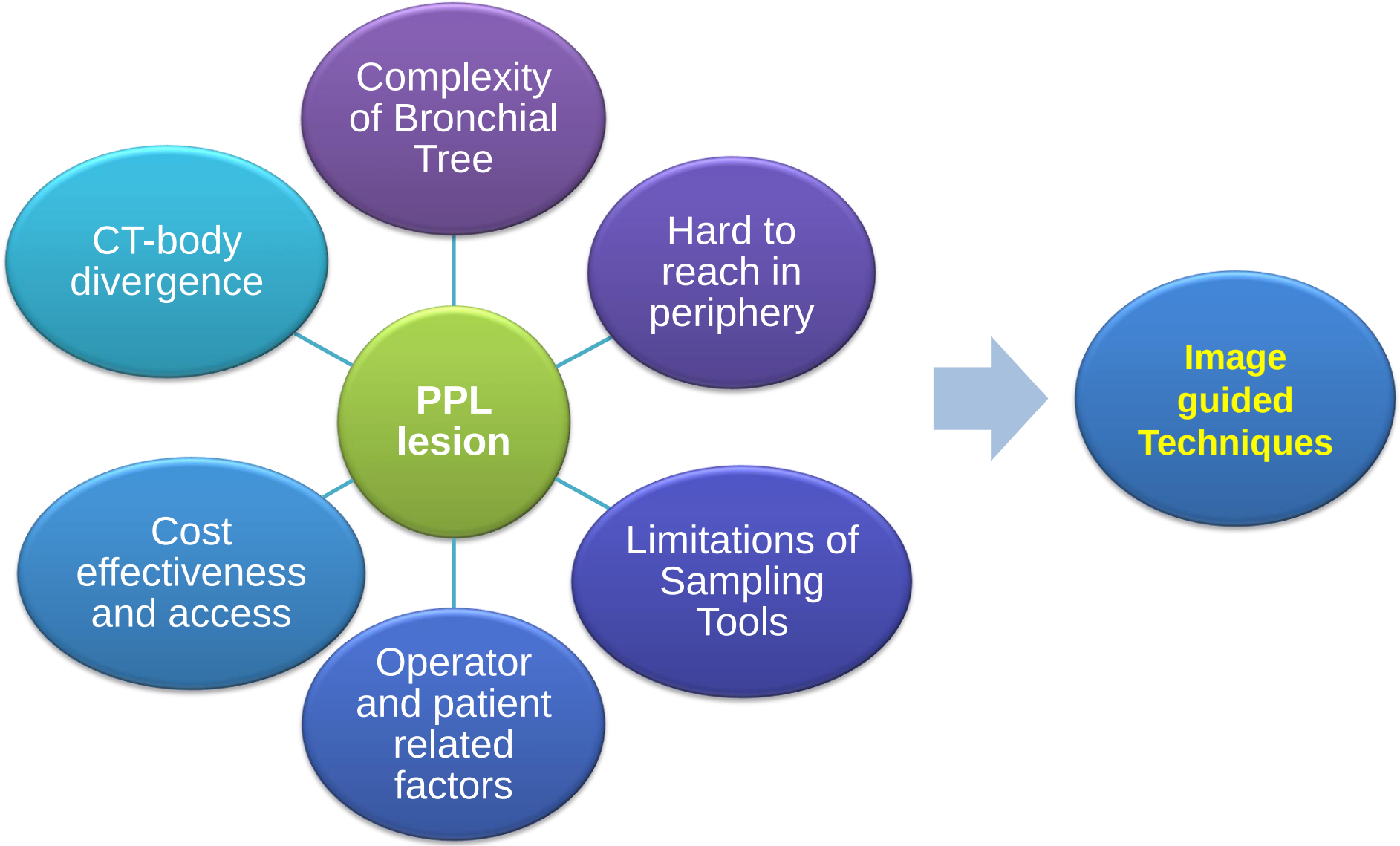
-> limitations from surrounding emphysema + lesions near diaphragm/major vessels





National Cancer Institute
Lee et al. Radiology. 2019

Challenges of Bronchoscopic Sampling of Peripheral Lesions



Preoperative Tissue Acquisition

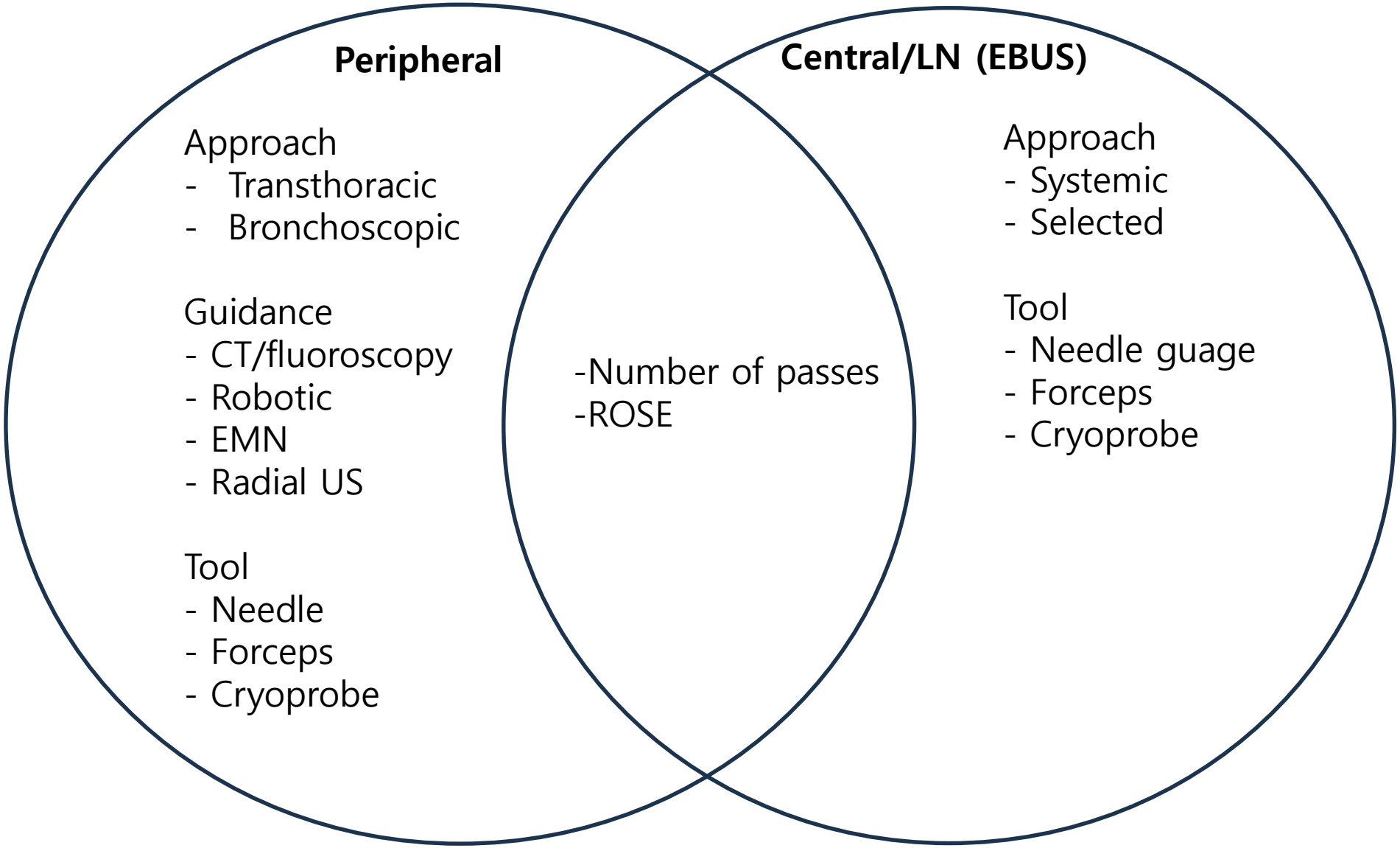
- **Tissue requirements**

H&E staining
- Few cells (10-50)
- Diagnosis
  -> Malignancy
  -> Histologic type

IHC
- 100 cells
  -> PD-L1
  -> EGFR
  -> ALK

NGS
->10% viable tumor
500ng – 2ug (1cc)
-> Target mutations
-> TMB
-> Large gene panels

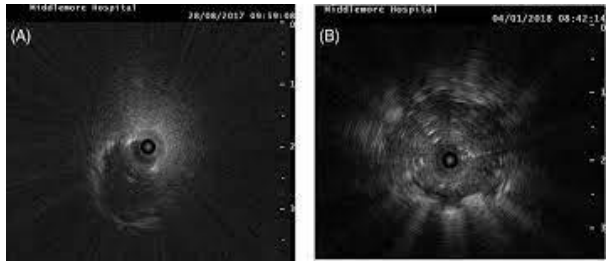
How to Optimize Tissue Adequacy



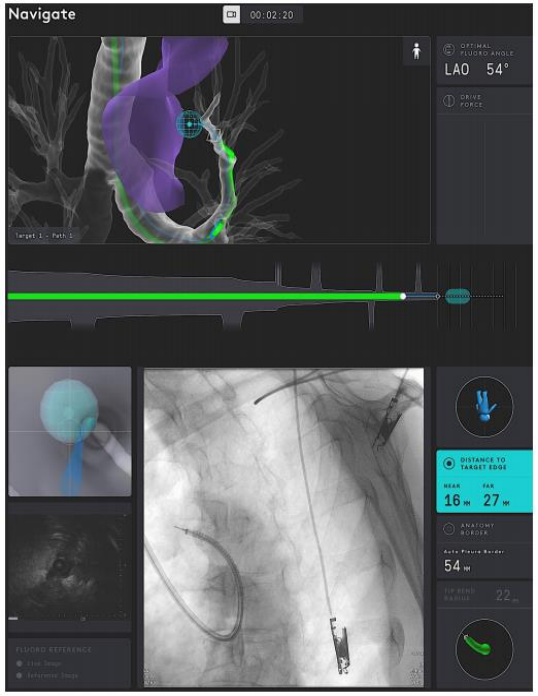
Advanced Image-guided Bronchoscopy

- **Moderate sedation or general anesthesia**
- **Diagnostic yield of 70-80%**
- **Lower risk of complications (pneumothorax rate <5%)**
- **Sequential mediastinal staging with EBUS is available**
- **Lower diagnostic yield for smaller nodules without bronchus sign**

Electromagnetic Navigation Bronchoscopy



Radial EBUS



Robot-assisted (shape sensing)

Kemp. Respiration. 2020
Simoff et al. BMC Pulm Med 2021

Choice for Initial Biopsy: TTNB or Bronchoscopy?

- **VERITAS: RCT evaluating the diagnostic accuracy of TTNB vs. ENB**

Diagnostic utility results

(Overall prevalence of malignancy: 66.7%)	NB	CT-TTNB	Overall	Difference (95% credible interval)	Posterior Probability of Noninferiority
Diagnostic yield	(n=121)	(n=113)	(n=234)		
Diagnostic	96 (79%)	88 (78%)	184 (79%)	0.02 (-0.02 to 0.05)	98.3%
Non-diagnostic	25 (21%)	25 (22%)	50 (21%)		
Diagnostic accuracy	(n=119)	(n=110)	(n=229)		
Accurate	94 (79%)	81 (74%)	179 (78%)	0.05 (0.02 to 0.09)	99.7%
Inaccurate	25 (21%)	29 (26%)	50 (22%)		

Lentz. ATS 2024

Landscape of Robotic & Navigation Assisted Bronchoscopy

SuperD
Medtronic

2004

Veran
Olympus

2005

Monarch
Johnson & Johnson

2018

Galaxy
Noah Medical

2023

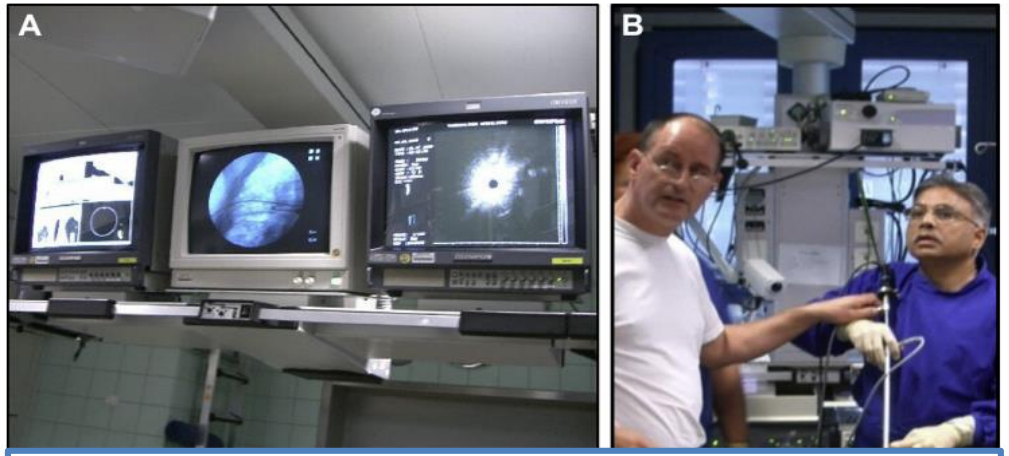
Electromagnetic Navigation Bronchoscopy

Ion
Intuitive

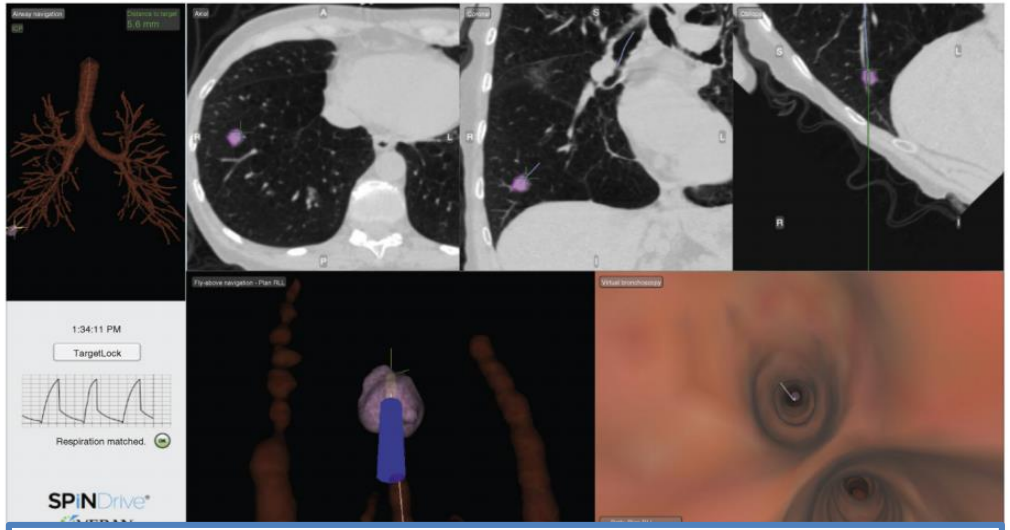
2019

Shape-sensing Navigation Bronchoscopy

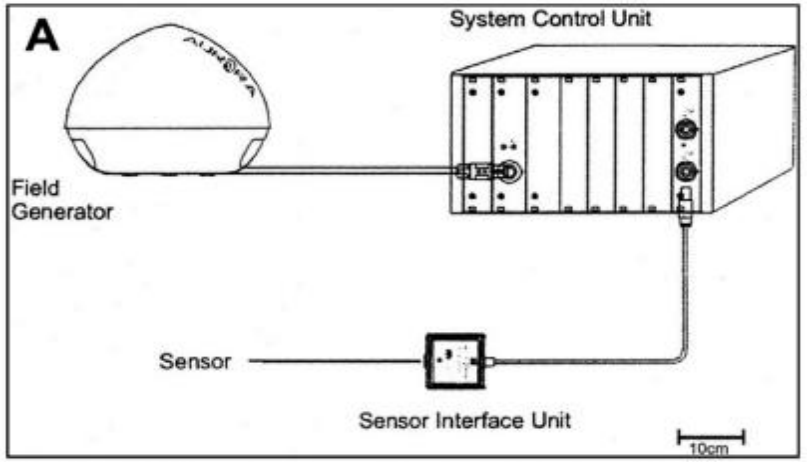
Electromagnetic Navigation Bronchoscopy

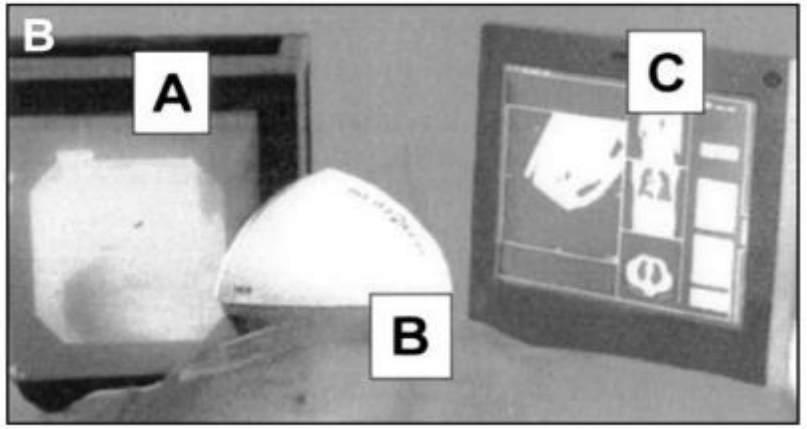


The first clinical study initiated in Germany, 2003 (SuperDimension)



Third system developed by Veran 2006

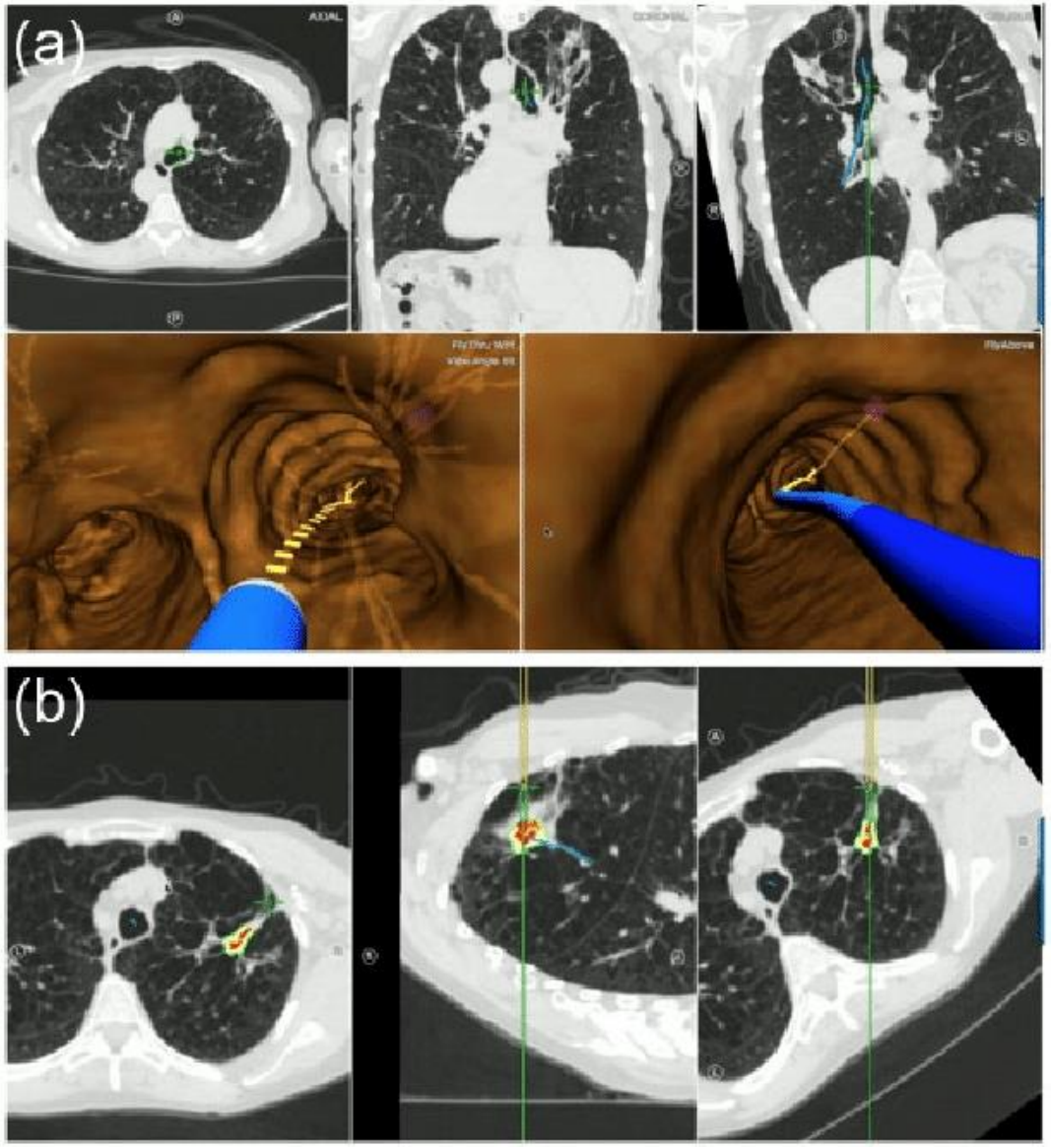


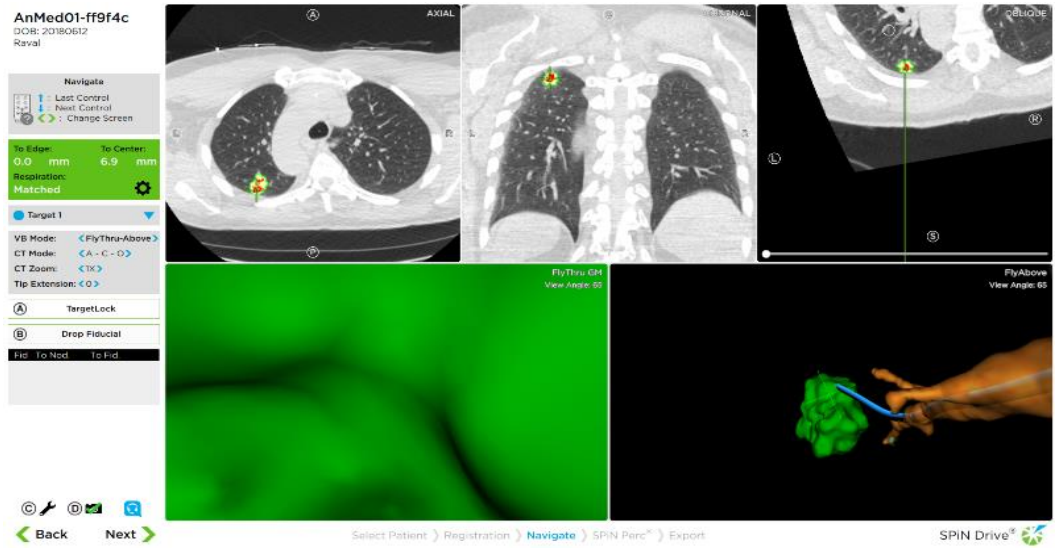


Second ENB system by Aurora (Canada), 2005

Mehta et al. Chest. 2018.

Current ENB Platforms

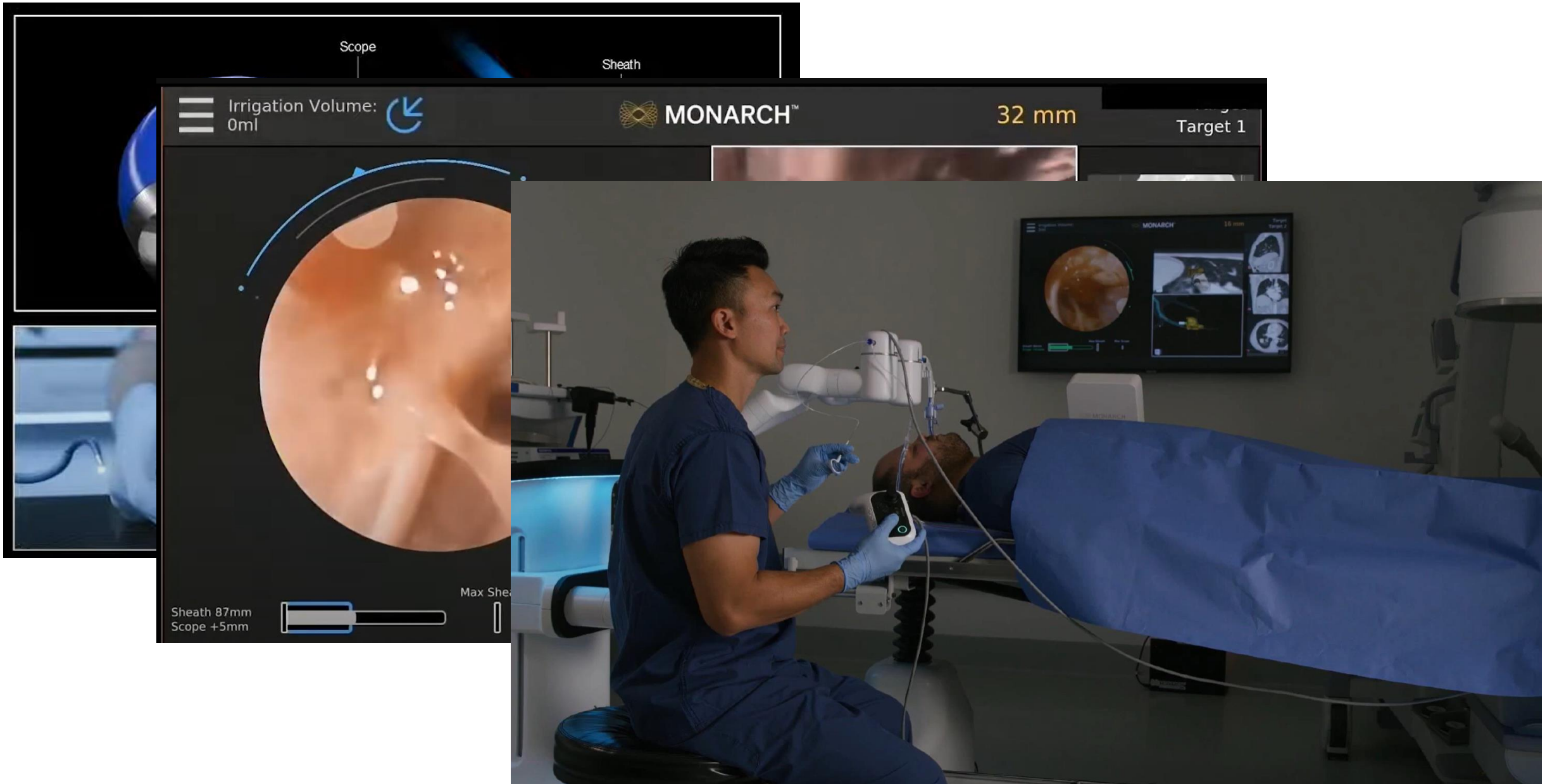




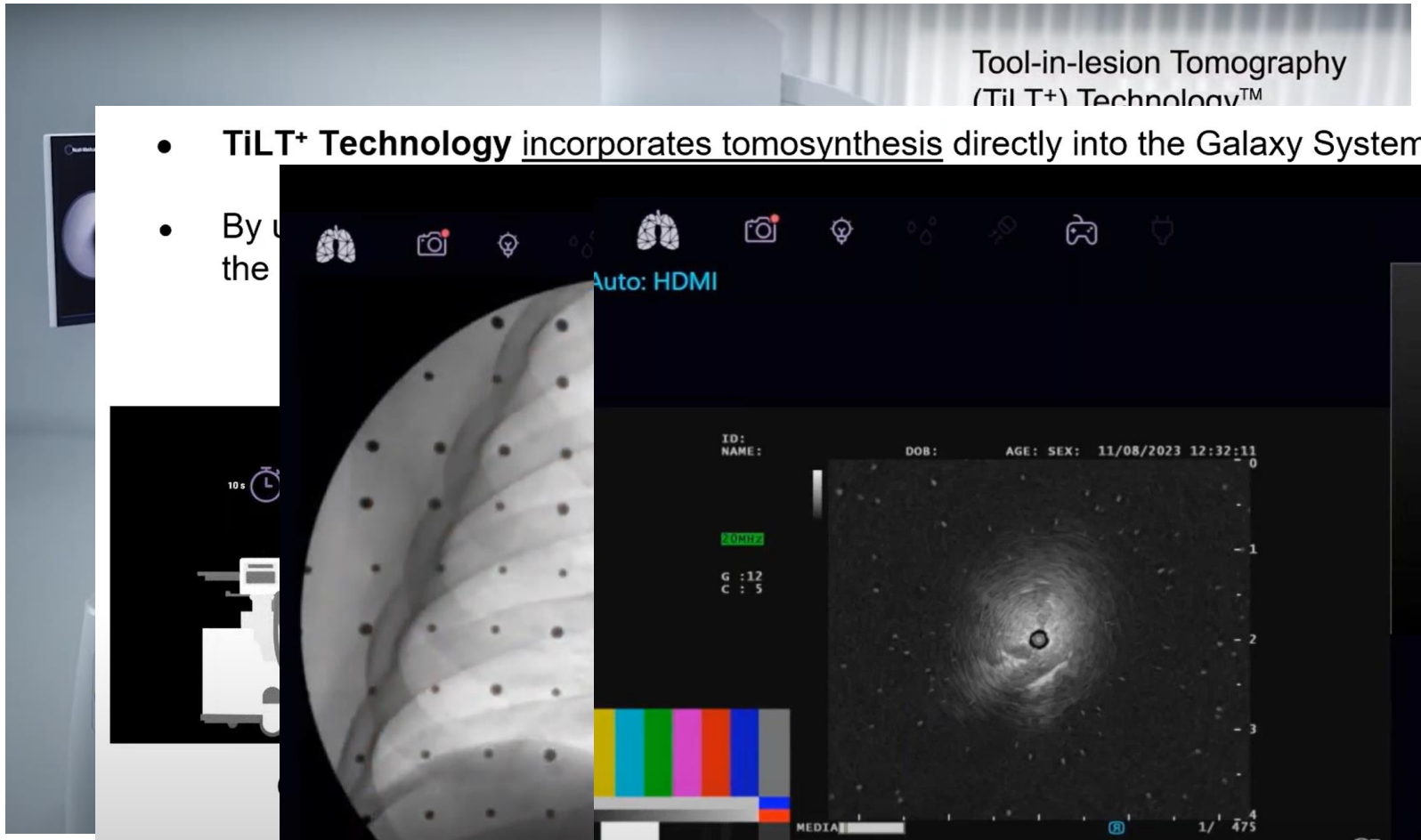
- Planning CT scan views
- Virtual bronchoscopic images.
- CT scan and lesion views guiding biopsy procedure.

Mehta et al. Chest. 2018.

Current RAB platforms: Monarch



Current RAB platforms: Galaxy



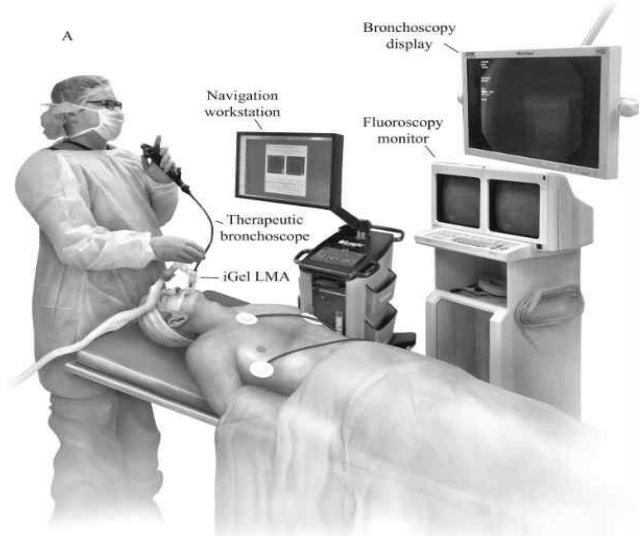
- **TiLT+ Technology** incorporates tomosynthesis directly into the Galaxy System
- By u
the

Shape-sensing Robotic Bronchoscopy: Ion

- **Fiber optic shape-sensing as a novel navigation technology**

Comparison with Conventional ENB

	Shape-sensing Robotic Bronchoscopy	Electromagnetic Navigation Bronchoscopy
Technology for Navigation guidance	Shape-sensing fiberoptic	Electromagnetic
EM Field generator, patient sensors	No	Yes
Metal interference	No	Yes
Visualization	Direct camera + Virtual	Virtual
Catheter tracking	Full Catheter	Tip (EM sensor in catheter or tool)
Catheter O.D	3.5mm	Bronchoscope: 6.0mm
Working channel	2.0mm	2.0mm
Flexible needle	Yes	No
EBUS compatible	Yes	Yes

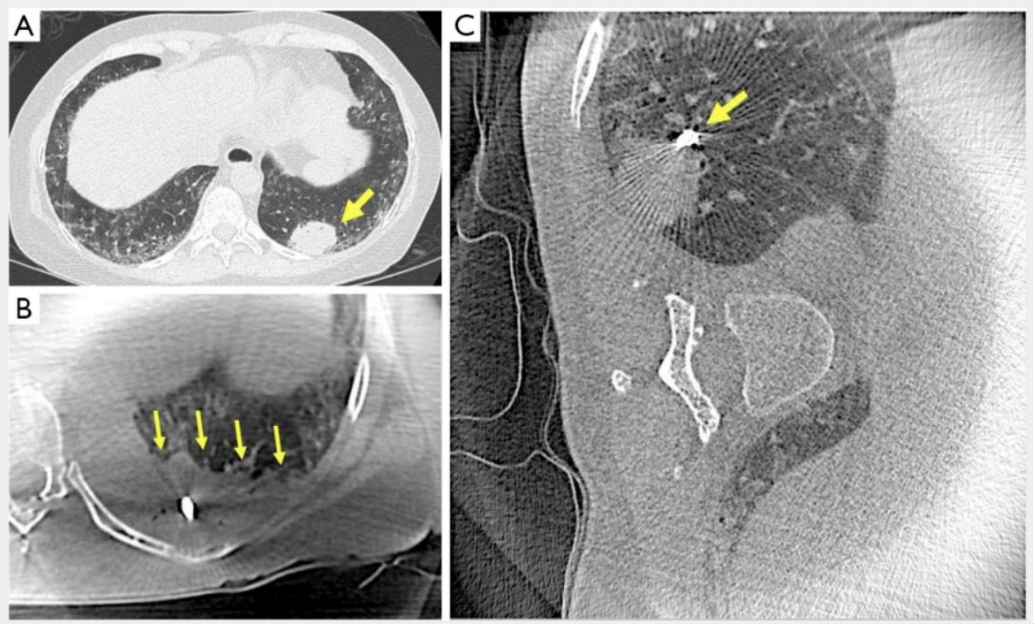


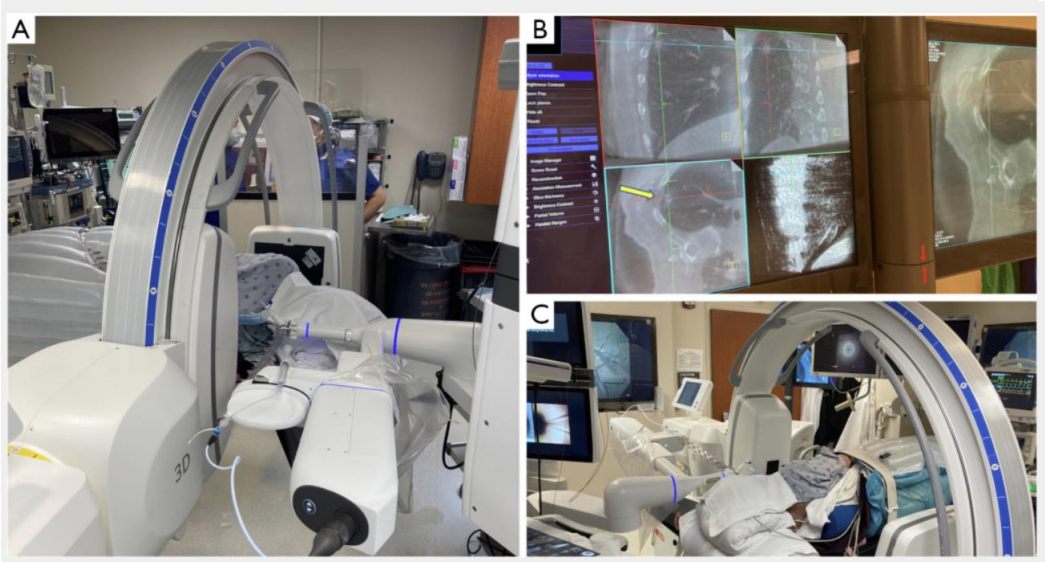
Comparison of Current Robotic Bronchoscopy Platforms

	MonarchTM Platform (Auris Health, Inc., Redwood City, CA, USA)	Ion Endoluminal RAB Platform (Intuitive Surgical©, Sunnyvale, CA, USA)	Galaxy SystemTM (Noah Medical, San Carlos, CA, USA)
Bronchoscope	Sheath: 6 mm OD Bronchoscope: 4.0 mm OD	Single Bronchosope: 3.5 mm OD	Single Bronchoscope: 4.0 mm OD
Working Channel	2.1 mm	2.0 mm	2.1 mm
Navigation	Electromagnetic	Shape-sensing	Electromagnetic
Vision During Navigation	Yes	Yes	Yes
Vision During Biopsy	Yes	No	Yes
Imaging Integration	None	Cios Spin mobile CBCT C-arm (Siemens Healthineers AG, Erlangen, Germany)	TILT+ Technology+TM digital tomosynthesis with augmented fluoroscopy

JTD. 2024.

Optimizing the Procedure: Anesthesia and Ventilation Protocol



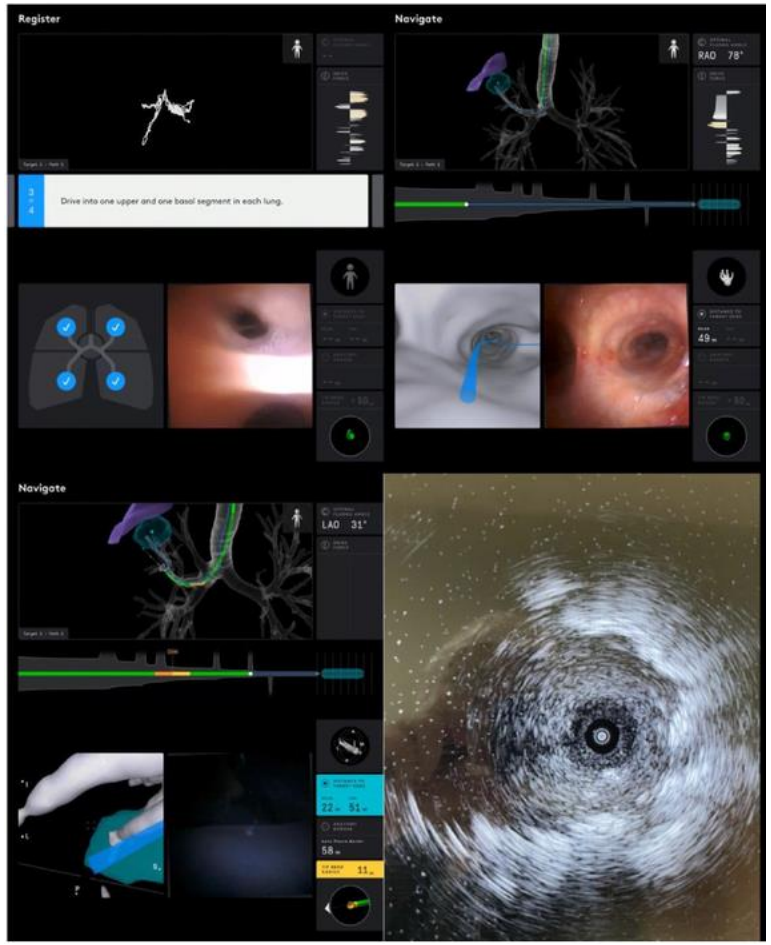


A comparison of two dedicated ventilation strategies for bronchoscopy: LNVP and VESPA

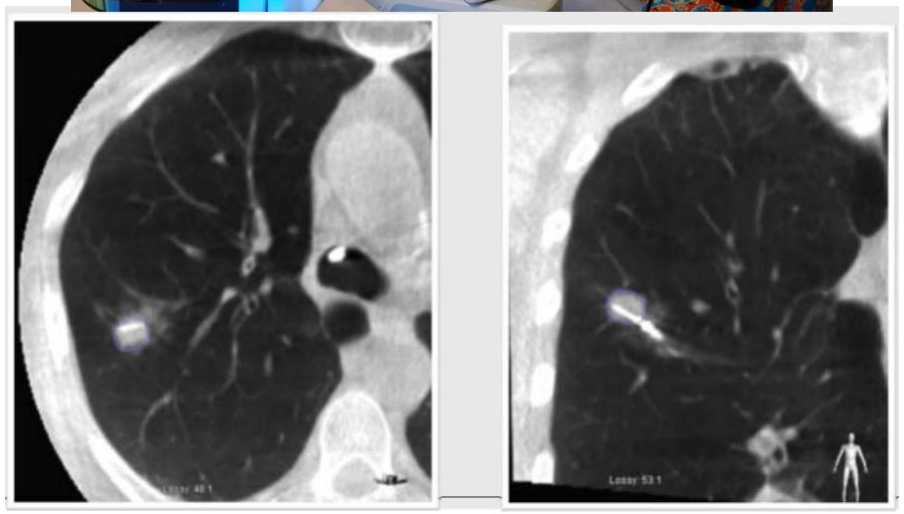
	LNVP	VESPA
Airway	Endotracheal tube	Endotracheal tube
Mode of ventilation	Dual ventilation strategy with pressure-controlled continuous mechanical ventilation and patient specific VT	Volume control
VT	10–12 cc/kg of IBW	6–8 cc/kg of IBW
FiO_2	Lowering to the lowest tolerable FiO_2	<100% (titrated as low as possible to maintain an oxygen saturation of >94%)
PEEP	Upper/middle lobe target:10–15 cmH_2O Lower lobe target: 15-20 cmH_2O‡	8–10 cmH_2O
Recruitment maneuver	Performed post-intubation → 4 alveolar recruitment maneuvers, hand-delivered via bagging the patient with 30 cmH_2O over 30 seconds or 40 cmH_2O over 40 seconds. Variability in timing and pressures based on anesthesiology personnel	Performed immediately post-intubation → 10 consecutive breaths at a plateau pressure of 40 cmH_2O, with a PEEP of 20 cmH_2O in pressure control mode*

Khan et al. J Thorac Dis. 2023
Bhadra et al. Interv Pulmonol. 2022
Salahuddin et al. Chest. 2022

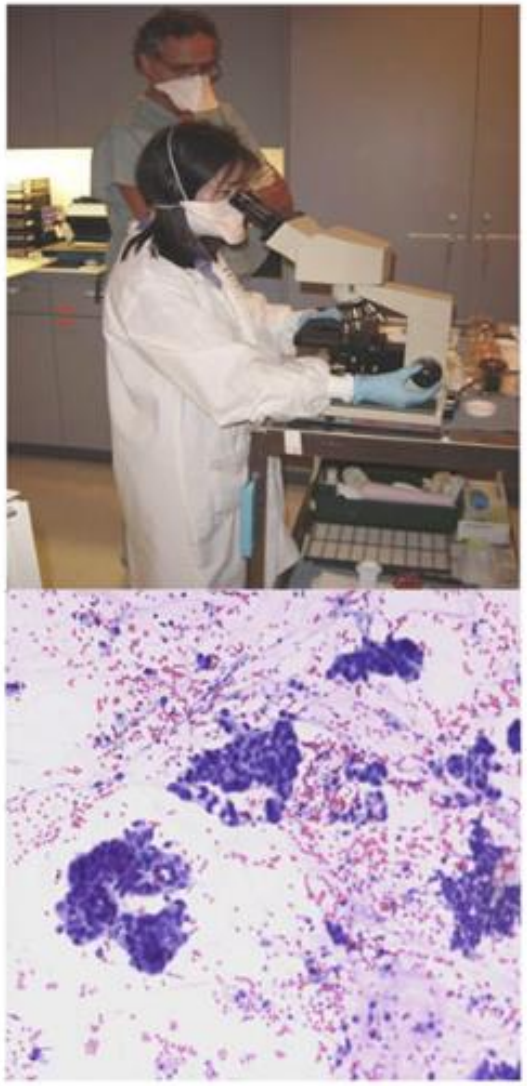
Optimizing the Procedure: Complementary Techniques



Radial EBUS



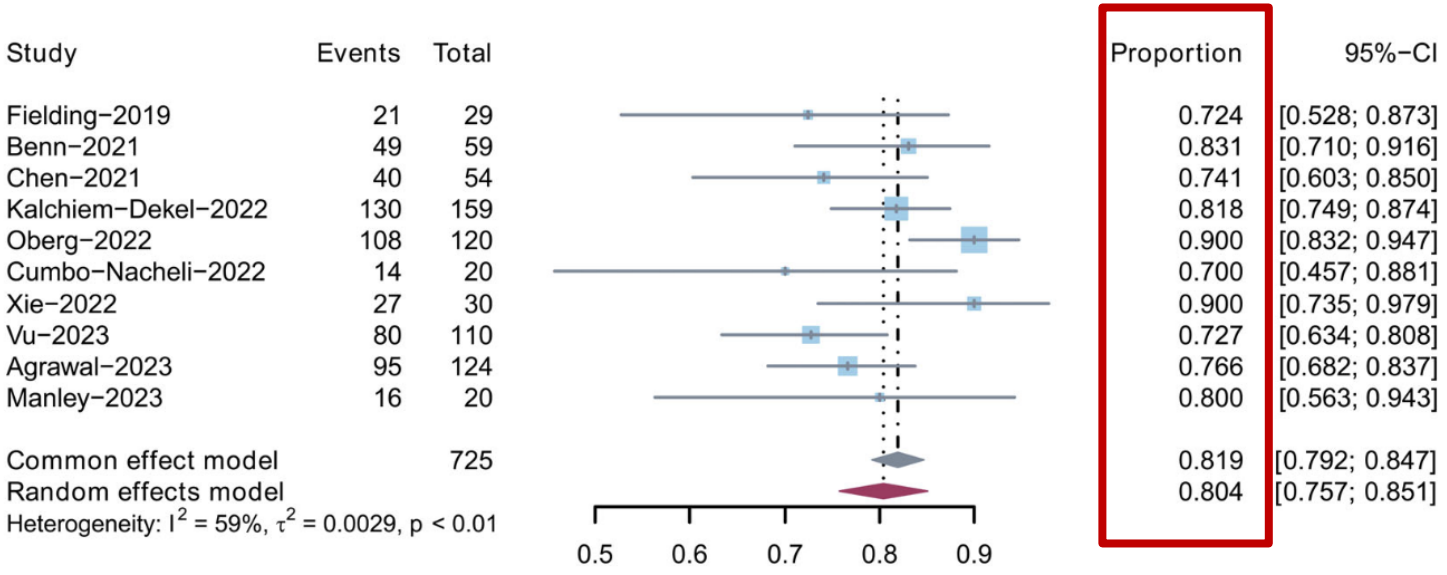
Cone-beam CT



ROSE

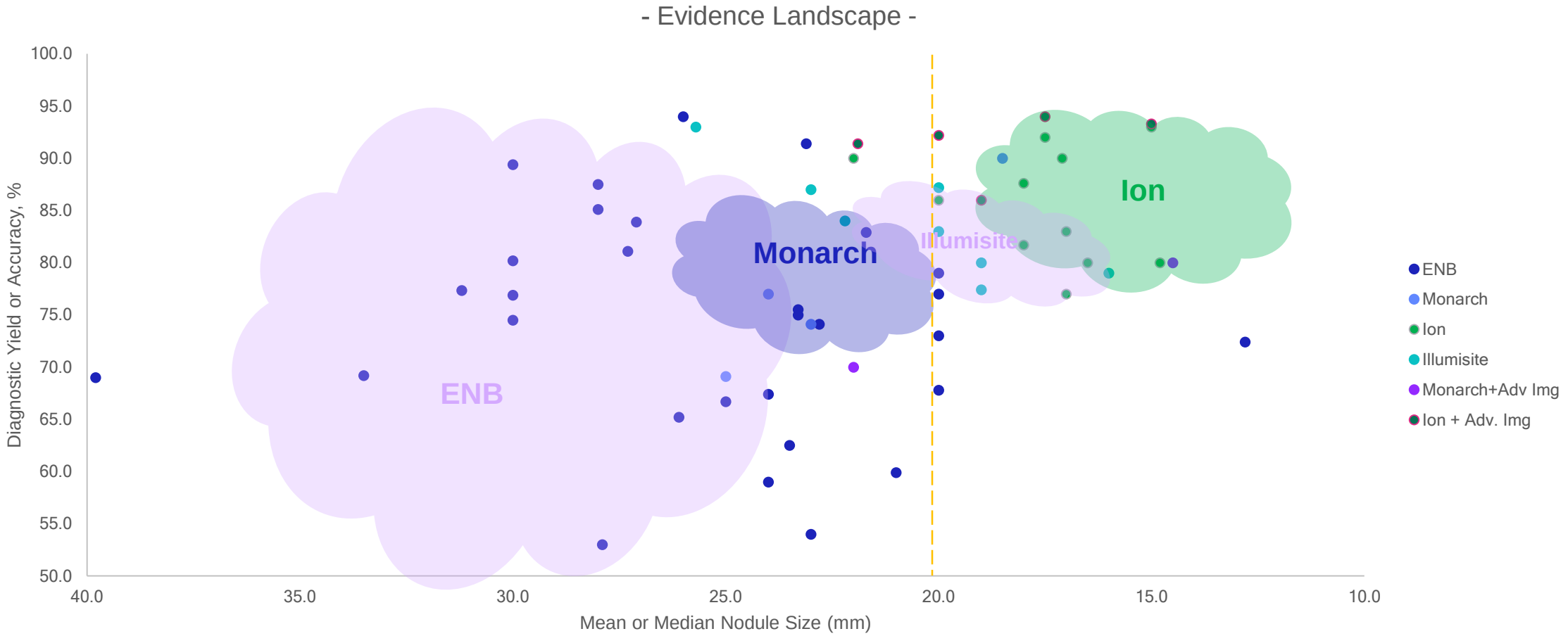
Reports of Diagnostic Yield

Study	Robotic platform	Study design	Patients, *n*	Lesions, *n*	Lesion size, mm	Bronchus sign, *n* (%)	Solid lesion, *n* (%)	Auxiliary technique	Sampling method
Fielding et al. 2019[31]	Ion	Pro	29	29	12.2 ± 4.2[a]	17 (58.6)	23 (79.3)	rE, Fl, ROSE	Needle, forceps, brush, BAL/wash
Benn et al. 2021[32]	Ion	Pro	52	59	19.6 ± 10.9[a]	27 (45.8)	41 (69.5)	CBCT, ROSE	Needle, forceps
Chen et al. 2021[33]	Monarch	Pro	54	54	23.2 ± 10.8[a]	32 (59.3)	NR	rE, Fl, ROSE	Needle, forceps
Kalchiem-Dekel et al. 2022[34]	Ion	Retro	130	159	18 (13–27)[b]	100 (62.9)	116 (73.0)	rE, Fl, ROSE	Needle, forceps, brush
Oberg et al. 2022[35]	Ion	Retro	112	120	22 (13–34.3)[b]	58 (48.3)	87 (72.5)	rE, Fl	Needle, forceps, cryoprobe
Cumbo-Nacheli et al. 2022[36]	Monarch	Retro	20	20	22 ± 7[a]	10 (50.0)	17 (85.0)	rE, CBCT	Needle, forceps
Xie et al. 2022[37]	Ion	Pro	30	30	17.1 ± 4.3[a]	23 (76.7)	26 (86.7)	rE, Fl, ROSE	Needle, forceps, brush
Vu et al. 2023[38]	Ion	Retro	110	110	20 (15–24)[b]	27 (24.5)	87 (79.1)	rE, Fl, ROSE	Needle, forceps
Agrawal et al. 2023[39]	Monarch	Retro	124	124	20.5 (13–30)[b]	93 (75.0)	71 (57.3)	rE, Fl, ROSE	Needle, forceps
Manley et al. 2023[40]	Monarch	Pro	20	20	14.5 (8–28)[c]	12 (60.0)	NR	rE, Fl, nCLE, ROSE	Needle, forceps

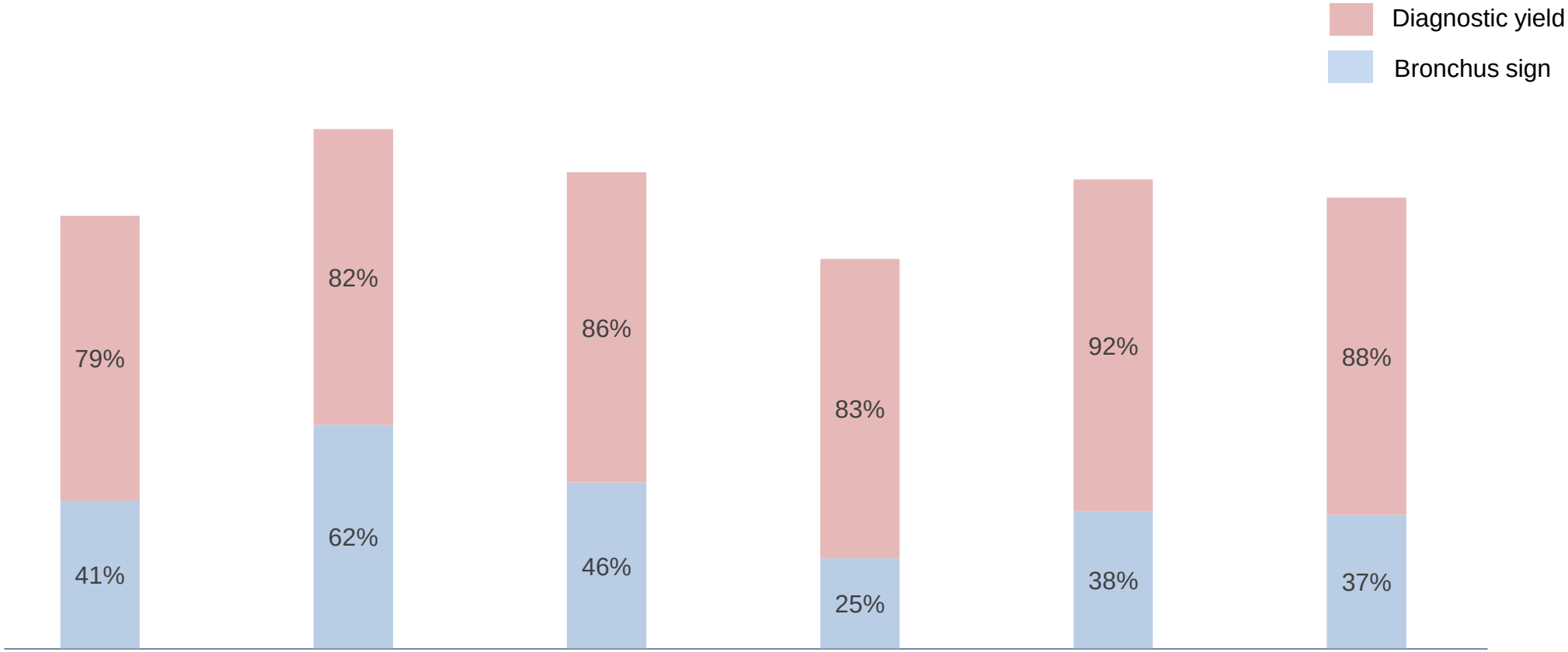


Zhang et al. Thorac Cancer. 2024.

Diagnostic Yield by Lesion Size and Platforms

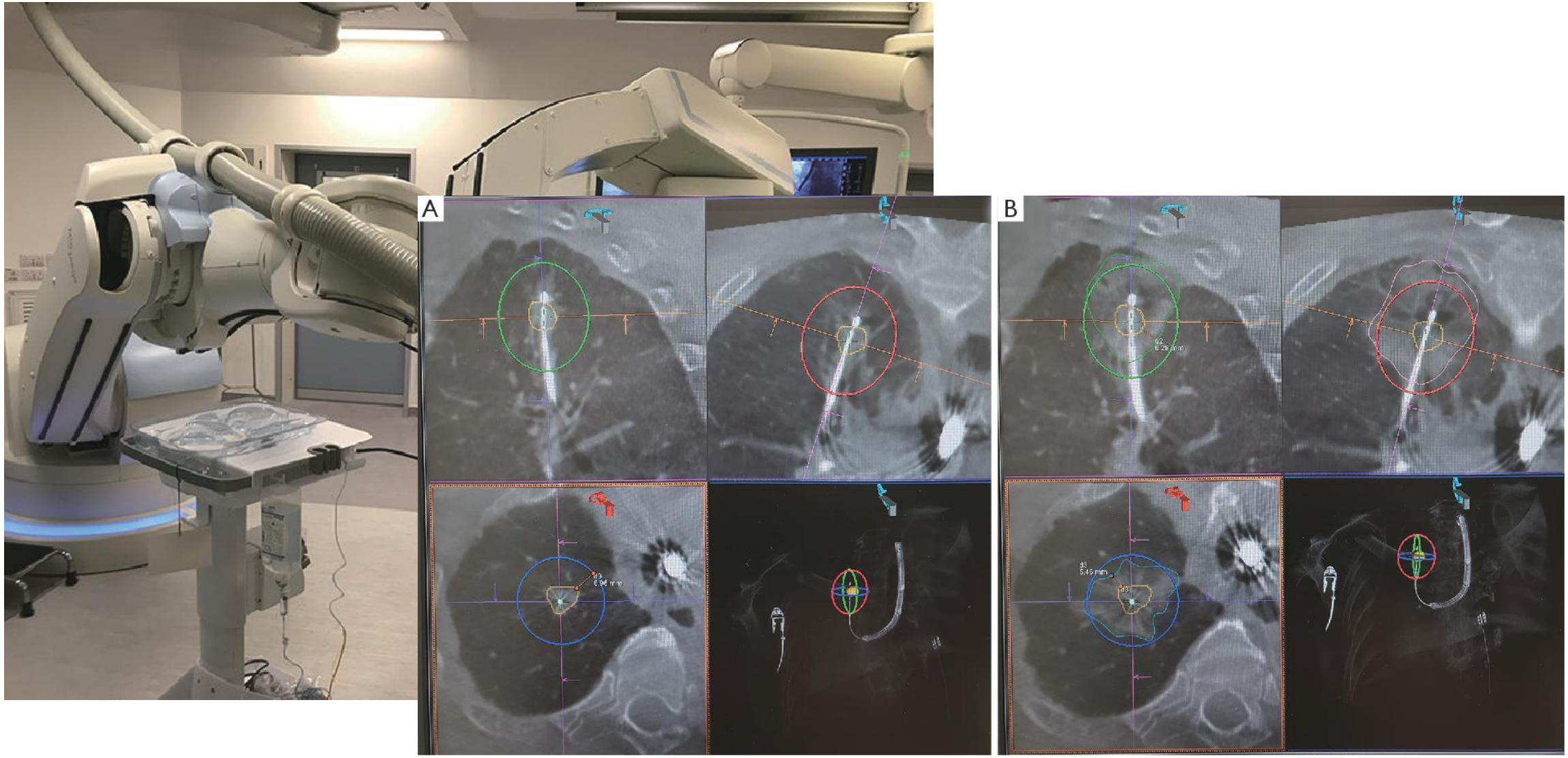


CT Bronchus Sign and Diagnostic Yield



	Fielding [1]	Kalchiem-Dekel [4]	Benn [5]	PRECISE [3]	Pritchett [6]	All Ion* [8]
Avg. lesion size	1.4cm	1.8cm	1.7cm	1.7cm	1.5cm	1.8cm
Imaging	rEBUS C-Arm	rEBUS CIOs CBCT	CBCT	rEBUS C-Arm	rEBUS CBCT (75%)	rEBUS (69%) C-Arm (68%) CBCT (15%)
No. of Nodules	29	131	59	69	192	7051

Future Directions of Research



Chan et al. Transl Lung Cancer Res. 2021.

Thank you for your attention

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