

Image-Guided Bronchoscopy for Peripheral Nodule Biopsy: A Phantom Study

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Introduction

- Bronchoscopy of peripheral nodules feasible
 - High-resolution 3D multi-detector CT (MDCT) scanners
 - Ultrathin bronchoscopes
- But, reliable bronchoscopic biopsy difficult
 - 3D CT-based preplanning problematic
 - Several airway generations must be traversed – physician gets lost?!
 - Blind – difficult to determine biopsy site
- **Objective:**
 - Assess performance of a computer-based system
 - Phantom study

Prior Work: Bronchoscopy of the Periphery

Bronchoscopy of peripheral nodules

- Baaklini *et al.* (*Chest* 2000): 14% → 31% yield

Electromagnetic sensor-based guidance

- Schwarz *et al.* (*Respiration* 2003); Gildea *et al.* (*Chest* 2006)

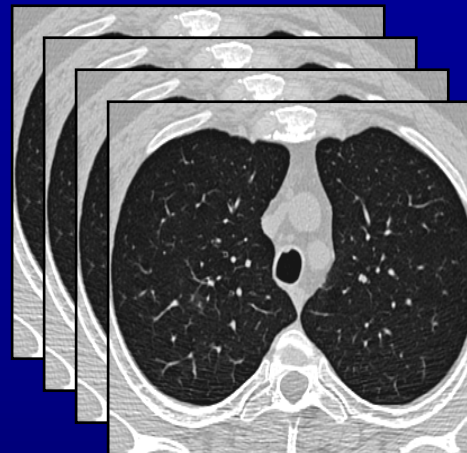
CT-derived virtual-bronchoscopic (VB) guidance

- Geiger *et al.* (*SPIE Med. Imaging* 2005)
- Asano *et al.* (*Bronchology* 2002, *AJRCCM* 2006)

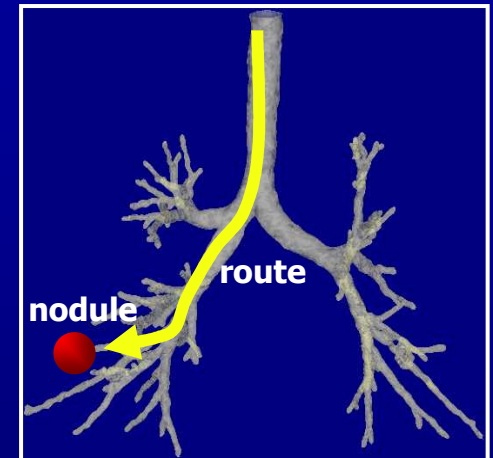
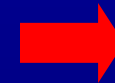
Workflow for Our System

1. 3D CT-Based Preplanning

- Airway tree
- Nodules
- Routes to nodules



3D CT Image



tree, routes, nodules

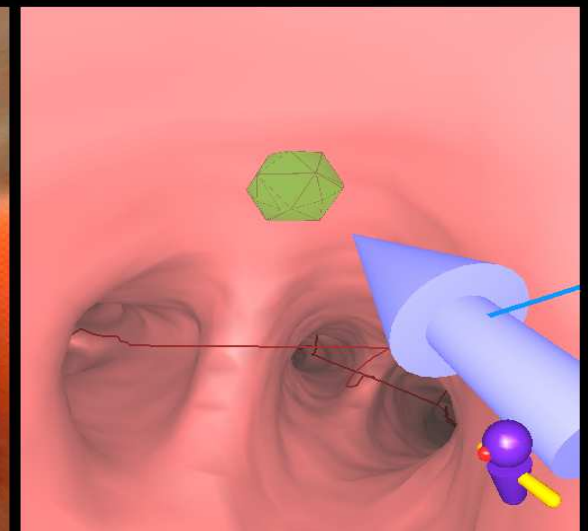
2. Guided Bronchoscopy

- Simple PC interface
- CT, video registered
- Augmented vision



Dist to ROI2 Center = 7.0 mm

Bronchoscopic Video

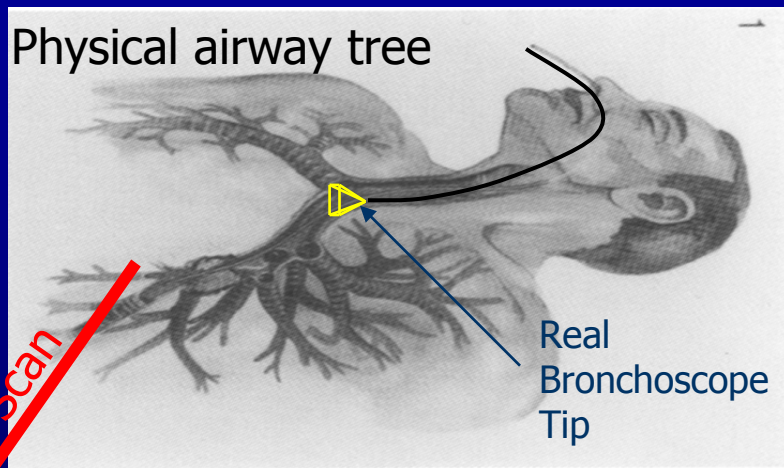


CT-based VB view

Real-Time Registration/Fusion

Merritt *et al.*, *SPIE Med. Imaging* 2006, 2007

Figure 19.4,
Wang/Mehta '95

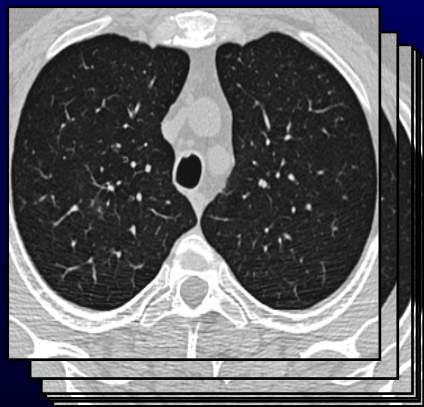


Real Bronchoscope Image
Observed at Time t I_r^t

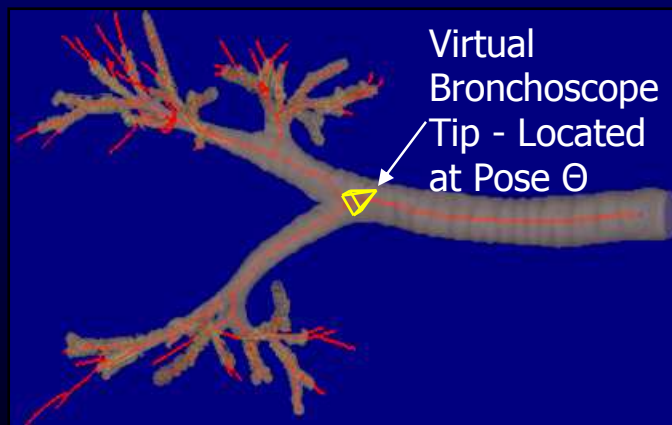


Real World

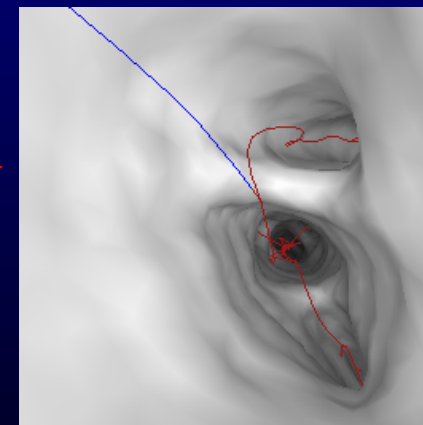
Virtual World



3D CT Slices

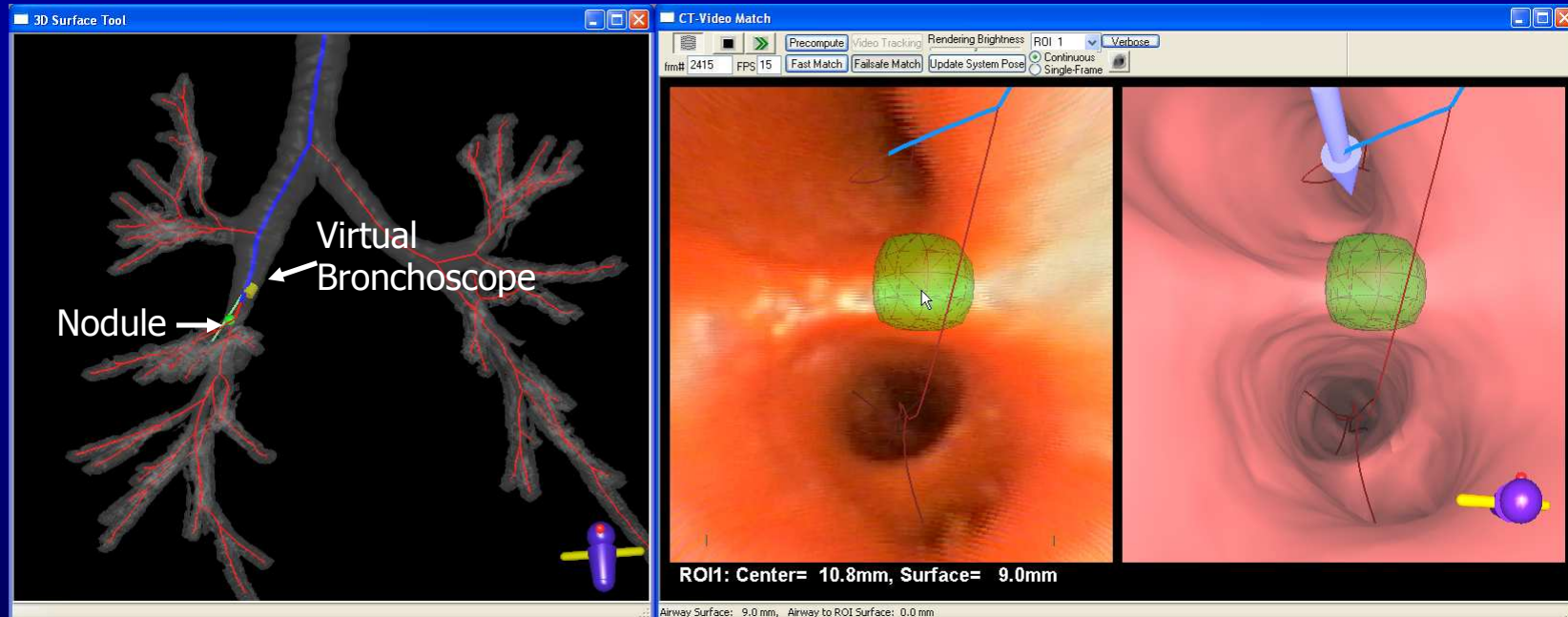


CT-Derived Virtual Airway Tree



Virtual Bronchoscope Image
Generated at Pose θ I_v^θ

Guidance Strategy (Briefly)



1. Start virtual bronchoscope at a reference location (main carina)
2. Physician moves bronchoscope nearby
3. Registration/Fusion is invoked; **Blue Line** indicates correct path
4. Repeat process until nodule reached
5. **Blue Arrow** - final biopsy site

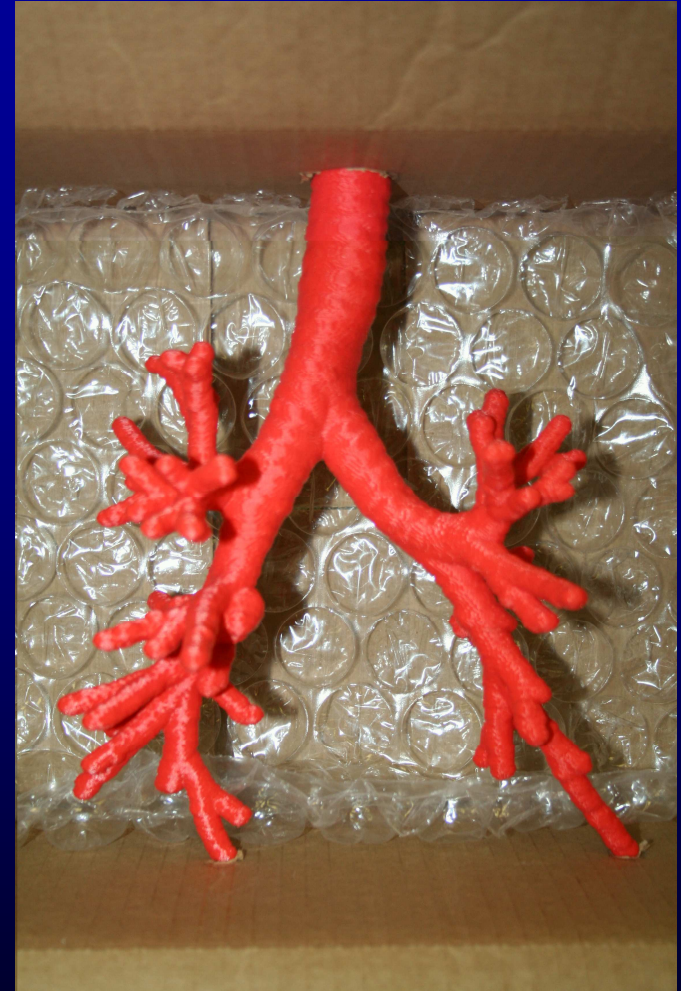
Study Set-up 1: Phantom

ABS-plastic phantom of airway tree

- By Stratasys, Inc.

Derived from human 3D MDCT scan

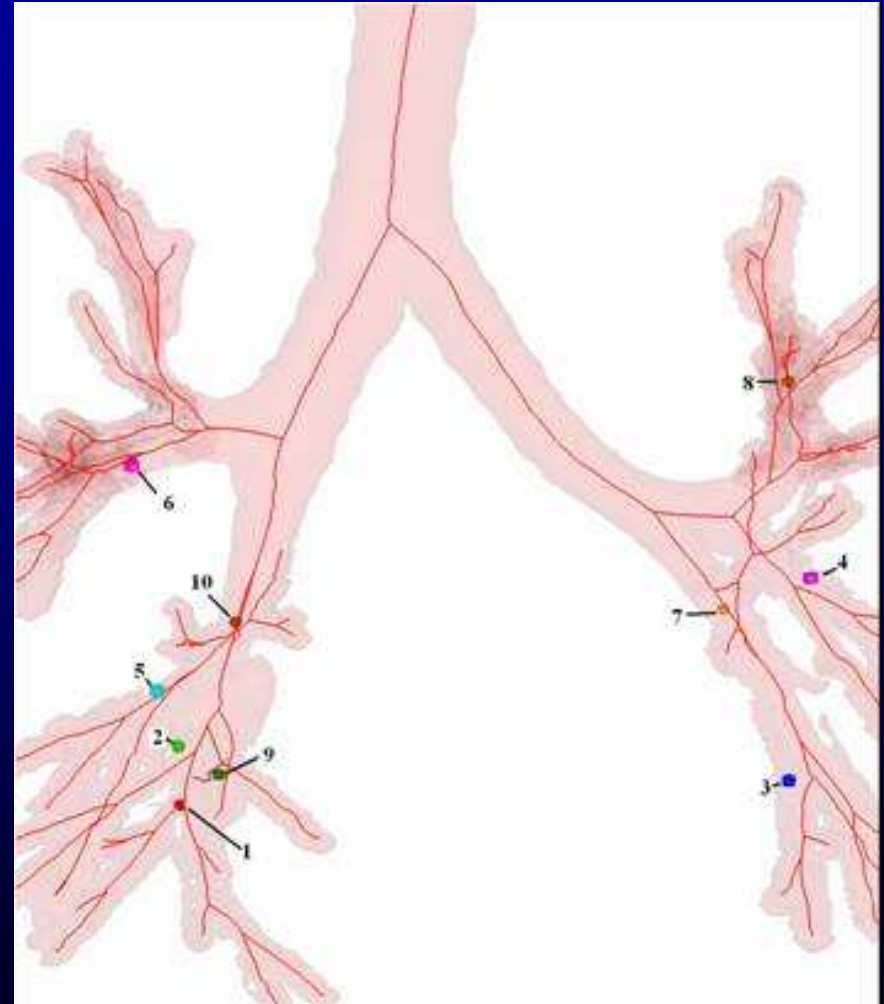
- 706 512x512 slices
- resolution: $\Delta x = \Delta y = 0.67\text{mm}$, $\Delta z = 0.5\text{mm}$
- Case 21405.3a



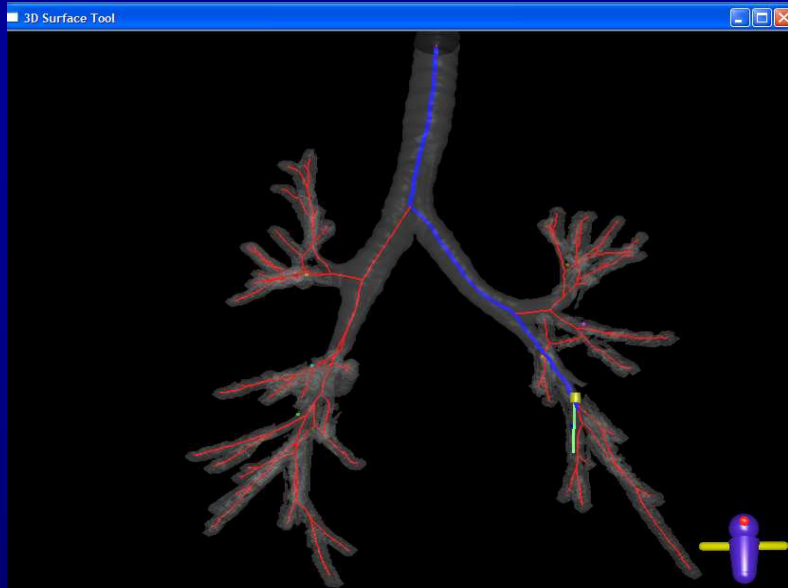
Study Set-up 2: 10 Predefined ROIs

10 nodules defined in 2 lungs

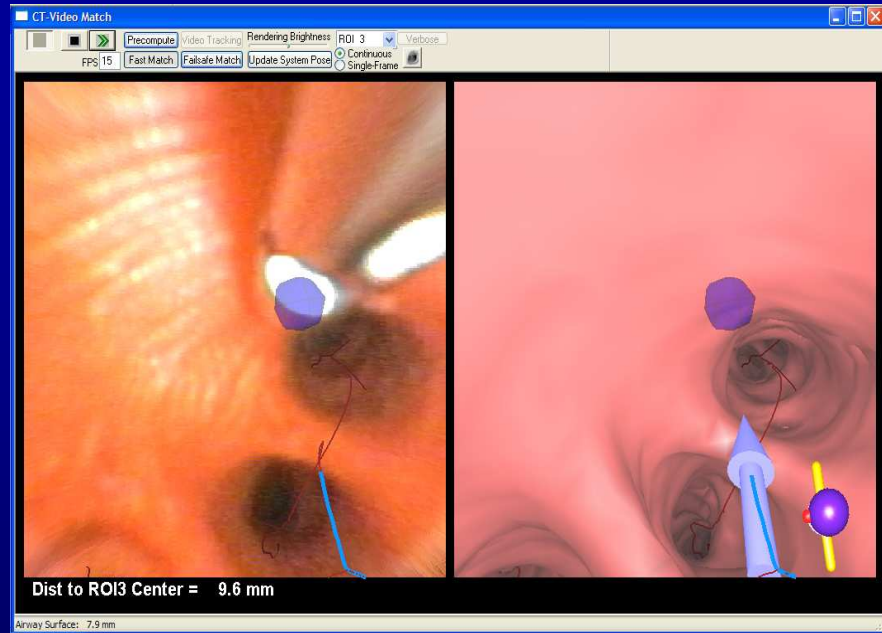
- Nodule = region of interest (ROI)
- 2.4mm diameter spheres
- Placed 3-8 generations deep
- In 3D MDCT scan data



Study Set-up 3: Display



3D Airway Tree + BLUE route and ROI



Live video + CT-based VB view



Transverse MDCT slices

Standard approach: MDCT slices

Guided approach: All 3 views

Study Set-up 4: Apparatus



1. Olympus BF XP260F ultrathin 2.8mm diameter
 - 1.2mm working channel
 - Closed forceps → point to biopsy site
 - Successful biopsy = within 5mm of ROI center
2. Phantom secured in a sealed box
3. Computer next to bronchoscope
4. Technician assists with computer, data collection

Study Set-up 5: Protocol



1. 12 Physicians involved
 - 6 staff physicians
 - 6 fellows in training
2. Each Physician performed test two ways: Standard, Guided
 - Tests spaced at least two weeks apart (learning effect?)
3. ROIs presented randomly in all tests
4. Physician gave confidence (1 – 5) at each bifurcation
5. Physician's voice and proceedings recorded on DVD

Biopsy Success (Hit) Rate

	STANDARD		IMAGE-GUIDED		p Value
	Hit Rate %	Position Error mean±SD (Range)	Hit Rate %	Position Error mean+/-SD (Range)	
Overall	43.3%	9.74 ± 9.09 (0.19-39.12)	94.2%	2.24 ± 2.25 (0.30-13.85)	< 10 ⁻¹⁵
Clinical Fellows	45.0%	9.46 ± 8.92 (0.72-38.72)	98.3%	1.79 ± 1.24 (0.30-6.95)	< 10 ⁻⁰⁸
Experienced Physicians	41.7%	10.03 ± 9.32 (0.19-39.12)	90.0%	2.69 ± 2.87 (0.35-13.85)	< 10 ⁻⁰⁶

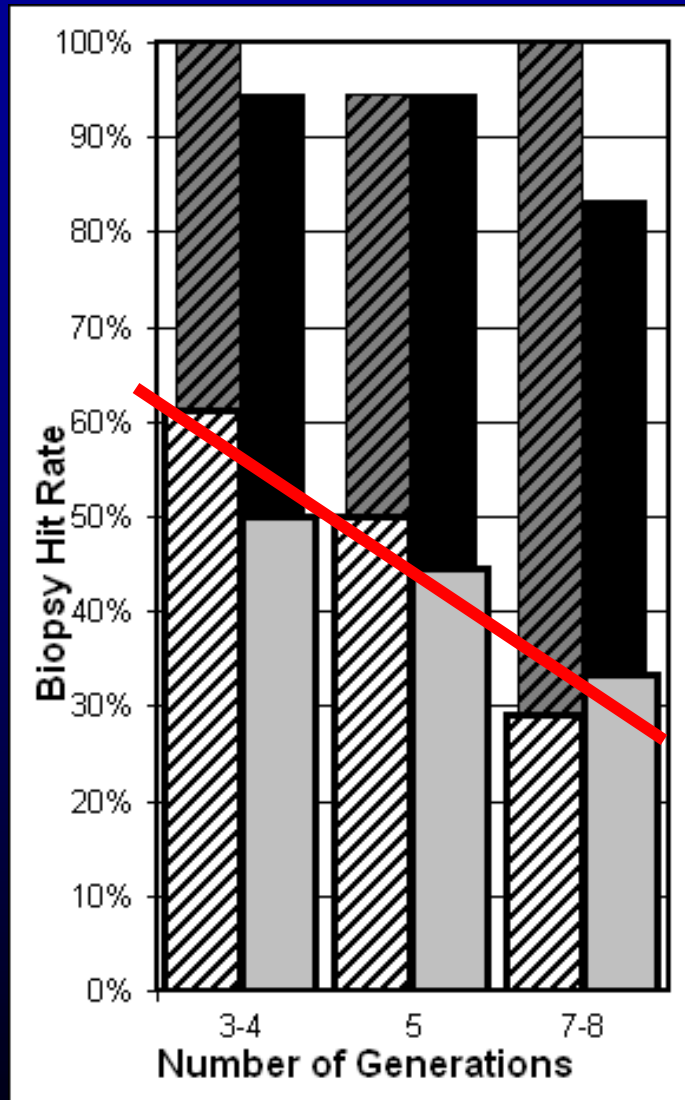
Guidance Dramatically Increases Success Rate:

- **Standard (Unguided) – 43% success rate**
- **Guided – 94% success rate**

Guidance Dramatically Increases Accuracy:

- Biopsy position error reduced from **10mm** to **2mm**

Biopsy Success Rate By Airway Generation Number



- Standard: performance deteriorates with increasing airway generation
- Guided: consistent performance

Decision Confidence (1-5)

Generation # (# of ROIs)	Overall	
	Standard	Guided
1 (10)	5.00	5.00
2 (10)	4.97	4.99
3 (9)	4.81	4.96
4 (7)	4.71	4.96
5 (4)	4.67	4.94
6 (4)	4.57	4.92
7 (1)	4.23	4.92

- Standard: Physician stays confident even though performance drops
- Guided: Physician consistently very confident throughout

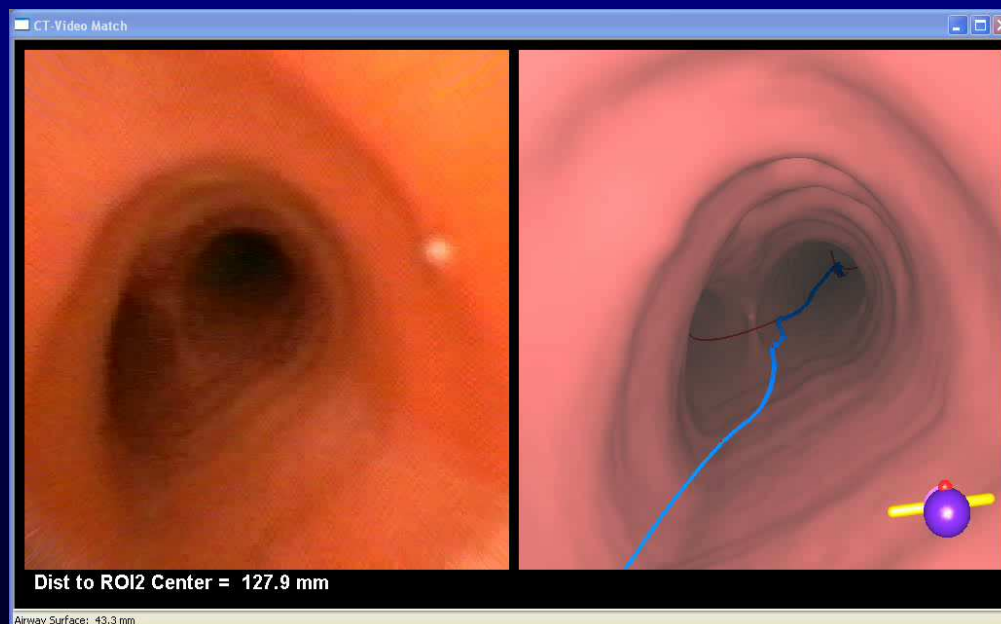
Impact of Method Order on Performance (Learning Effect?)

	All Physicians	
	Standard	Guided
No Experience	46.7%	95.0%
After Exposure to Other Method	40.0%	93.33%
Increase in Hit Rate	-6.7% (+4 misses)	-1.67% (+1 miss)
One-tailed p Value	0.842	0.781

- Order of tests had no significant impact
→ No learning effect

Conclusion

- Standard: 43% success Guided: 94% success
- Standard: 10mm error Guided: 2mm error
- Reduce impact of experience and skill?
- Potential for bronchoscopy of peripheral nodules
- *Asano et al., AJRCCM 2006*: CT-based VB guidance sufficient!

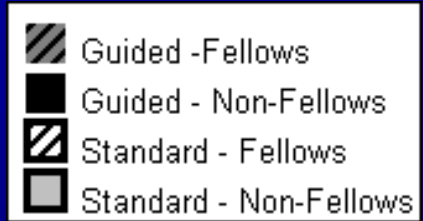
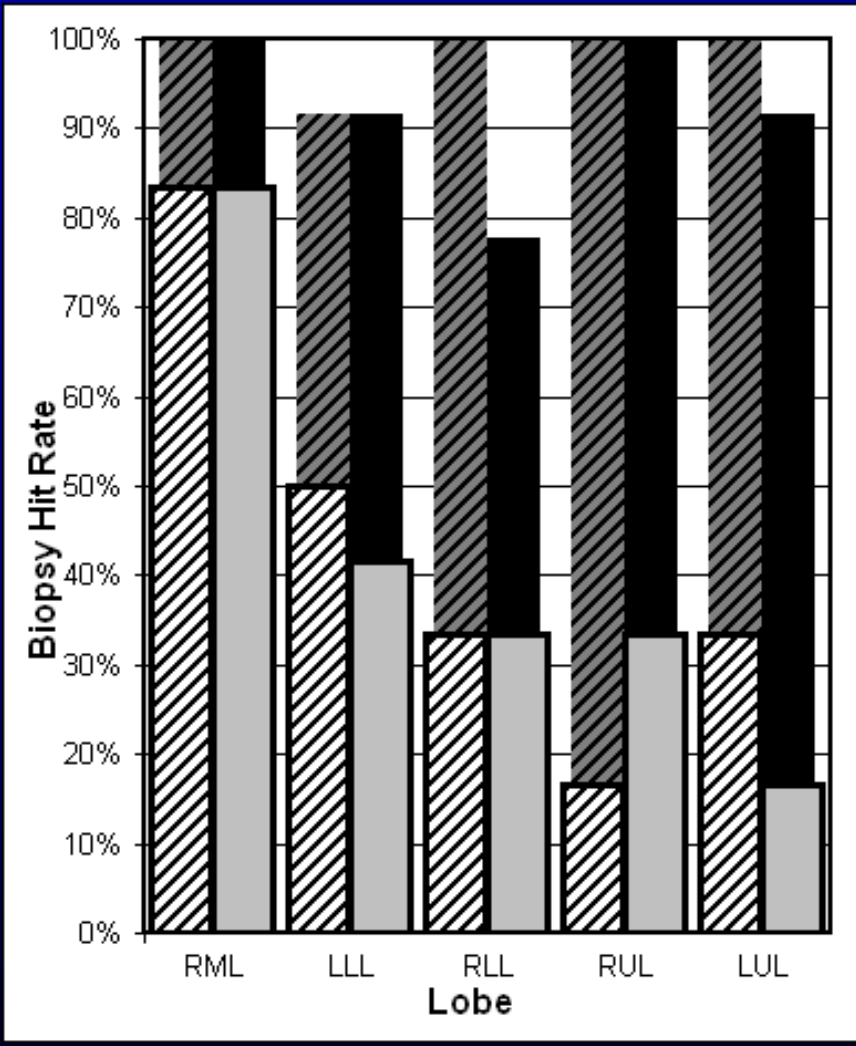


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NIH NIBIB grant #EB000305



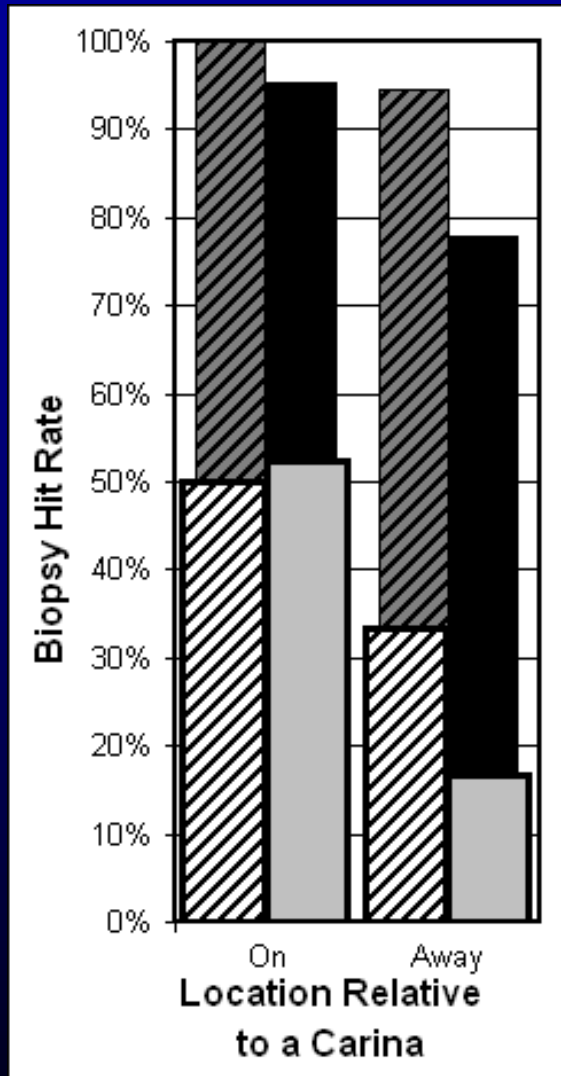
Biopsy Success Rate – By Lobe



- Standard: performance poor for most lobes
- Guided: high consistent performance



Biopsy Success Rate - Location



- Standard: performance poorer for non-carinal sites
- Guided: performance not dependent on location

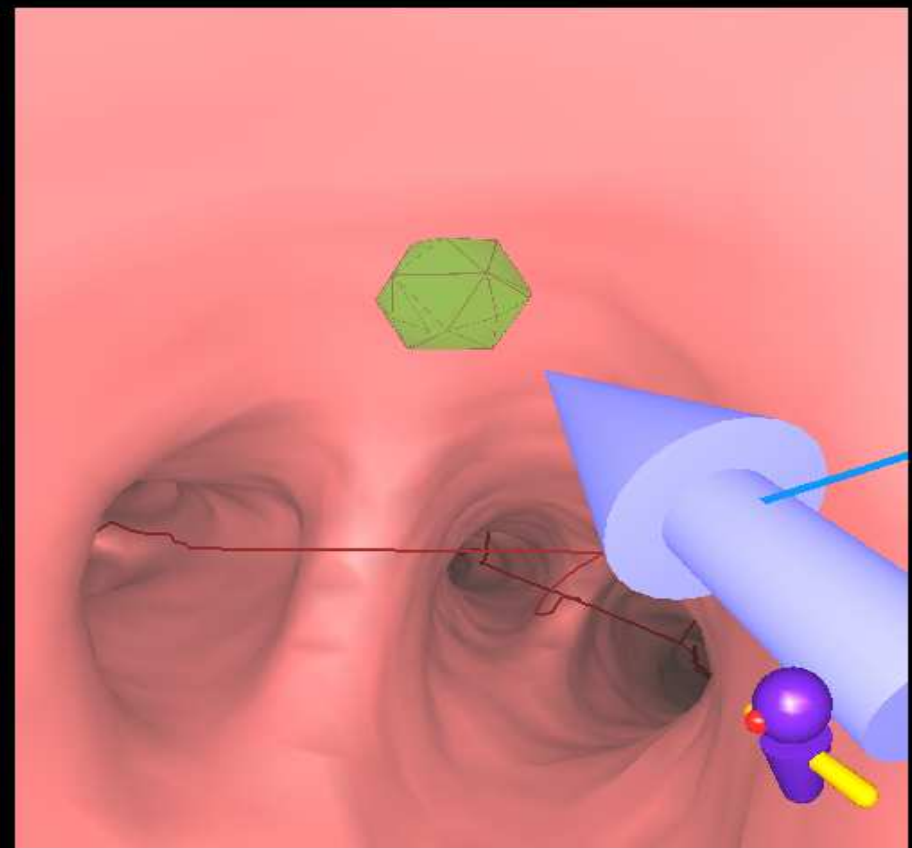
Live Bronchoscopic Guidance - Movie

- Blue line shows desired route
- Blue arrow shows final destination



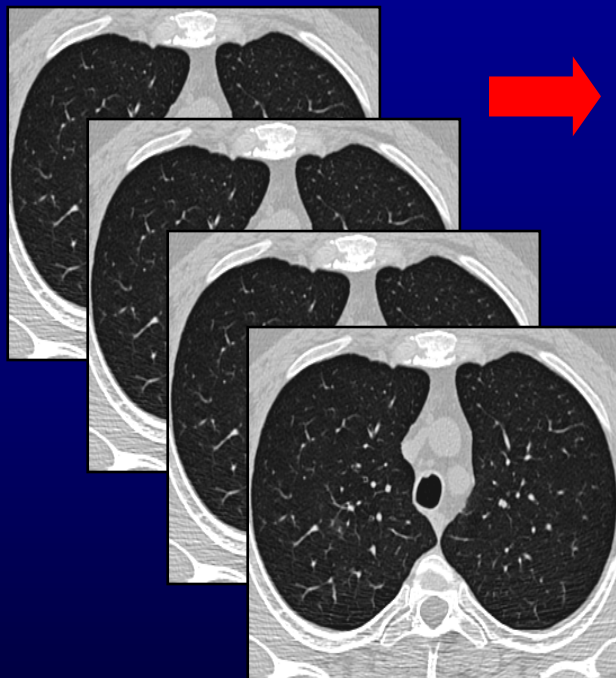
Dist to ROI2 Center = 7.0 mm

Videobronchoscope

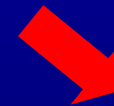
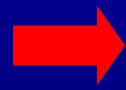


Virtual View

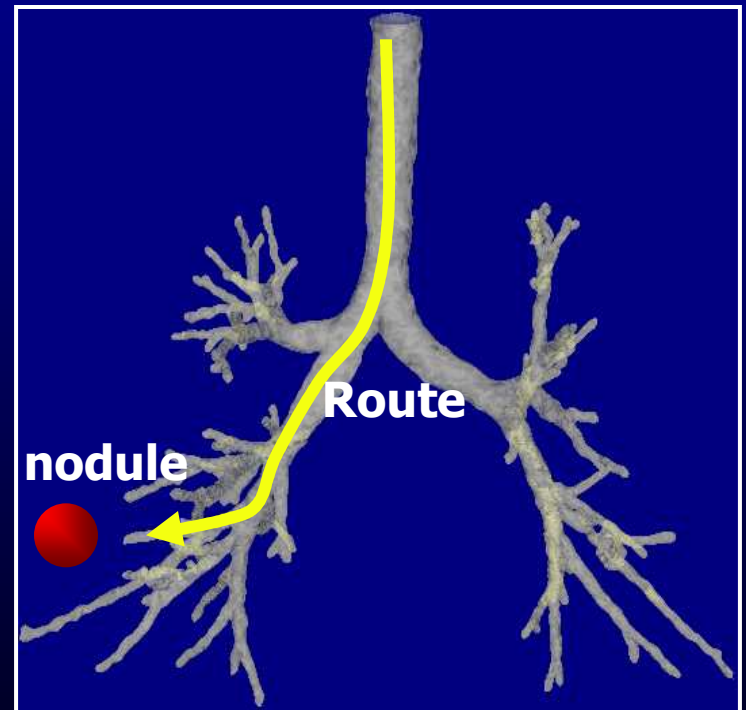
Mental 3D Route Planning to Peripheral Nodules Difficult



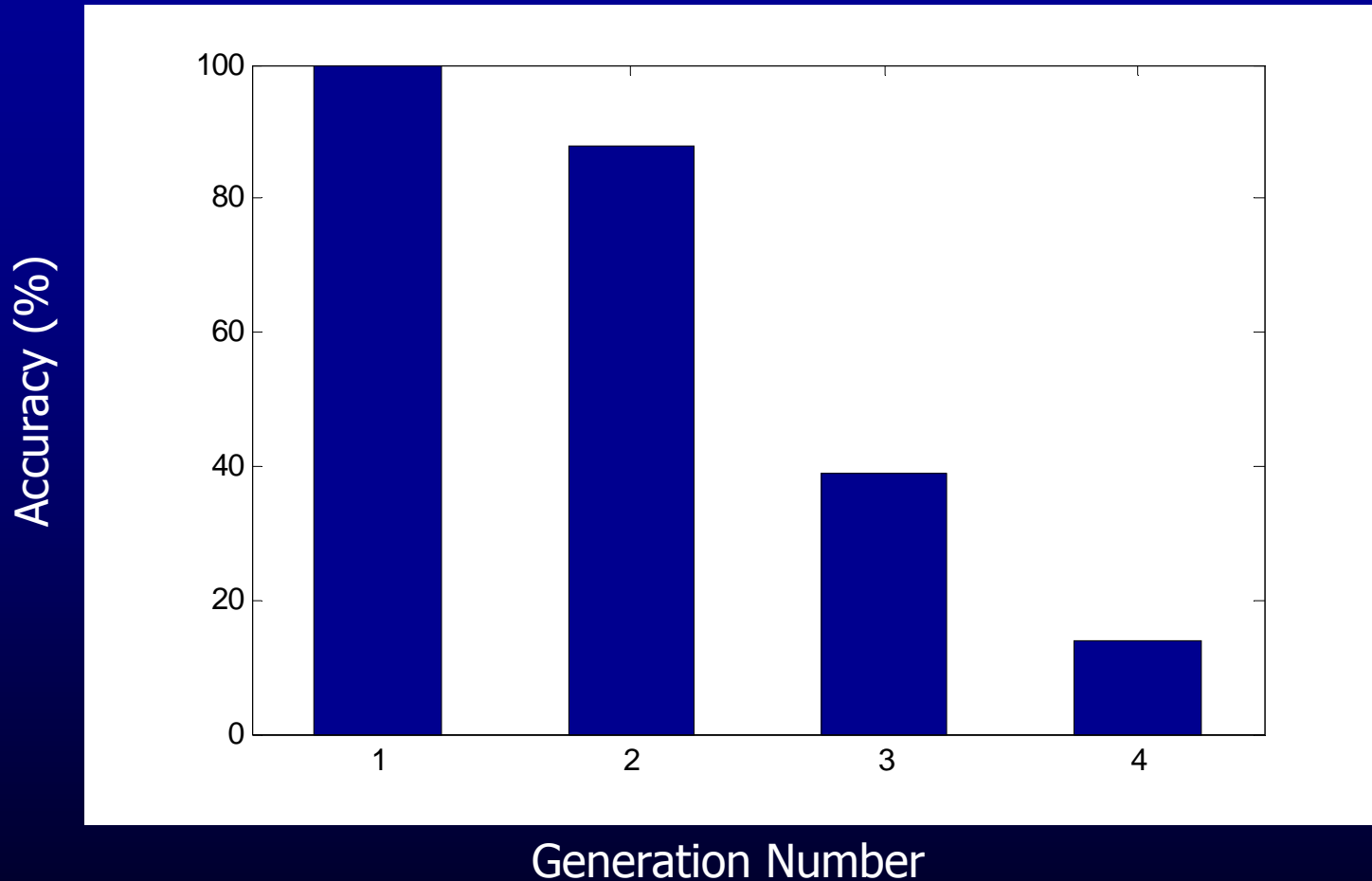
3D CT chest image



Airway tree



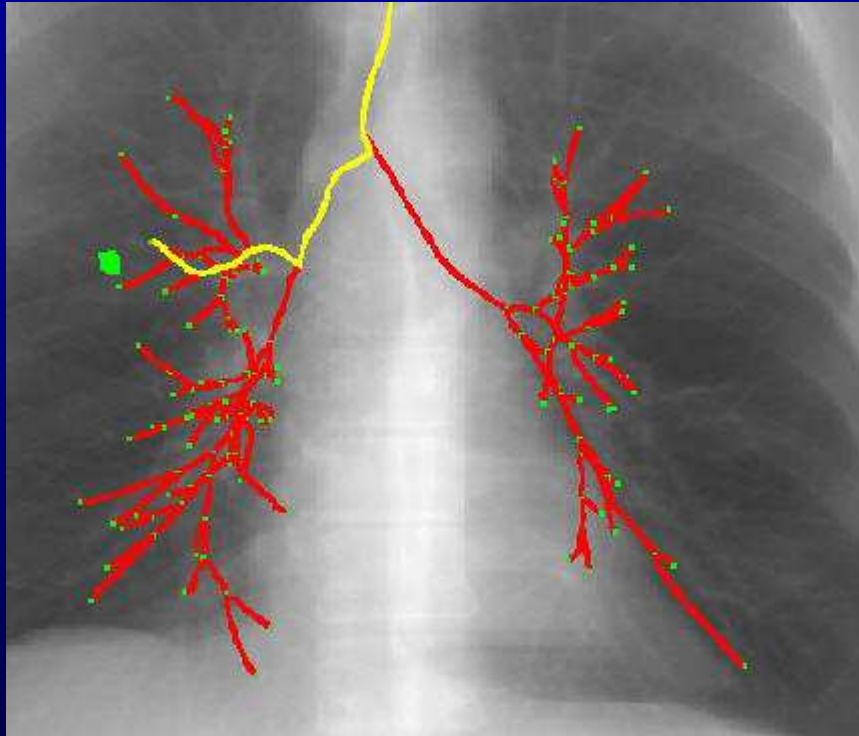
CT-Based Route Planning Performance Deteriorates Rapidly



Dolina *et al.*, "Comparison of Transverse Chest CT Images and a Virtual Navigation Endoluminal Image for Bronchoscopy Path Selection to Endoluminal Pulmonary Nodules," *ATS 2006*.

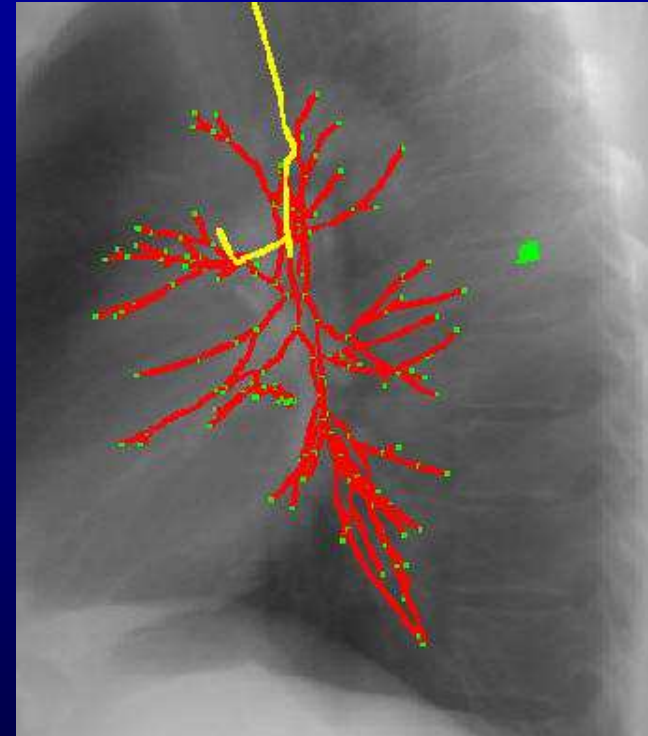
Fluoroscopy can be very misleading

Coronal Projection



Route appears to go to nodule

Sagittal Projection



Route actually going the wrong way!