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

2. Guided Bronchoscopy
   - Simple PC interface
   - CT, video registered
   - Augmented vision
Real-Time Registration/Fusion

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

Real Bronchoscope Image Observed at Time $t$

Virtual Bronchoscope Image Generated at Pose $\Theta$

Real World

Virtual World

CT Scan

Physical airway tree

3D CT Slices

CT-Derived Virtual Airway Tree

Real Bronchoscope Tip

Virtual Bronchoscope Tip - Located at Pose $\Theta$

Figure 19.4, Wang/Mehta '95
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

**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

<table>
<thead>
<tr>
<th></th>
<th>STANDARD</th>
<th>IMAGE-GUIDED</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hit Rate %</td>
<td>Position Error mean±SD (Range)</td>
<td>Hit Rate %</td>
</tr>
<tr>
<td>Overall</td>
<td>43.3%</td>
<td>9.74 ± 9.09 (0.19-39.12)</td>
<td>94.2%</td>
</tr>
<tr>
<td>Clinical Fellows</td>
<td>45.0%</td>
<td>9.46 ± 8.92 (0.72-38.72)</td>
<td>98.3%</td>
</tr>
<tr>
<td>Experienced Physicians</td>
<td>41.7%</td>
<td>10.03 ± 9.32 (0.19-39.12)</td>
<td>90.0%</td>
</tr>
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</table>

**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)

<table>
<thead>
<tr>
<th>Generation # (# of ROIs)</th>
<th>Overall</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard</td>
<td>Guided</td>
</tr>
<tr>
<td>1 (10)</td>
<td>5.00</td>
<td>5.00</td>
</tr>
<tr>
<td>2 (10)</td>
<td>4.97</td>
<td>4.99</td>
</tr>
<tr>
<td>3 (9)</td>
<td>4.81</td>
<td>4.96</td>
</tr>
<tr>
<td>4 (7)</td>
<td>4.71</td>
<td>4.96</td>
</tr>
<tr>
<td>5 (4)</td>
<td>4.67</td>
<td>4.94</td>
</tr>
<tr>
<td>6 (4)</td>
<td>4.57</td>
<td>4.92</td>
</tr>
<tr>
<td>7 (1)</td>
<td>4.23</td>
<td>4.92</td>
</tr>
</tbody>
</table>

- **Standard**: Physician stays confident even though performance drops
- **Guided**: Physician consistently very confident throughout
## Impact of Method Order on Performance (Learning Effect?)

<table>
<thead>
<tr>
<th></th>
<th>All Physicians</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard</td>
</tr>
<tr>
<td>No Experience</td>
<td>46.7%</td>
</tr>
<tr>
<td>After Exposure to Other Method</td>
<td>40.0%</td>
</tr>
<tr>
<td>Increase in Hit Rate</td>
<td>-6.7% (+4 misses)</td>
</tr>
<tr>
<td>One-tailed p Value</td>
<td>0.842</td>
</tr>
</tbody>
</table>

- 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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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 Bronchoscoposcopic Guidance - Movie

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

Videobronchoscope

Virtual View

Dist to ROI2 Center = 7.0 mm
Mental 3D Route Planning to Peripheral Nodules Difficult

3D CT chest image

Mental Planning

Airway tree

Route

nodule
Fluoroscopy can be very misleading

Coronal Projection

Route appears to go to nodule

Sagittal Projection

Route actually going the wrong way!