Image-guided Breast Interventions: Ultrasound and Stereotactic

Ingrid Reiser, PhD DABR
Department of Radiology, The University of Chicago
July 2018

Outline

- Clinical aspects of breast cancer screening and breast interventions
- Mammography biopsy guidance
- Stereotactic imaging
- System configurations
- Tomosynthesis biopsy guidance
- Ultrasound biopsy guidance
Early signs of breast cancer

Spiculated mass

MLO view


Image-guided breast interventions

Image-guided biopsy

Image-guided localization

Image-guided breast biopsy

• Advantage over excisional biopsy: Similar accuracy with fewer complications
• Imaging techniques:
  • Ultrasound
  • Stereotactic breast biopsy (SBB)
  • MRI
Stereotactic biopsy
- Prone
- Upright/lateral

US-guided biopsy

MRI-guided biopsy

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**Imaging techniques**

- Non-palpable masses:
  - Overall: 83% needle biopsies
  - Stereotactic biopsy most common (52%) for non-palpable tumors
  - Reasons for excisional biopsy:
    - Too far, too superficial, to posterior (5%)
    - Patient preference (5%)
    - Small (<1cm) or superficial, easier to excise (4%)

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**Imaging techniques**

- Palpable masses

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Clinical performance

- Procedures:

<table>
<thead>
<tr>
<th>Method</th>
<th>US</th>
<th>MRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBB (table)</td>
<td>2570</td>
<td>544</td>
</tr>
<tr>
<td>SBB (upright)</td>
<td>5308</td>
<td>544</td>
</tr>
</tbody>
</table>

- Technical success rates:

<table>
<thead>
<tr>
<th>Method</th>
<th>US</th>
<th>MRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBB</td>
<td>99.1%</td>
<td>99.0%</td>
</tr>
<tr>
<td>SBB (table)</td>
<td>99.6%</td>
<td>98.4%</td>
</tr>
</tbody>
</table>

- Complications:

<table>
<thead>
<tr>
<th>Method</th>
<th>US</th>
<th>MRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBB</td>
<td>4%</td>
<td>8%</td>
</tr>
</tbody>
</table>


Sampling techniques: FNA, CB, VAB

<table>
<thead>
<tr>
<th>Lesion type</th>
<th>Fine-needle aspiration</th>
<th>Core biopsy</th>
<th>Vacuum-assisted biopsy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malignant</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Microcalcification</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Asymmetric density</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Axillary lymph node</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

- Primarily US guidance
- Primarily mammography guidance

Stereotactic biopsy principle

- Fixed reference frame
- Lesion coordinates
  - Breast is fixed in space between breast support plate and compression paddle
  - Stereo image pair to determine target lesion coordinates
- Biopsy needle positioning device
  - Moves needle to target coordinates
**Stereotactic biopsy system**

- Needle guidance system
- Breast imaged within reference frame

**Needle mount and firing mechanism**

- Fixed reference frame
- Breast is fixated in space between breast support plate and compression paddle
- Stereo image pair to determine target lesion coordinates
- System calculates target x,y,z based on images

**Needle positioning**

- Fixed reference frame
- Breast is fixated in space between breast support plate and compression paddle
- Stereo image pair to determine target lesion coordinates
- System calculates target x,y,z based on images
- Guidance system automatically positions needle x,y
- Z-positioning such that needle trough is under lesion post-firing
Needle z-positioning and firing

- **Stroke**: Distance needle moves when fired
- **Pre-fire Z positioning**: Needle is advanced manually to a pull-back distance (differential)
- **Pull-back** is determined such that firing will advance center of trough underneath lesion (depends on needle)

- **Pre-fire Stroke**
- **Post-fire Stroke Margin**

Trough length and dead space varies for needle makers and sizes.

Stroke Margin

- **Distance from needle tip to breast support, after firing**

Stroke margin needs to be positive ...

Stereo imaging

Biopsy procedure

• Biopsy site(s) marked at mammography (skin markers)

Biopsy target near center of biopsy window
**Biopsy procedure**

- Acquisition of stereo pair
- Biopsy location marked

**Stereo pair**

Horizontal line helps guide marker placement

**Biopsy procedure**

Target is marked, system calculates target coordinates

Coordinates are transmitted to needle guidance system

**Biopsy procedure**

Pre-fire stereo pair to verify needle positioning

If target is lined up with needle, fire
Biopsy procedure

Post-fire stereo pair

If needle location is good, obtain samples

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Tissue samples

- Typical needle gauge: 9 (3.78 mm OD)
- Vacuum-assist biopsy device
- Immediate imaging of core samples (faxitron)
- Place marker

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Biopsy procedure

Marker placement
Marking the biopsy site

- Obtain post-procedure mammogram to verify marker location

Error due to uncertainty

- Lesion more shallow than calculated (+3/-3mm error on +15/-15 views)
- Lesion deeper than calculated (-3/+3mm error on +15/-15 views)

Error due to uncertainty

- Can affect targeting of small masses
- Can cause failure during positioning QA (within few mm)
Failed stereo localization

Positioning
Clinical systems

Prone SBB table

Upright add-on system

Prone table vs. upright system

Table
• Greater patient comfort if patient can lie prone
• Limit on patient weight
• Positioning can be difficult
• Dedicated unit, space requirements
• Few vasovagal events

Upright
• Add-on to mammographic unit
• Efficient space use
• Easier positioning, overall faster procedure
• Potential for vasovagal event

Stereo guidance → Tomosynthesis guidance
Tomosynthesis Basics

Depth resolution in DBT depends on detail size, and is poor except for small targets or sharp margins.

Tomosynthesis-guided biopsy principle

- Tomosynthesis reconstructed image space provides the target reference frame
  - Target lesion location is marked in the DBT volume
  - No need for marking in stereo images
  - System is still capable of performing stereo imaging

- Biopsy device reference frame is defined by the DBT volume
Tomosynthesis-guided stereotactic biopsy

- Position lesion near center of biopsy window
- DBT biopsy images, lesion marked in in-focus slice
- Prefire stereo pair
- Postfire stereo pair
- Post-biopsy tomo

Biopsy display window. After target selection on scout DBT images, the touch-screen display window depicts the lesion's coordinates and confirms location of needle and target within the breast.
DBT for biopsy planning “scout DBT”

In-focus slice [21]

Pre-fire shot 1
Pre-fire shot 2

Post-fire shot 2
Post-fire shot 1

Post-biopsy DBT

In-focus slice [21]
screening digital mammograms of the right breast in a 51-year-old asymptomatic woman demonstrate an architectural distortion in the right upper outer quadrant.

DBT VAB vacuum-assisted biopsy in the lateral decubitus position

74 × 62-mm biopsy window
CC DBT for biopsy planning

Re-identify architectural distortion and indicate the position of the target with a cursor
Coordinates are automatically determined by the biopsy software

Post-fire stereotactic images

Post-fire DBT. The arrow marks the tip of the needle.

Post-procedure DBT and c-view after clip placement

Histologic findings: radial scar

The time needed to perform the entire intervention was 12 minutes:
4 minutes to target the lesion and obtain the needle trajectories
8 minutes were needed to perform the tissue sampling.
**Procedure time**

**Total intervention**

**Biopsy procedure**

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**DBT vs. Prone Stereotactic (PS)**

Schrading et al:
- **Success:** 100% with DBT VAB vs. 93% with PS VAB
- **Mean time:** $13 \pm 3.7$ mins DBT vs. $29 \pm 10.1$ SB.
- **Time for tissue sampling same**
- **DBT successful in one of 11 lesions in which PS failed**
- **Significantly more “low-contrast” (ie, uncalcified) biopsied with DBT vs. PS**
- **One vasovagal in DBT and PS**

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**Biopsy guidance with ultrasound**
**Sampling techniques: FNA, CB, VAB**

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<th>Core biopsy</th>
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<tr>
<td>Mass</td>
<td>++</td>
<td>++</td>
<td>+</td>
</tr>
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<td>++</td>
<td>++</td>
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</tr>
<tr>
<td>Asymmetry density</td>
<td>++</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Auxiliary lymph node</td>
<td>++</td>
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</table>

Primarily US guidance


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**Biopsy guidance with US: System requirements**

Same requirements as diagnostic breast imaging (ACR practice guidelines):

- High-resolution, real-time, linear-array, broad-bandwidth transducer
- Center frequency of at least 12 MHz
- Focal zones should be electronically adjustable
- Penetration depth of at least 4 cm with good spatial resolution
- Depiction of a 20-gauge needle in breast parenchyma along the image plane
- Good differentiation of breast tissues
- Good visualization of tumor margins, cysts, mass irregularities

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**Sampling techniques**

Vacuum-assisted biopsy device (VAB), 7G (4.57mm)

Core-needle biopsy (CN), 14 G (2.11mm)

Fine-needle aspiration (FNA), 21 G (0.82mm)

Performing the biopsy

Pre-core

Post-core

Pre-clip

Post-clip

Good positioning

Needle positioning

- Biopsy needle needs to be guided parallel to the transducer and chest wall, as horizontal as possible
- Needle needs to be exactly in center of transducer, in the image plane
- Press transducer as needed to achieve horizontal skin contact
- Slide transducer parallel to needle to achieve maximal visualization of the needle
Needle not parallel to transducer axis – needle tip cannot be reliably identified

Needle axis at angle to transducer axis (transducer at angle to chest wall)

Skin puncture site too close to transducer end, making it difficult to reach deep lesion (needle should not be tilted towards chest wall)

No comment

Potential complications

- **Thorax puncture**: If needle is pointed towards the thoracic wall during biopsy, it is possible to puncture the thorax, resulting in potentially life-threatening complications.
  - Needle should be kept parallel to the thoracic wall as much as possible!
- **Missed biopsy**: While accuracy of US-guided biopsy is high, the target might be missed. For hard to visualize lesions (microcalcifications), specimen imaging needs to be performed to correlate with imaging findings.


Achieving good results

- **PRACTICE**
  - Coordination of needle and transducer movements in three dimensions
  - Lesion needs to be kept in image plane, transducer and needle axes kept parallel
  - Lesion visualization may become difficult when air is introduced into the biopsy site and the lesion begins to bleed. This can affect small or difficult to visualize lesions
  - Small lesions (<5mm) may become completely excised and not detectable for surgical planning

US biopsy training phantoms - commercial

Home-made training phantoms

https://youtu.be/vk_6n3t/NfNM
Microcalcification clusters?

Mary Scott Soo et al, Sonographic Detection and Sonographically Guided Biopsy of Breast Microcalcifications. AJR 2003 180(4), 941-948

Suspicious microcalcifications seen on ultrasound (~20%) can be biopsied successfully under US guidance.

Image quality requirements

<table>
<thead>
<tr>
<th>Adequate image quality</th>
<th>Insufficient image quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient imaged on two different US units 2 weeks apart, identical model/make</td>
<td>Same imaging parameters</td>
</tr>
</tbody>
</table>
Bad transducer?

Good system

Bad system

Transducers swapped

Imaging a tissue-mimicking home-made test phantom

Good system

Bad system

Solution:
Service replaced all channel boards

Same imaging parameters

Thoughts ...

• Both the “good” and “bad” systems passed ACR annual QC testing two weeks prior
• Phantom images: Notable difference between both systems was depth of penetration
• Current testing requirements:
  • Current test verifies change compared to prior year
  • No minimum depth of penetration specified
  • Elevational resolution testing not included
  • Multi-purpuse US QC phantoms contain cylindrical elements
Summary

- Minimally invasive breast biopsy includes FNA, CNB and VAB
  - Stereotactic and Ultrasound guidance
  - Imaging modality is chosen so as to best visualize lesion
- Stereotactic guidance:
  - Relatively straightforward to perform
  - Prone: long procedure time, but reduced risk of vasovagal events
  - DBT: Facilitates targeting, available as upright and prone systems
- Ultrasound guidance:
  - Requires highly skilled and experienced radiologist

Conclusions

- Interventional imaging equipment:
  - Physics support to help ensure high quality imaging, optimum system performance
- Risk/Benefit:
  - Dose is of some concern
  - Real risks are incorrect sampling due to poorly visualized lesions
  - Focus on image quality

Acknowledgments

D. Sheth, MD
K. Kulkarni, MD
Morlie Wang, MD
S. Orban
Z. F. Lu, PhD
K. Little, PhD
Thank you

Questions?