Image-guided Breast Interventions: Ultrasound and Stereotactic

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THE UNIVERSITY OF CHICAGO

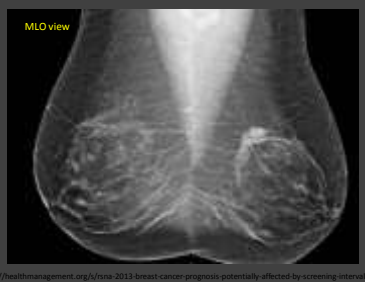
Outline

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

ACR.org

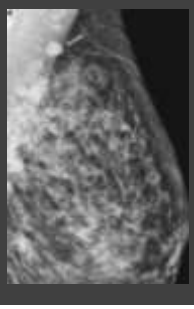
Early signs of breast cancer

Spiculated mass

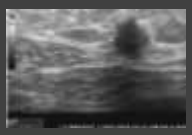


https://healthmanagement.org/s/rsna-2013-breast-cancer-prognosis-potentially-affected-by-screening-intervals

https://healthmanagement.org/s/rsna-2013-breast-cancer-prognosis-potentially-affected-by-screening-intervals



47-year-old with a 9 mm mass histologically proven to be a DCIS



M.K. Shetty (ed.), *Breast Cancer Screening and Diagnosis: A Synopsis*. Springer Science+Business Media New York 2015 93

Image-guided breast interventions

Image-guided biopsy

Image-guided localization

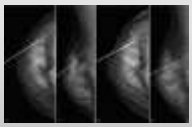


Image-guided breast biopsy

- 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

E.A.M. O'Flynn, "Image-guided breast biopsy: state-of-the-art", Clinical Radiology 65 (2010) 259–270

Imaging techniques

All

D. R. Lannin, T Ponn, L. Andrejeva, L. Philpotts, Should all breast cancers be diagnosed by needle biopsy? The American Journal of Surgery 192 (2006) 450–454

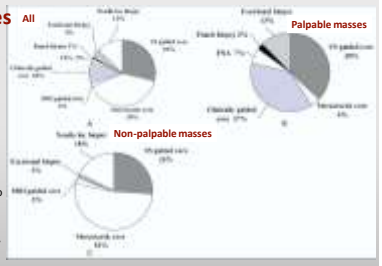
Imaging techniques

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

All

Palpable masses

Non-palpable masses



D. R. Lannin, T Ponn, L. Andrejeva, L. Philpotts, Should all breast cancers be diagnosed by needle biopsy? The American Journal of Surgery 192 (2006) 450–454

Clinical performance

- Procedures:

SBB	US	MRI
5308 (table) 544 (upright)	2570	544

- Technical success rates:

SBB	US	MRI
99.1%	99.6%	98.4%

- Complications

SBB	US	MRI
6% (table) 5% (upright)	4%	8%

T. Imschweiler et al. MRI-guided vacuum-assisted breast biopsy: comparison with stereotactically guided and ultrasound-guided techniques. Eur Radiol (2014) 24:128–135

Sampling techniques: FNA, CB, VAB

Comparison of sampling choice for specific lesion type

Lesion type	Fine-needle aspiration	Core biopsy	Vacuum-assisted biopsy
Mass	+	+++	+
Microcalcification		+	+++
Asymmetric density		+	+++
Axillary lymph node	+++	+	

Primarily US guidance

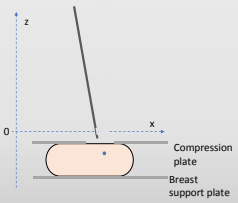
Primarily mammography guidance

E.A.M. O'Flynn, "Image-guided breast biopsy: state-of-the-art", Clinical Radiology 65 (2010) 259–270

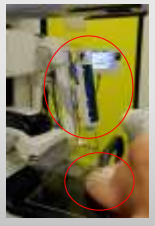
Stereotactic biopsy principle

Fixed reference frame

- Lesion coordinates
  - Breast is fixated 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



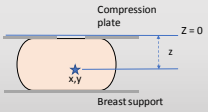
Needle guidance system

Breast imaged within reference frame

"Digital Breast Tomosynthesis-guided Vacuum-assisted Breast Biopsy: Initial Experiences and Comparison with Prone Stereotactic Vacuum-assisted Biopsy" Simone Schrading. Radiology Vol. 274, No. 3: 654-66. Copyright RSNA, 2015

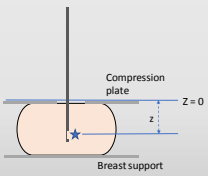
Needle mount and firing mechanism

- 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



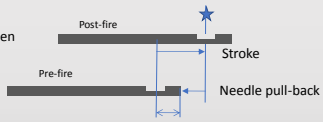
Needle positioning

- 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)

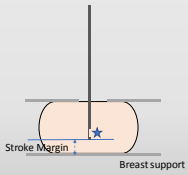


Trough length and dead space varies for needle makers and sizes

Stroke Margin

- Distance from needle tip to breast support, after firing

Stroke margin needs to be positive ..



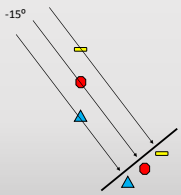
Stereo imaging

SH Parker et al, Stereotactic Breast Biopsy with a Biopsy Gun. **Radiology 1990**; 176:741-747.

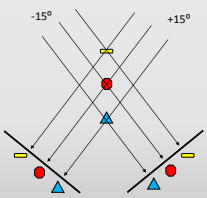
Stereo Basics

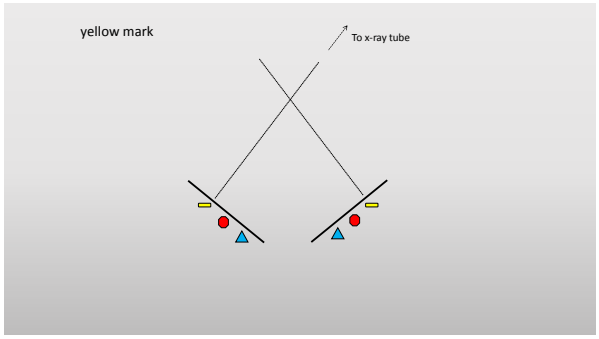
K. Kulkarni, MD

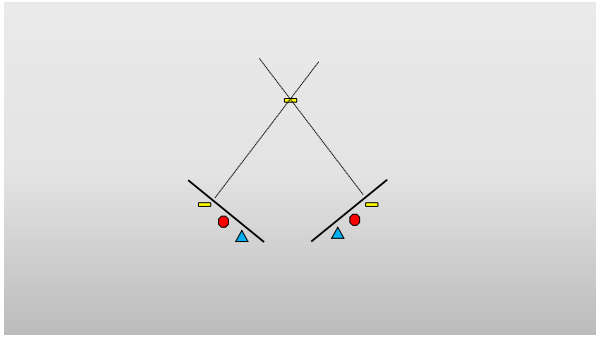
First Stereo Image

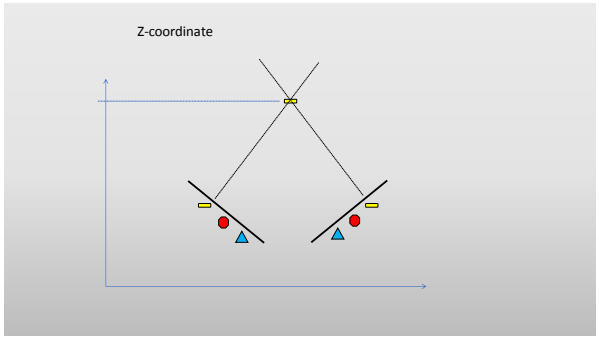


Second Stereo Image




yellow mark
To x-ray tube

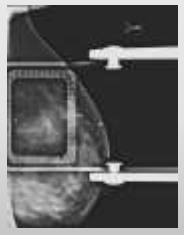



Z-coordinate

Biopsy procedure

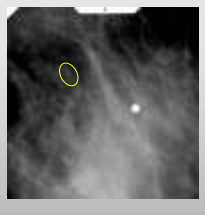
Biopsy procedure

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



Biopsy procedure

Biopsy target near center of biopsy window



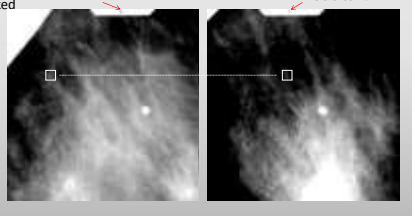
Biopsy procedure

- Acquisition of stereo pair
- Biopsy location marked

Horizontal line helps guide marker placement

Stereo pair

Reference mark



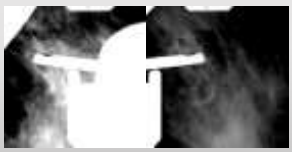
Biopsy procedure

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

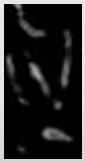
Biopsy procedure

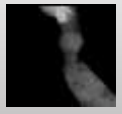
Post-fire stereo pair

If needle location is good, obtain samples

Tissue samples

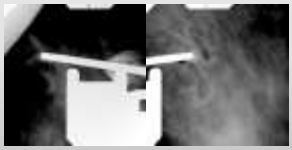
- Typical needle gauge: 9 (3.78 mm OD)
- Vacuum-assist biopsy device
- Immediate imaging of core samples (faxitron)
- Place marker





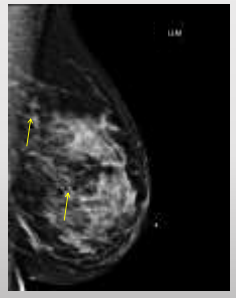
Biopsy procedure

Marker placement

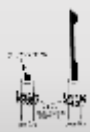


Marking the biopsy site

- Obtain post-procedure mammogram to verify marker location

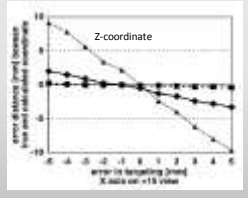


Error due to uncertainty



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

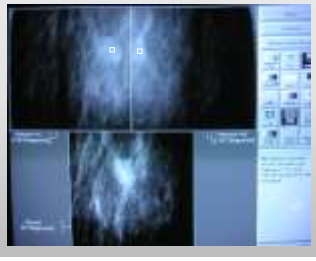
Lesion deeper than calculated
(-3/+3mm error on +15/-15 views)

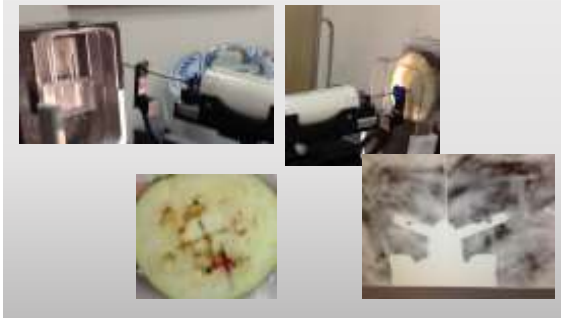


JJ Carr et al, Stereotactic localization of breast lesions: How it works and methods to improve accuracy. RadioGraphics 2001; 21:463–473

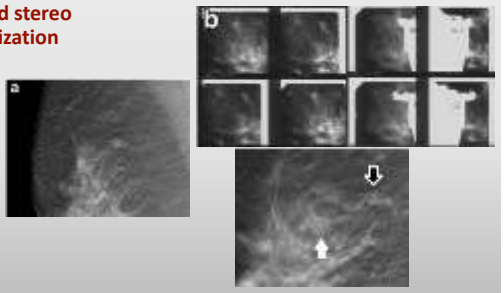
Error due to uncertainty

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



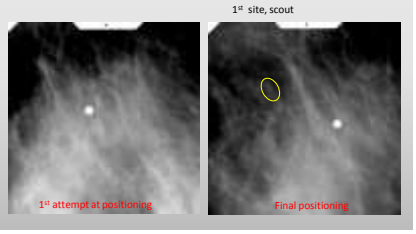


Failed stereo localization

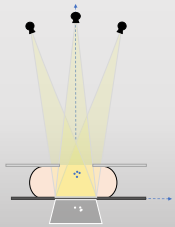


Waldherr C, Berclaz G, Altermatt HJ, et al. Tomosynthesis-guided vacuum-assisted breast biopsy: A feasibility study. Eur Radiol 2016; 26: 1582–9

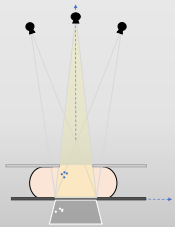
Positioning



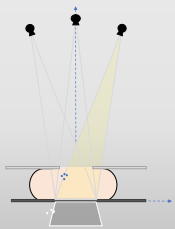
Stereo acquisition with fixed detector



Proximal lesion off-centered on scout



Proximal lesion off-centered on scout



Clinical systems

Prone SBB table

Upright add-on system

Biopsy-unit as add-on for mammography systems

ML Huang et al. Stereotactic breast biopsy: Pitfalls and Pearls. Tech Vasc Interventional Rad 17:32-39

Prone table vs. upright system

Table

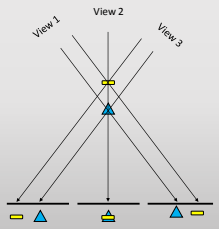
- Greater patient comfort if patient can lie prone
- Limit on patient weight
- Positioning can be difficult
- Dedicated unit, space requirements
- Few vasovagal events

Upright

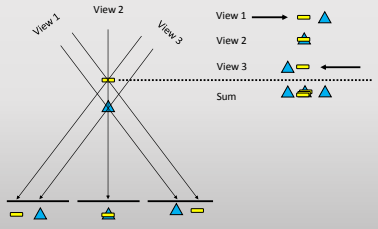
- Add-on to mammographic unit
- Efficient space use
- Easier positioning, overall faster procedure
- Potential for vasovagal event

Stereo guidance → Tomosynthesis guidance

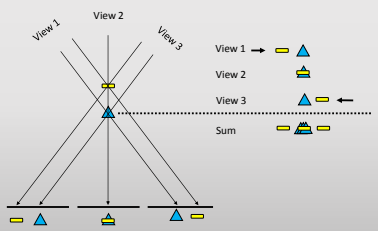
Tomosynthesis Basics



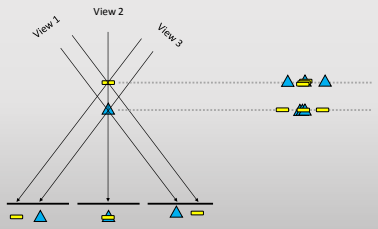
Tomosynthesis Basics



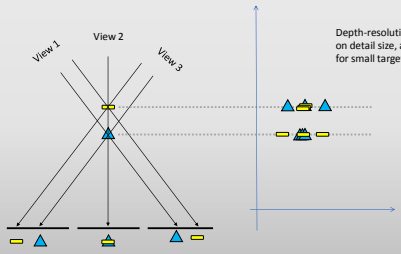
Tomosynthesis Basics



Tomosynthesis Basics



Tomosynthesis Basics



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

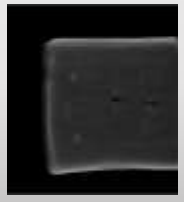
Tomosynthesis-guided stereotactic biopsy

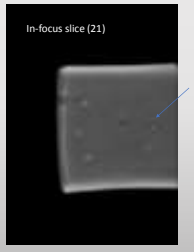
- Position lesion near center of biopsy window
- DBT biopsy images, lesion marked in in-focus slice
- Prefire stereo pair
- Postfire stereo pair
- Post-biopsy tomo

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**.

Implementation of Upright Digital Breast Tomosynthesis-guided Stereotactic Biopsy. Toma S. Omofoye, MD, Sarah Martaindale, MD, Davis C. Teichgraeber, MD, Jay R. Parikh, MD, FACR Acad Radiol 2017; 24:1451–1455

DBT for biopsy planning “scout DBT”





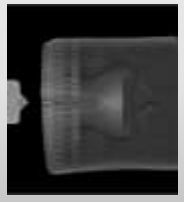
Pre-fire shot 1

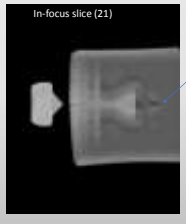
Pre-fire shot2

Post-fire shot 2

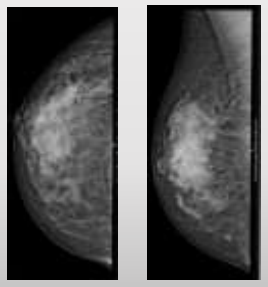
Post-fire shot1

Post-biopsy DBT





screening digital mammograms of the right breast in a 51-year-old asymptomatic woman demonstrate an architectural distortion in the right upper outer quadrant.



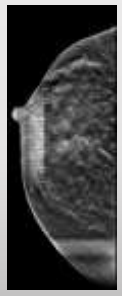
"Digital Breast Tomosynthesis-guided Vacuum-assisted Breast Biopsy: Initial Experiences and Comparison with Prone Stereotactic Vacuum-assisted Biopsy". Simone Schrading et al. Radiology Vol. 274, No. 3: 654-66. Copyright RSNA, 2015

DBT VAB vacuum-assisted biopsy in the lateral decubitus position

74 × 62-mm biopsy window

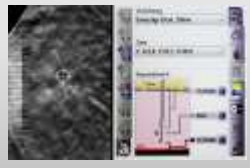
"Digital Breast Tomosynthesis-guided Vacuum-assisted Breast Biopsy: Initial Experiences and Comparison with Prone Stereotactic Vacuum-assisted Biopsy" Simone Schrading. Radiology Vol. 274, No. 3: 654-66. Copyright RSNA, 2015

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



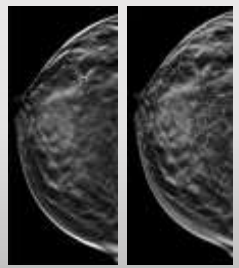
"Digital Breast Tomosynthesis-guided Vacuum-assisted Breast Biopsy: Initial Experiences and Comparison with Prone Stereotactic Vacuum-assisted Biopsy". Simone Schrading et al. Radiology Vol. 274, No. 3: 654-66. Copyright RSNA, 2015

Post-fire stereotactic images

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

"Digital Breast Tomosynthesis-guided Vacuum-assisted Breast Biopsy: Initial Experiences and Comparison with Prone Stereotactic Vacuum-assisted Biopsy". Simone Schrading et al. Radiology Vol. 274, No. 3: 654-66. Copyright RSNA, 2015

Post-procedure DBT and c-view after clip placement



Histologic findings: radial scar

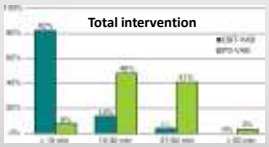
The time needed to perform the entire intervention was 12 minutes:

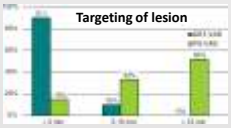
4 minutes to target the lesion and obtain the needle trajectories

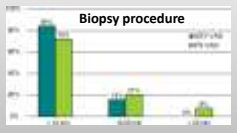
8 minutes were needed to perform the tissue sampling.

"Digital Breast Tomosynthesis-guided Vacuum-assisted Breast Biopsy: Initial Experiences and Comparison with Prone Stereotactic Vacuum-assisted Biopsy". Simone Schrading et al. Radiology Vol. 274, No. 3: 654-66. Copyright RSNA, 2015

Procedure time







Simone Schrading et al, "Digital Breast Tomosynthesisguided Vacuum-assisted Breast Biopsy: Initial Experiences and Comparison with Prone Stereotactic Vacuum-assisted Biopsy". Radiology Vol. 274, No. 3: 654-66. Copyright RSNA, 2015

DBT vs. Prone Stereotactic (PS)

Schrading et al:

- Success: 100% with DBT VAB vs. 93% with PS VAB
- Mean time: **13±3.7** mins DBT vs**. 29±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

Simone Schrading et al, "Digital Breast Tomosynthesisguided Vacuum-assisted Breast Biopsy: Initial Experiences and Comparison with Prone Stereotactic Vacuum-assisted Biopsy". Radiology Vol. 274, No. 3: 654-66. Copyright RSNA, 2015

Biopsy guidance with ultrasound

Sampling techniques: FNA, CB, VAB

Comparison of sampling choice for specific lesion type

Lesion type	Fine-needle aspiration	Core biopsy	Vacuum-assisted biopsy
Mass	+	+++	+
Microcalcification		+	+++
Asymmetric density		+	+++
Axillary lymph node	+++	+	

Primarily US guidance

E.A.M. O'Flynn, "Image-guided breast biopsy: state-of-the-art", Clinical Radiology 65 (2010) 259–270

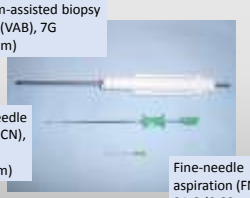
Biopsy guidance with US: System requirements

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

Sampling techniques

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

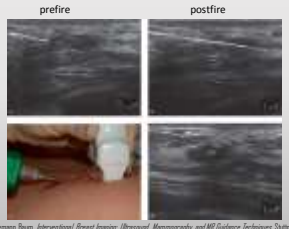


Core-needle biopsy (CN), 14 G (2.11mm)

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

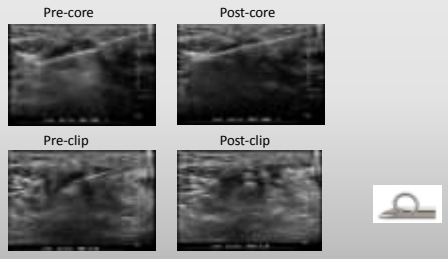
E.A.M. O'Flynn, "Image-guided breast biopsy: state-of-the-art", Clinical Radiology 65 (2010)

Performing the biopsy



Fischer, Uwe, MD, and Friedemann Baum. *Interventional Breast Imaging: Ultrasound, Mammography, and MR Guidance Techniques.* Stuttgart: Thieme Medical Pub., 2010.

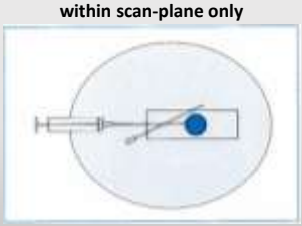
Performing the biopsy



Good positioning

Madjar, H., Ellen B. Mendelson, and Jack Jellins. *The Practice of Breast Ultrasound: Techniques--findings--differential Diagnosis.* Stuttgart; New York: Thieme, 2008.

Visualization of needle portion within scan-plane only

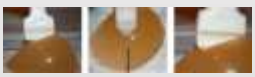


Madjar, H., Ellen B. Mendelson, and Jack Jellins. *The Practice of Breast Ultrasound: Techniques--findings--differential Diagnosis*. Stuttgart: New York: Thieme, 2008.

Needle covering mass

Madjar, H., Ellen B. Mendelson, and Jack Jellins. *The Practice of Breast Ultrasound: Techniques--findings--differential Diagnosis*. Stuttgart: New York: Thieme, 2008.

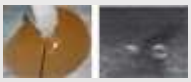
Needle positioning



- 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

Fischer, Uwe, MD, and Friedemann Baum. *Interventional Breast Imaging: Ultrasound, Mammography, and MR Guidance Techniques*. Stuttgart: Thieme Medical Pub., 2010.



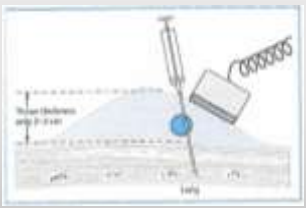
Needle not parallel to transducer axis – needle tip cannot be reliably identified

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)

Fischer, Uwe, MD, and Friedemann Baum. *Interventional Breast Imaging: Ultrasound, Mammography, and MR Guidance Techniques*. Stuttgart: Thieme Medical Pub., 2010.

No comment



Madjar, H., Ellen B. Mendelson, and Jack Jellins. *The Practice of Breast Ultrasound: Techniques--findings--differential Diagnosis*. Stuttgart; New York: Thieme, 2008.

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

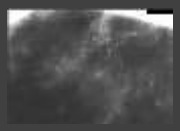
Achieving good results

- **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 my 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

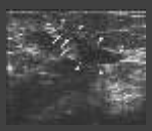
US biopsy training phantoms - commercial

Home-made training phantoms

https://youtu.be/u9_1md1f-NM

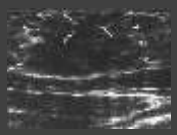


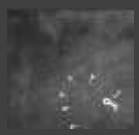
Microcalcification clusters?



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



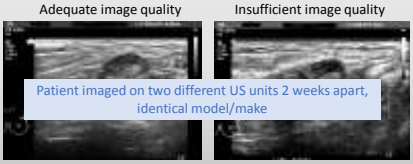


Mary Scott Soo et al, Sonographic Detection and Sonographically Guided Biopsy of Breast Microcalcifications AJR 2003 180:4, 941-948

Image quality requirements

Adequate image quality

Insufficient image quality

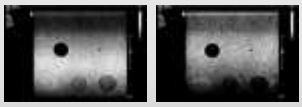


Patient imaged on two different US units 2 weeks apart, identical model/make

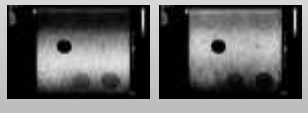
Same imaging parameters

Bad transducer?

Good system | Bad system

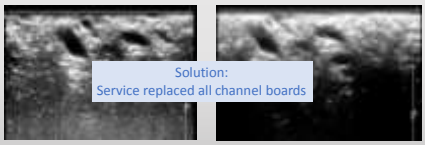


Transducers swapped



Imaging a tissue-mimicking home-made test phantom

Good system | Bad system



Solution:
Service replaced all channel boards

Same imaging parameters

Images courtesy of Z. F. Lu, PhD, University of Chicago

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-purpose US QC phantoms contain cylindrical elements

Summary

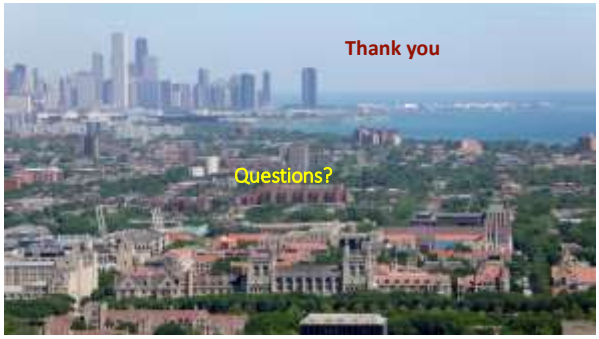
- Minimally invasive breast biopsy includes FNA, CNB and VAB
  - Stereotactic and Ultrasound-guidance
  - Imaging modality is chosen so as to best visualize lesion
- Stereotactic guidance:
  - Relatively straightforward to perform
  - Prone: long procedure time, but reduced risk of vasovagal events
  - 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?