localization accuracy of mammogram-guided breast biopsy

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Breast cancer diagnosis

1 IN 8 WOMEN in the United States will develop breast cancer in her lifetime.

Physical inspection  ultrasound  mammography  biopsy
Breast biopsy techniques

Ultrasound-guided core needle biopsy

Digital stereotactic/tomosynthesis-guided breast biopsy

Courtesy of MAYO foundation for Medical Education and Research (www.mayoclinic.org).
Mammogram-guided Breast Biopsy (SBB) clinical workflow

(1) The patient is positioned (prone/upright) and preliminary localization images are acquired.
Mammogram-guided Breast Biopsy (SBB) clinical workflow

(2) The target is marked on stereo pair or tomosynthesis images and target coordinates is determined.

(3) Needle size is selected (standard or petite) based on the breast thickness and lesion depth.
(4) Automatic targeting system is activated, and the needle is positioned outside the breast on a machine determined reference point.

(5) The needle is manually advanced to the pre-fire position. Pre-fire images are acquired and appropriate positioning of the needle relative to the target is confirmed.

(6) The needle is deployed to the post-fire position and post-fire images are acquired.

(7) Lastly, the vacuum assisted biopsy is performed.
Mammogram-guided Breast Biopsy (SBB) phantom demonstration – Cranio-caudal configuration

Reference point

Pre-fire position

post-fire position
Stereotactic Breast Biopsy

Geometric configuration of target localization: moving detector

- Imaging plane rotates with the x-ray source and it’s always perpendicular to the central x-ray.
- The reference point and center of rotation are located anterior to the breast at the compression plate.
- The z axis is perpendicular to the imaging plane and the z = 0 is anterior to the breast at the reference hole above the biopsy window in the compression plate.
Stereotactic Breast Biopsy

geometric configuration of target localization: stationary detector

- Imaging plane remains stationary and is only perpendicular to the central x-ray at 0 degree.
- The location of $z=0$ is posterior to the breast near the imaging plane, and $z$ increases in value as the object approaches the x-ray source.
- The center of rotation is located behind the breast near the imaging plane.
Stereotactic Breast Biopsy
target localization: depth calculation

- Target location is determined using the stereo pair images:

\[
\tan \theta = \frac{\text{shift}}{2Z} \quad \theta = 15^\circ \\
Z = \frac{\text{shift}}{2 \tan 15} = 1.866 \ast \text{shift}
\]
Stereotactic Breast Biopsy

target localization: phantom demonstration

- Target location is determined using the stereo pair images:

\[ \text{Shift} = 101.7 - 56.8 = 44.90 \text{ mm} \]
\[ Z = 1.866 \times \text{shift} = 1.866 \times 44.9 = 83.77 \text{ mm} \]
\[ T: (53.5, 79.3, 83.8) \text{ mm} \]
Tomosynthesis-guided breast biopsy

**target localization**

- Target position is determined directly on tomosynthesis images: No calculations required!
Localization accuracy test

current daily test performed by a technologist (Hologic)
Localization accuracy test
current annual test performed by a Medical Physicist
Localization accuracy test

current annual test performed by a Medical Physicist
A novel approach for localization accuracy test

test setup

Upright unit lateral arm biopsy

Upright unit cranio-caudal biopsy

Prone unit lateral arm biopsy
A novel approach for localization accuracy test

new localization analysis

nominal stroke length

$A : (x_A, y_A, z_A)$

$B : (x_B, y_B, z_B)$

$C$

$T : (x_T, y_T, z_T)$

$Pre fire position$

$Post fire position$

(i) Stroke length

(ii) Euclidian distance

(iii) Lateral distance

(iv) Longitudinal distance

(A) Pre fire needle position

(B) Post fire needle position

(T) Target

(C) Center of the aperture
A novel localization accuracy test

calculation of point C

1. A 3D line was fitted to points A and B which defines needle’s trajectory. The parametric equation of the line is:

\[
\begin{align*}
  x &= x_A + t(x_B - x_A) \\
  y &= y_A + t(y_B - y_A) \\
  z &= z_A + t(z_B - z_A)
\end{align*}
\]

2. The distance between point \( B : (x_B, y_B, z_B) \) and point \( C : (x_C, y_C, z_C) \) is:

\[
|BC| = |AB||t| \\
|t| = |BC|/|AB|
\]

3. Point C is obtained, by substituting \(|t|\) the \( \overrightarrow{AB} \) parametric equation \((d = |BC|)\)

\[
\begin{align*}
  x_C &= x_A + \frac{d}{|AB|}(x_B - x_A) \\
  y_C &= y_A + \frac{d}{|AB|}(y_B - y_A) \\
  z_C &= z_A + \frac{d}{|AB|}(z_B - z_A)
\end{align*}
\]

\[
|AB| = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2 + (z_B - z_A)^2}
\]
A novel approach for localization accuracy test

(i) **Stroke length error**: The difference between the true stroke length, $|\overrightarrow{AB}|$ and the nominal stroke length

\[
\text{stroke length error} = \left| |\overrightarrow{AB}| - \text{nominal stroke length} \right|
\]

(ii) **Euclidian distance**: The Euclidian distance between the target (T) and center of the needle’s aperture in post-fire position:

\[
|\overrightarrow{TC}| = \sqrt{(x_T - x_C)^2 + (y_T - y_C)^2 + (z_B - z_A)^2}
\]

(iii) **Lateral distance**: The perpendicular (shortest) distance between the target and the needle’s trajectory $\overrightarrow{AB}$:

\[
|T \perp \overrightarrow{AB}| = \frac{|\overrightarrow{AB} \times \overrightarrow{BT}|}{|\overrightarrow{AB}|}
\]

(iv) **Longitudinal distance**: The distance between the projection of the target on needle’s trajectory and the center of the aperture:

\[
\text{longitudinal distance} = \sqrt{|\overrightarrow{TC}|^2 - |T \perp \overrightarrow{AB}|^2}
\]
An excel spreadsheet for localization error calculations
stereotactic-based error analysis

### Depth(Z) calculation

<table>
<thead>
<tr>
<th>YEAR</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-fire needle tip (A)</td>
<td>64.13</td>
<td>60.54</td>
<td>60.48</td>
</tr>
<tr>
<td>Target in Pre-fire (T)</td>
<td>60.00</td>
<td>59.85</td>
<td>59.85</td>
</tr>
<tr>
<td>Post-fire needle tip (B)</td>
<td>64.56</td>
<td>64.73</td>
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### Pre-fire distance calculation

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### Calculation

- Measured stroke length (ABS): 13.00
- Stroke length error: 0.00

### Pre-fire position

- Pre-fire needle position
- Nominal stroke length: 23mm
- Nominal stroke: A: (x1, y1, z1)

### Post-fire position

- Post-fire needle position
- Stroke length: 20mm
- Stroke length error: 0.00

### Diagram

- Image receptor
- Image shift
- Compression paddle
- Target depth
- Breast support
- Z = 0
- Z = 9
Stereotactic-guided biopsy
identification of key points on stereo pair images

Target (T) and pre-fire needle’s tip (A) on pre-fire stereo pair images

Post-fire needle’s tip (B) on post-fire stereo pair images

Pre/post fire images were acquired at different kVps
An excel spreadsheet for localization error calculations

tomosynthesis-based error analysis
Tomosynthesis-guided biopsy
identification of key points on tomosynthesis images

Offline analysis (e.g., on OsiriX DICOM viewer)

In room analysis (i.e., on biopsy unit)
Tomosynthesis-guided biopsy
identification of key points on tomosynthesis images (lateral vs. CC)

Point A
- Value: 905.000
- 2D Pos: X:1276.513 px Y:1643.538 px
- 3D Pos: X:142.287 mm Y:110.287 mm Z:52.289 mm

Point T
- Value: 1023.000
- 2D Pos: X:1286.971 px Y:1567.914 px
- 3D Pos: X:135.761 mm Y:111.191 mm Z:54.322 mm

Point B
- Value: 543.000
- 2D Pos: X:1275.014 px Y:1373.145 px
- 3D Pos: X:118.522 mm Y:110.158 mm Z:53.406 mm

Point A
- Value: 470.000
- 2D Pos: X:1558.627 px Y:1297.574 px
- 3D Pos: X:106.505 mm Y:137.223 mm Z:37.468 mm

Point T
- Value: 1023.000
- 2D Pos: X:1566.328 px Y:1209.551 px
- 3D Pos: X:106.637 mm Y:137.901 mm Z:29.467 mm

Point B
- Value: 851.000
- 2D Pos: X:1618.911 px Y:1250.059 px
- 3D Pos: X:110.018 mm Y:142.532 mm Z:17.220 mm
Conclusion

- A quantitative localization accuracy test allows for trend analysis as well as the comparison across vendors, units, and modes of operation.
- A tolerance level for localization accuracy of biopsy units needs to be established.
- The proposed workflow has the potential to replace the current practice for the annual localization accuracy test.
Thank you.

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