localization accuracy of mammogram-guided breast biopsy

Reyhaneh Nosrati, Da Zhang, Robert MacDougall, Jordana Phillips, Matt Palmer

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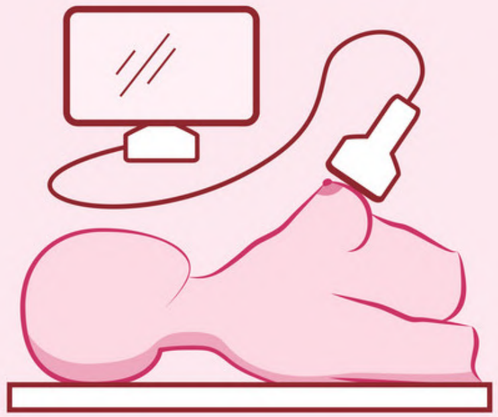
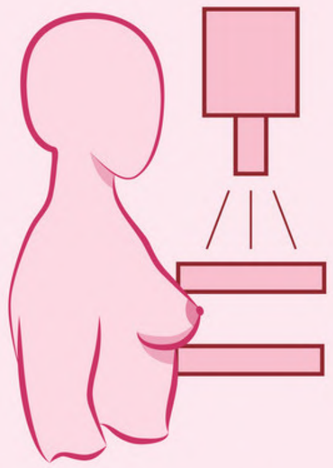
Breast cancer diagnosis

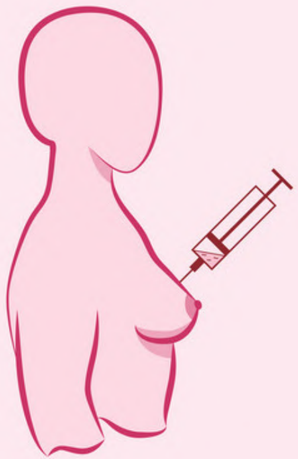
Physical inspection



ultrasound



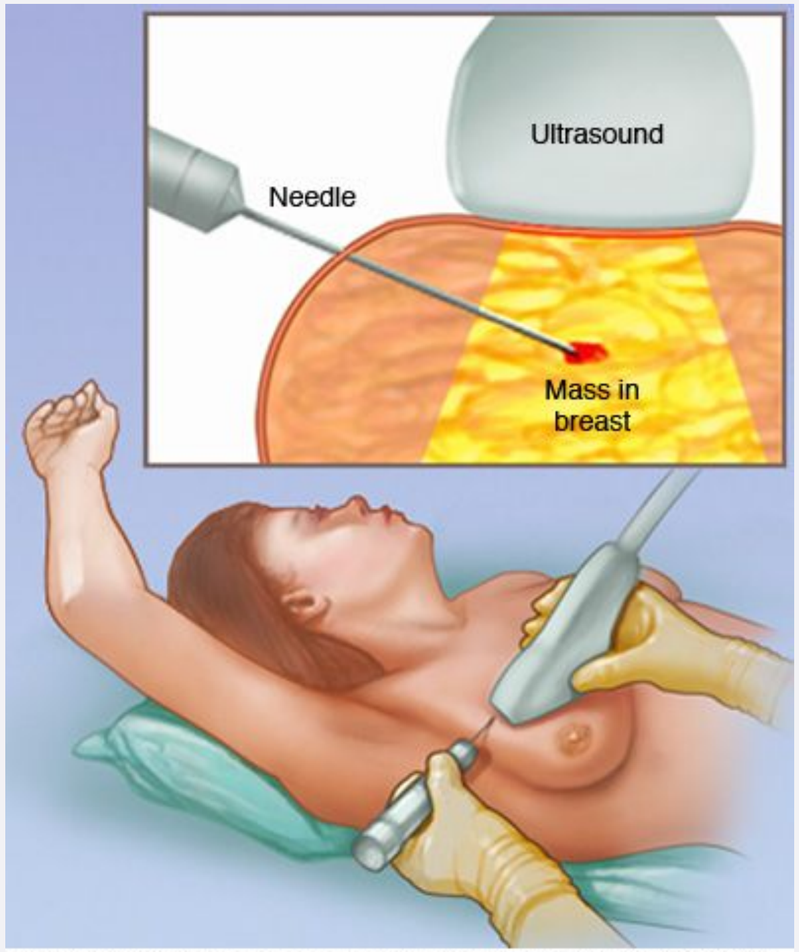
mammography



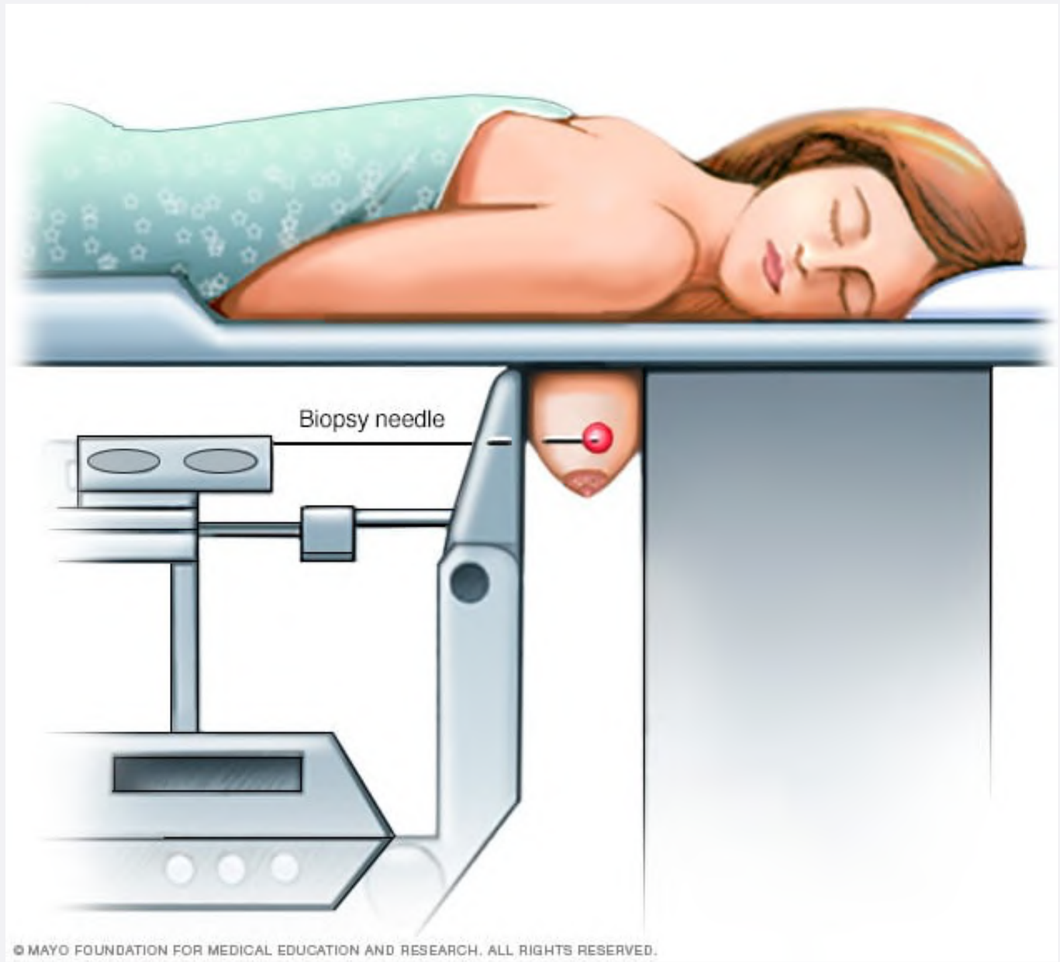
biopsy

Breast biopsy techniques

Ultrasound-guided core needle biopsy



Digital stereotactic/tomosynthesis-guided breast biopsy

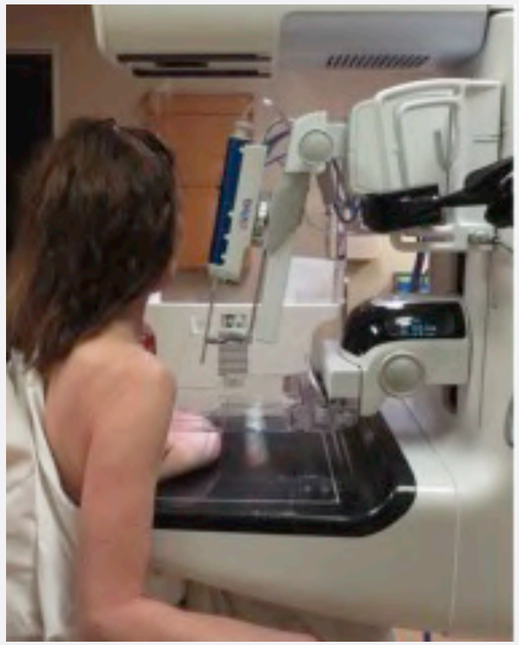


Courtesy of MAYO foundation for Medical Education and Research (www.mayoclinic.org).

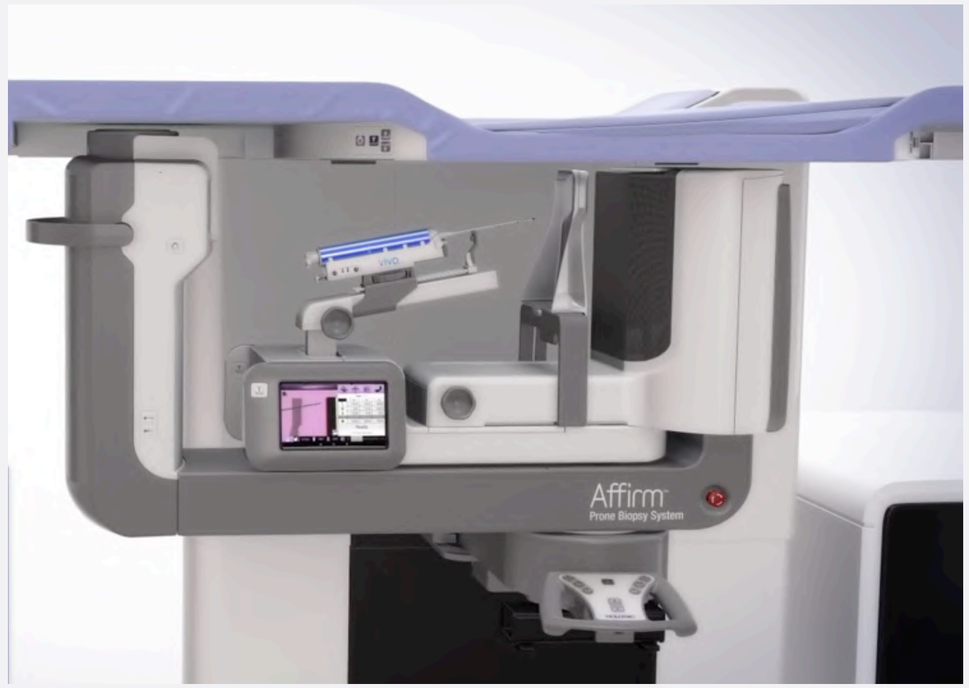
Mammogram-guided Breast Biopsy (SBB)
clinical workflow

(1) The patient is positioned (prone/upright) and preliminary localization images are acquired.

Prone table cranio-caudal (CC) biopsy



Upright CC biopsy

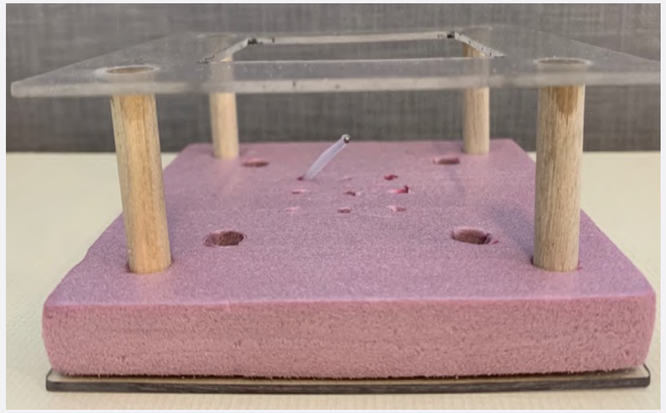


Hologic Affirm prone biopsy system
(www.youtube.com/watch?v=HOtwugpEvXQ&t=3s)

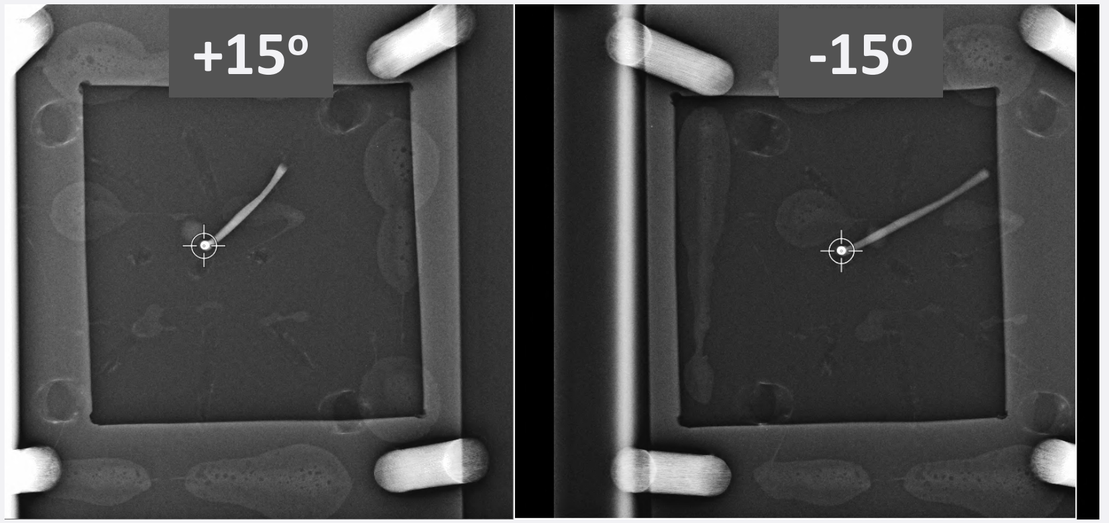
Mammogram-guided Breast Biopsy (SBB)
clinical workflow

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

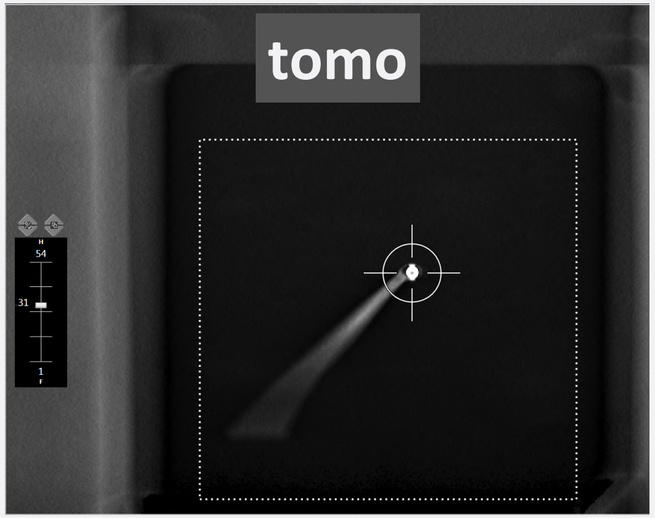
Biopsy phantom

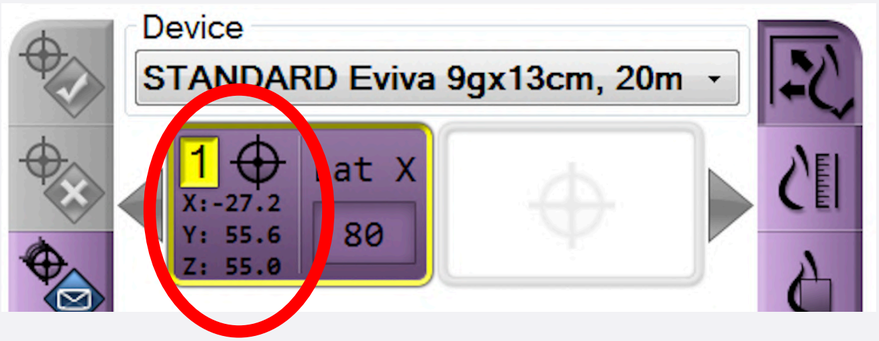


Target identification on stereo pair



Target identification on tomo images





(3) Needle size is selected (standard or petite) based on the breast thickness and lesion depth.

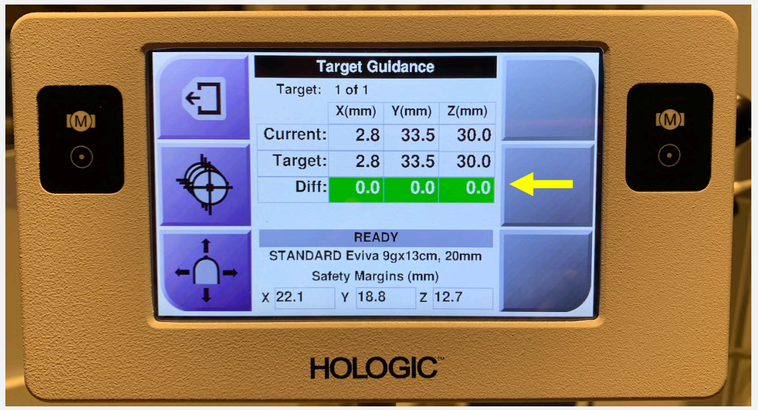
Mammogram-guided Breast Biopsy (SBB)
clinical workflow (cont'd)

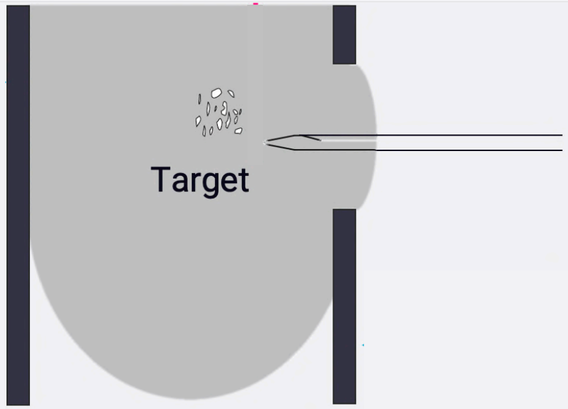
(4) Automatic targeting system is activated, and the needle is positioned outside the breast on a machine determined reference point.

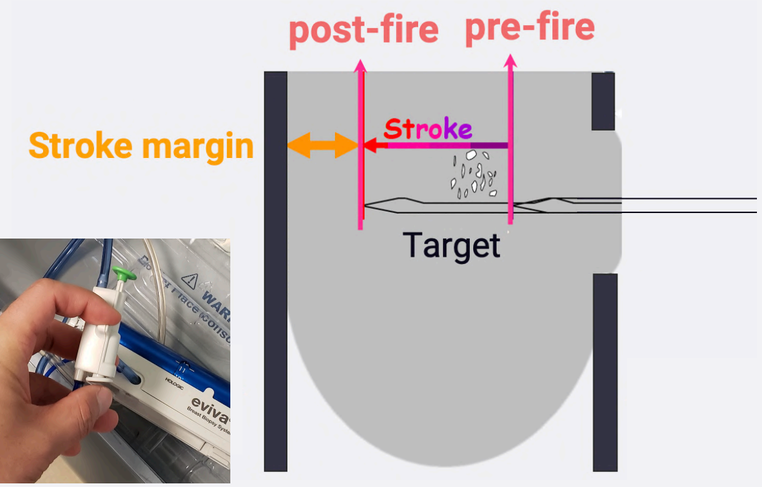
(5) The needle is manually advanced to the **pre-fire** position. Pre-fire images are acquired and appropriate positioning of the needle relative to the target is confirmed.

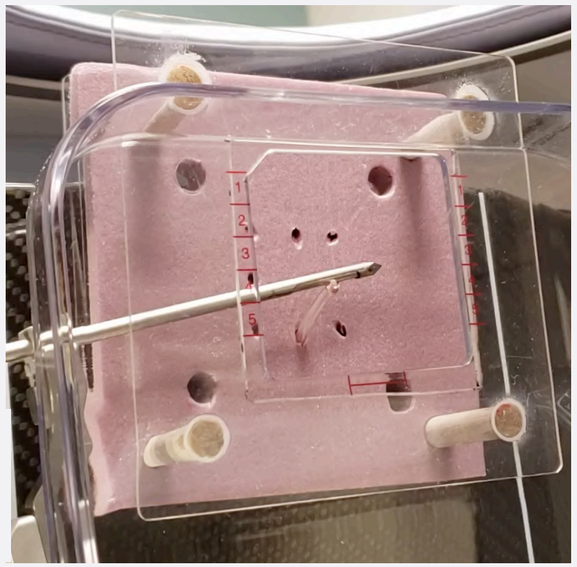
(6) The needle is deployed to the **post-fire** position and post-fire images are acquired.

(7) Lastly, the vacuum assisted biopsy is performed.



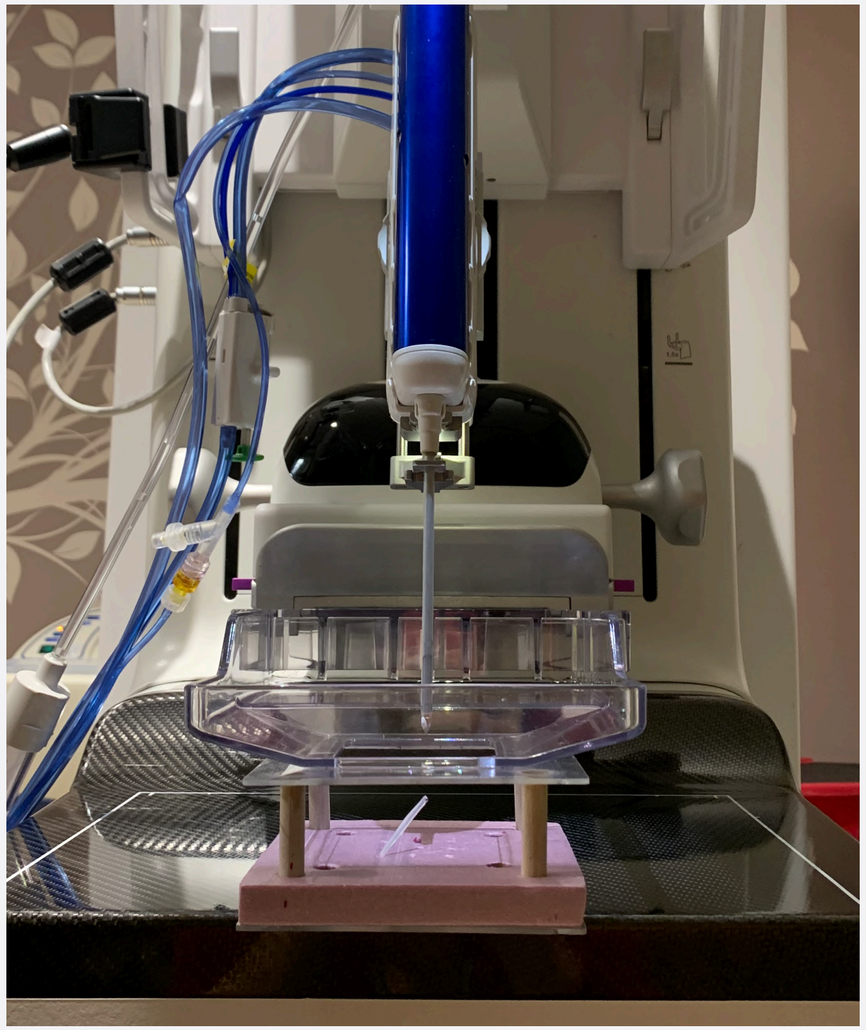




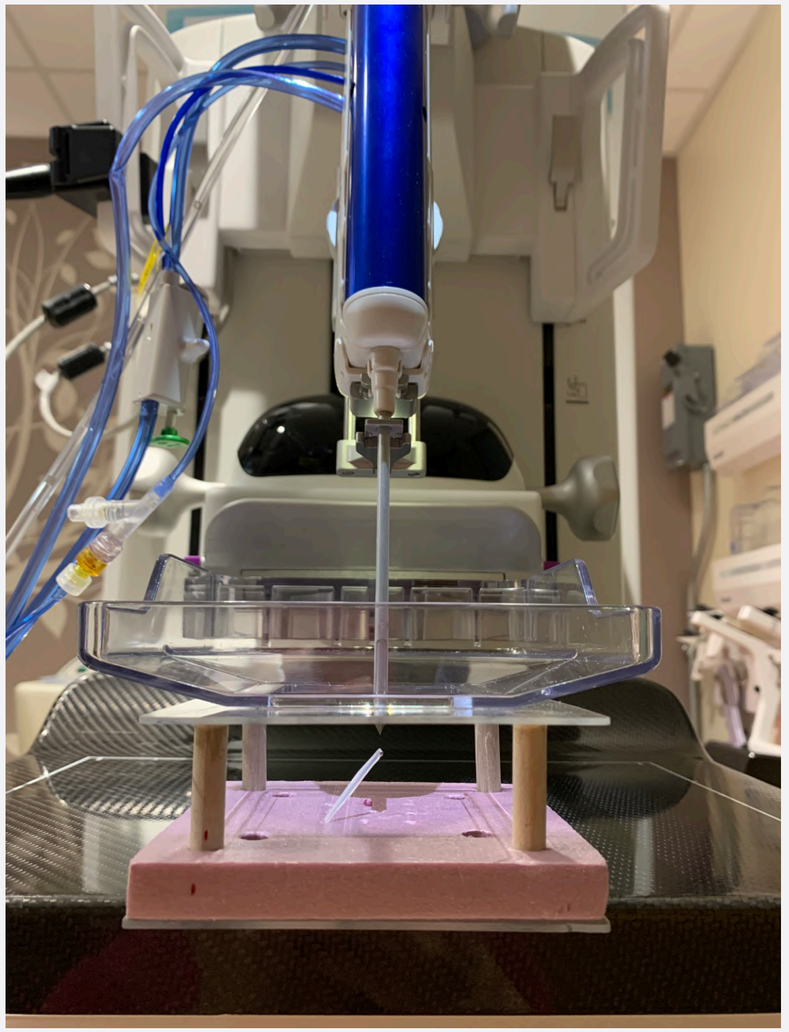


Mammogram-guided Breast Biopsy (SBB)
phantom demonstration – Cranio-caudal configuration

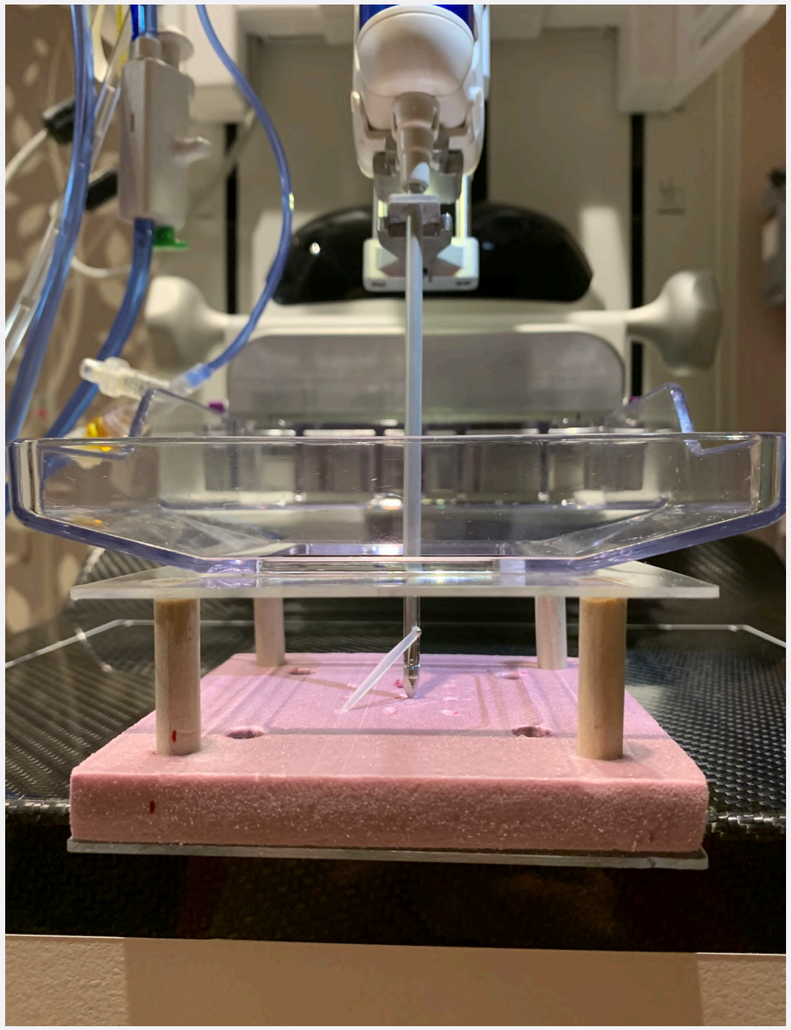
Reference point



Pre-fire position

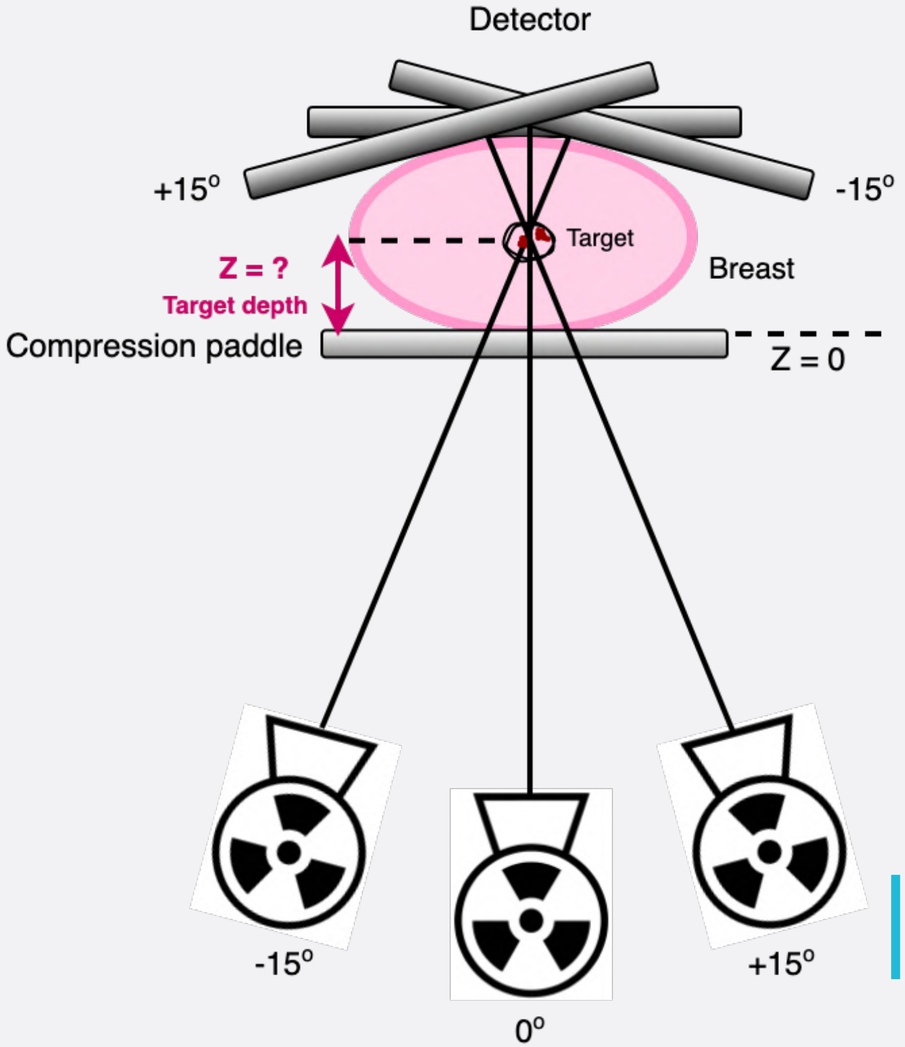


post-fire position



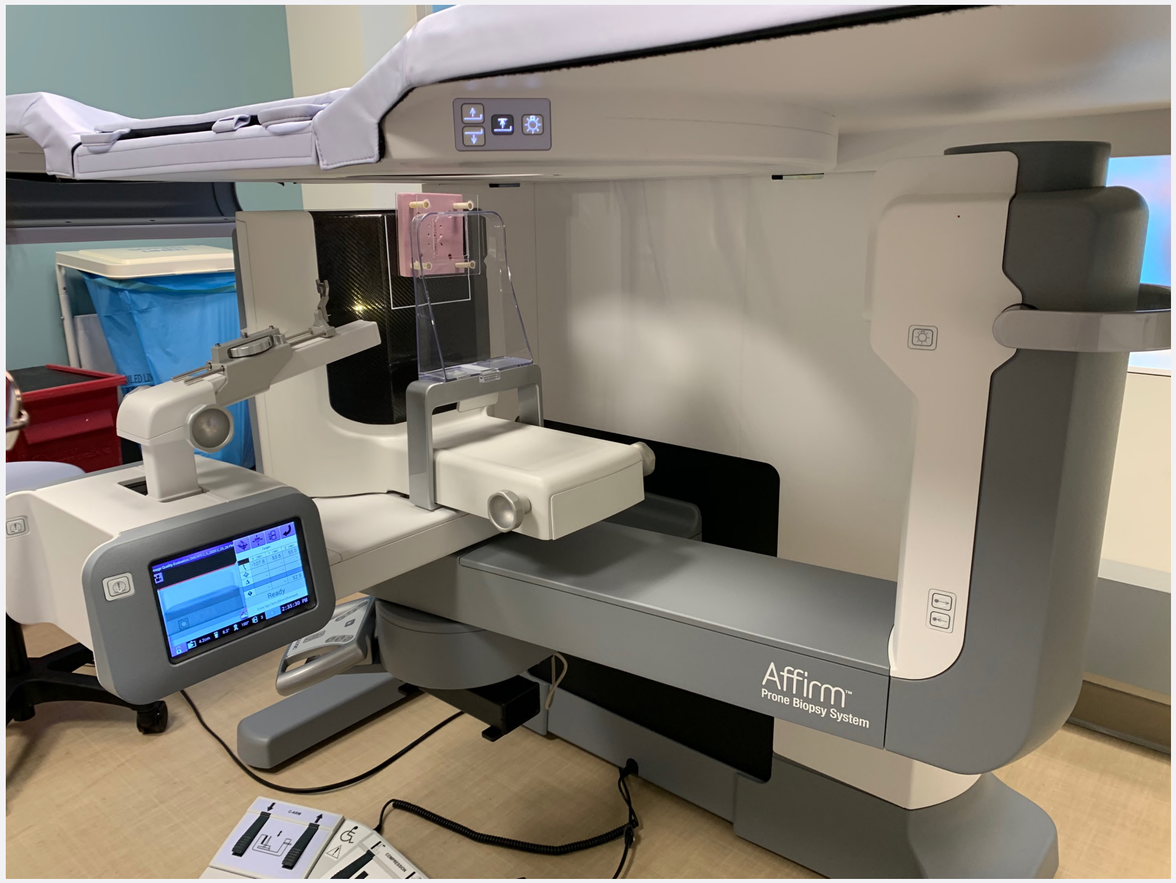
Stereotactic Breast Biopsy
geometric configuration of target localization: moving detector

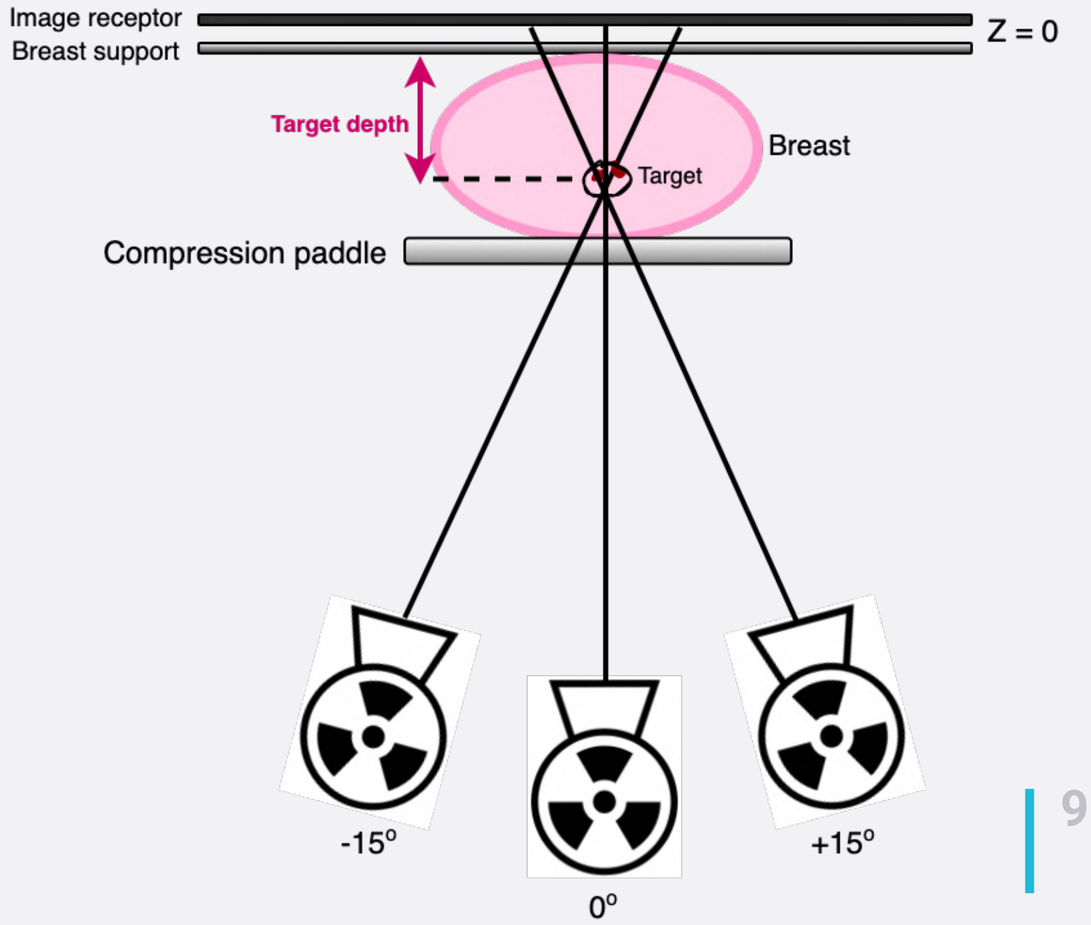
- Imaging plane rotates with the x-ray source and it’s always perpendicular to the central x-ray.
- The reference point and center of rotation are located anterior to the breast at the compression plate.
- The z axis is perpendicular to the imaging plane and the z = 0 is anterior to the breast at the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



Stereotactic Breast Biopsy
geometric configuration of target localization: stationary detector

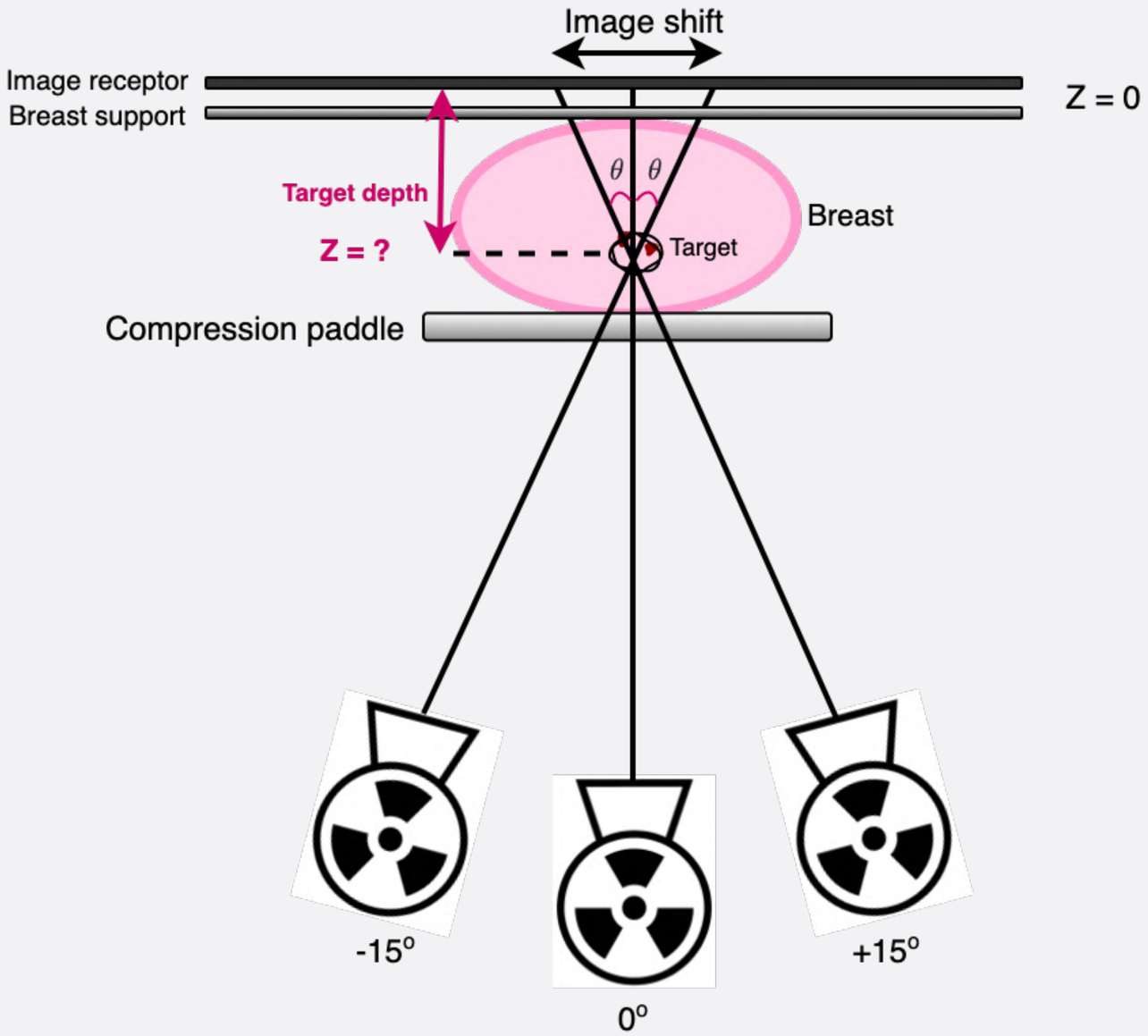
- Imaging plane remains stationary and is only perpendicular to the central x-ray at 0 degree.
- The location of z =0 is posterior to the breast near the imaging plane, and z increases in value as the object approaches the x-ray source
- The center of rotation is located behind the breast near the imaging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

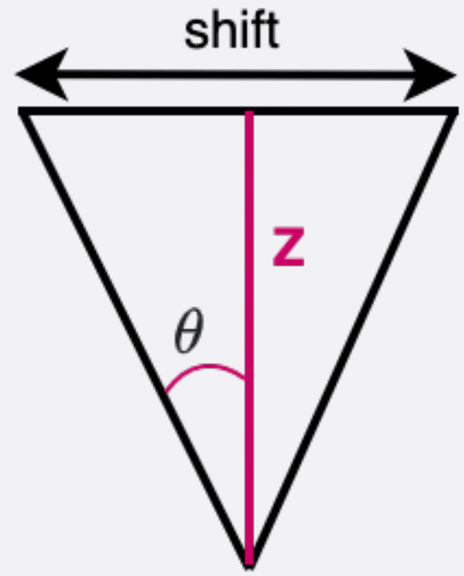




Stereotactic Breast Biopsy
target localization: depth calculation

- Target location is determined using the stereo pair images:



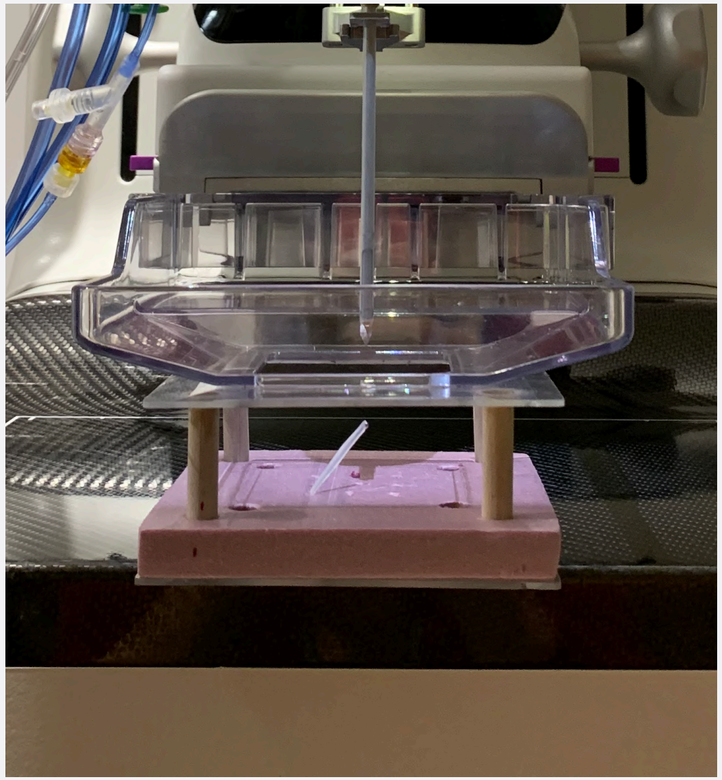


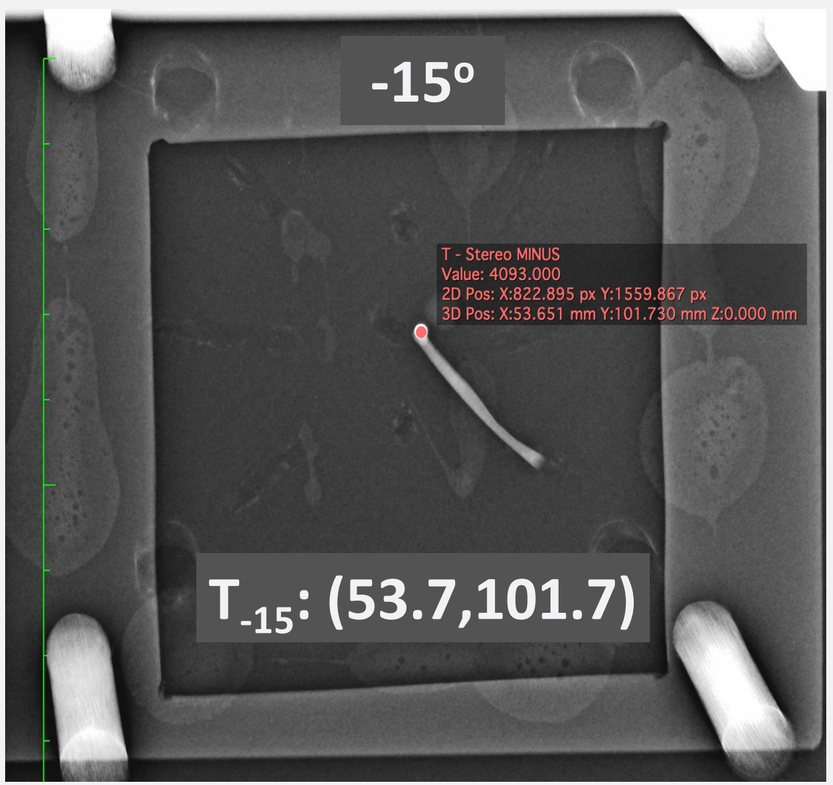
$$tan\theta = \frac{shift/2}{Z} \qquad \theta = 15^o$$

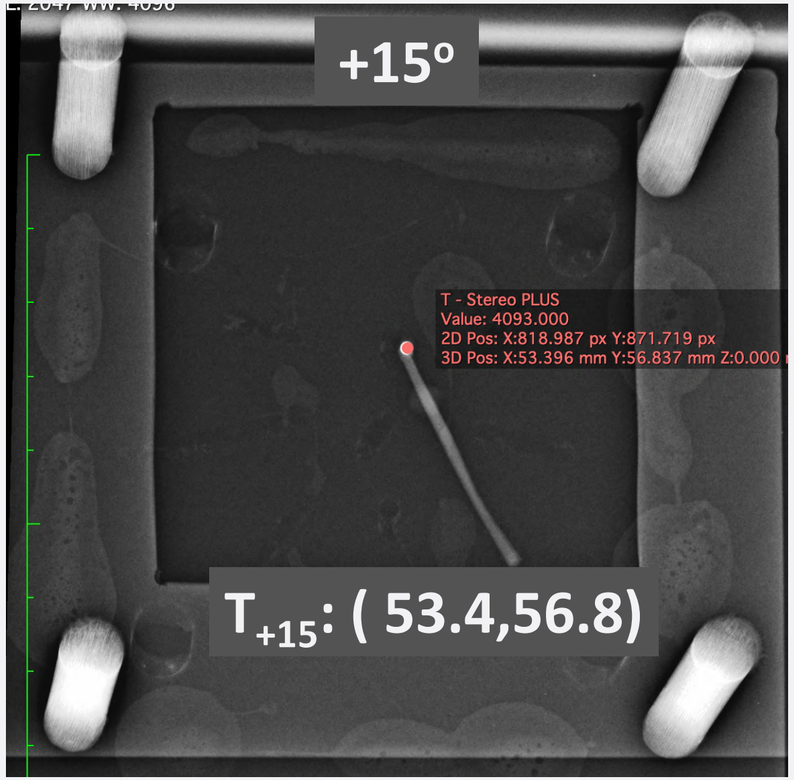
$$\boldsymbol{Z = \frac{shift}{2\tan 15} = 1.866 * shift}$$

Stereotactic Breast Biopsy
target localization: phantom demonstration

- Target location is determined using the stereo pair images:







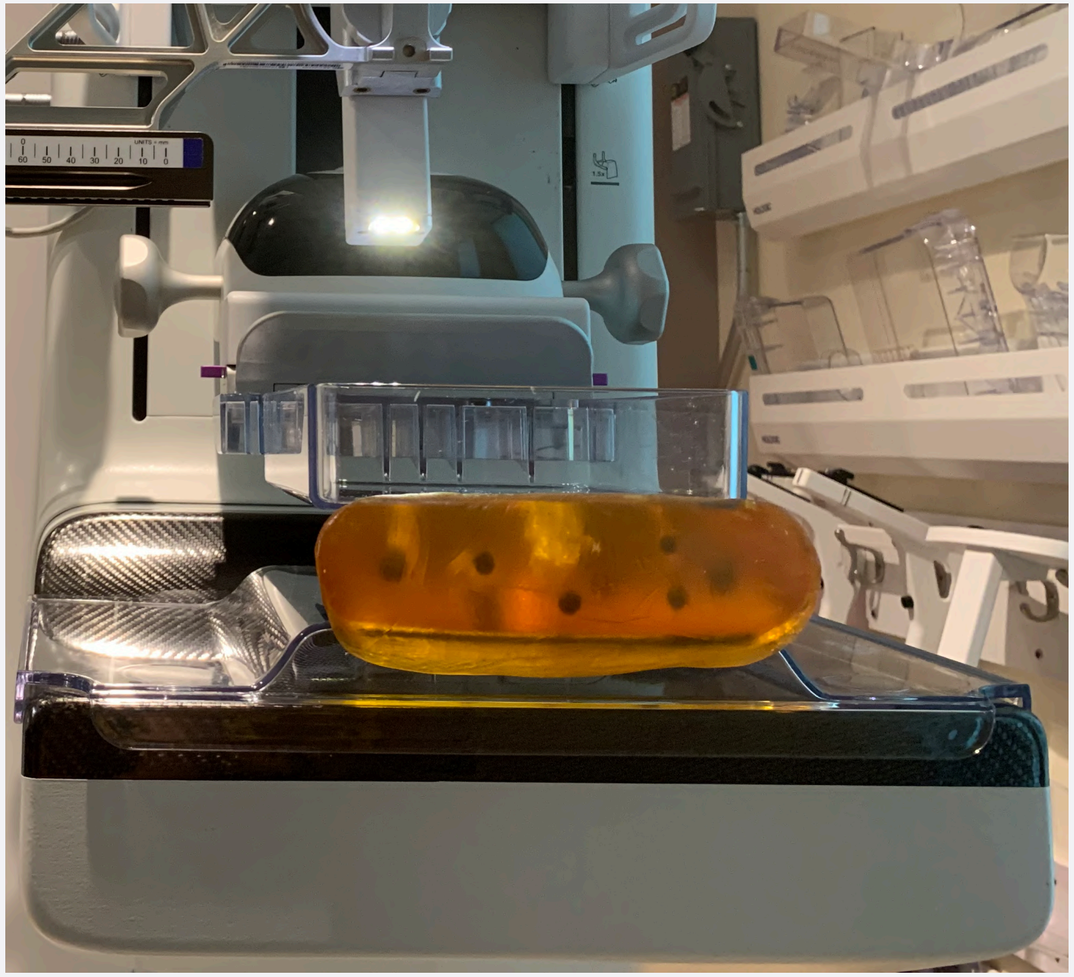
$$Shift = 101.7 - 56.8 = 44.90\ mm$$

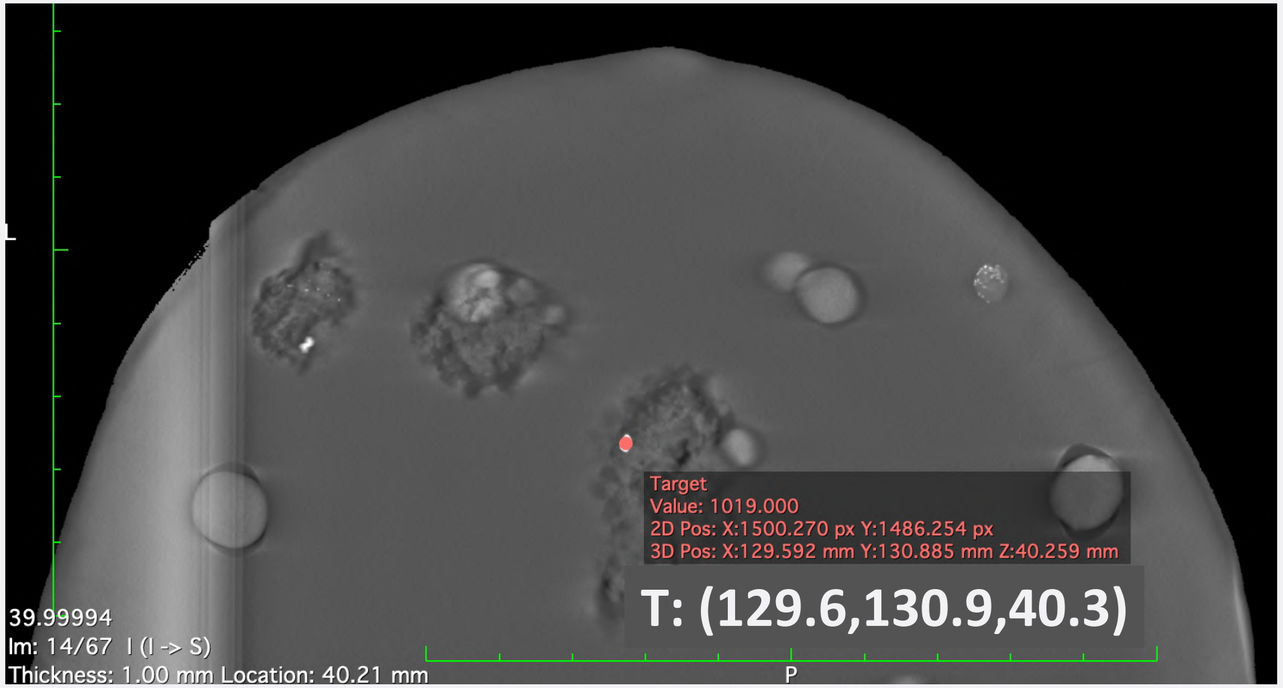
$$Z = 1.866 * shift = 1.866 * 44.9 = 83.77\ mm$$

$$T\text{: } (53.5, 79.3, 83.8)\ mm$$

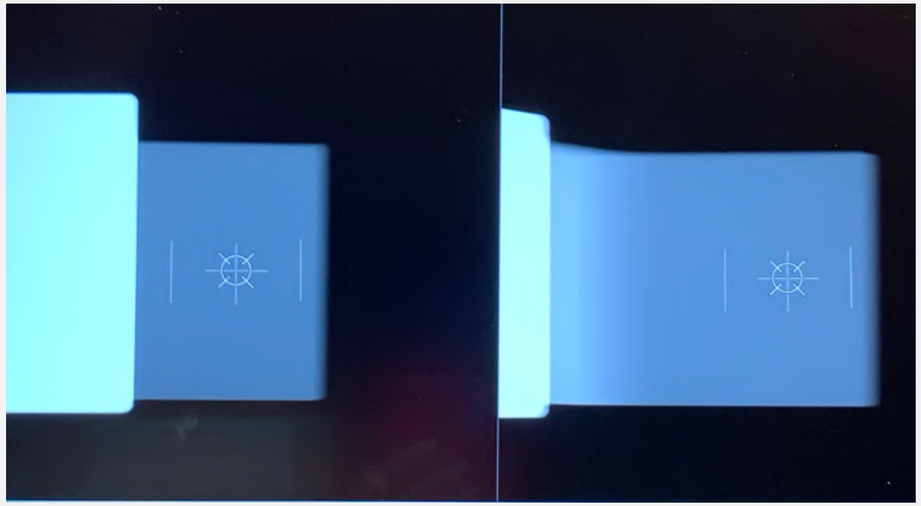
Tomosynthesis-guided breast biopsy
target localization

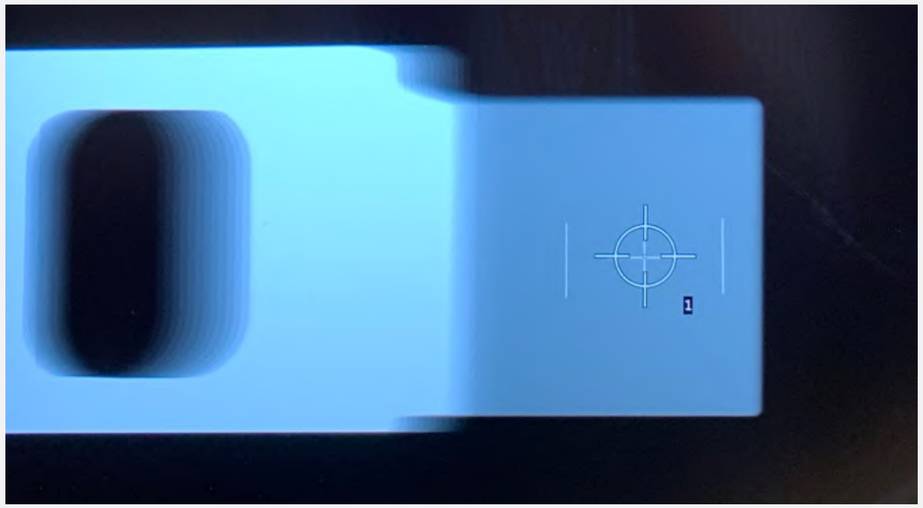
- Target position is determined directly on tomosynthesis images: No calculations required!



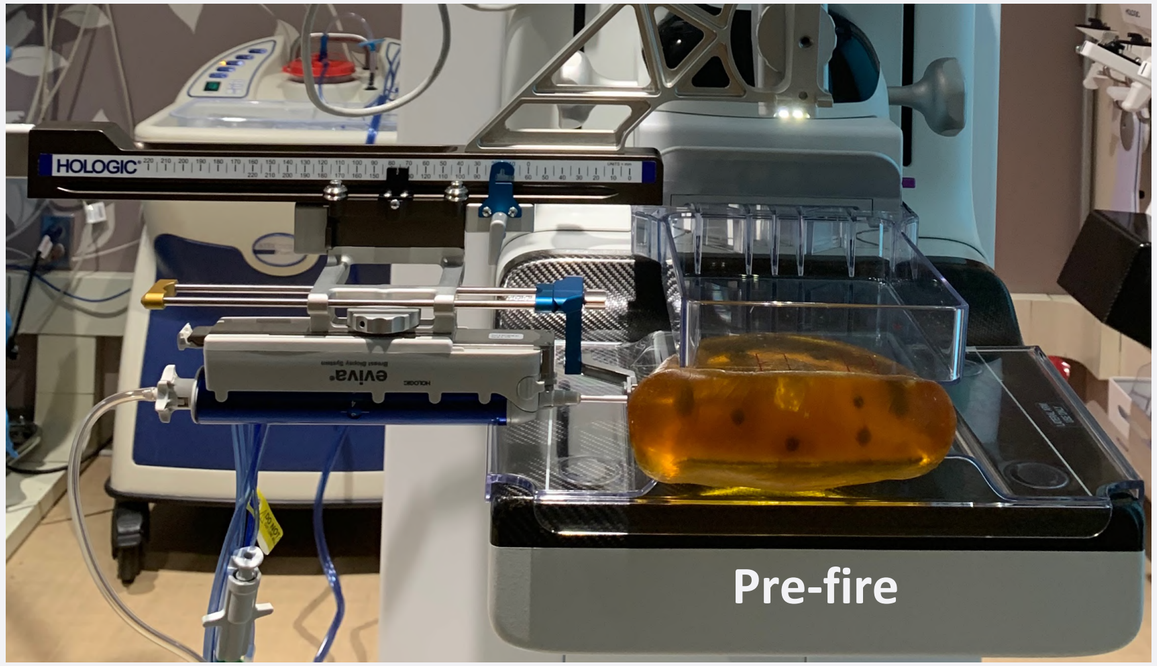


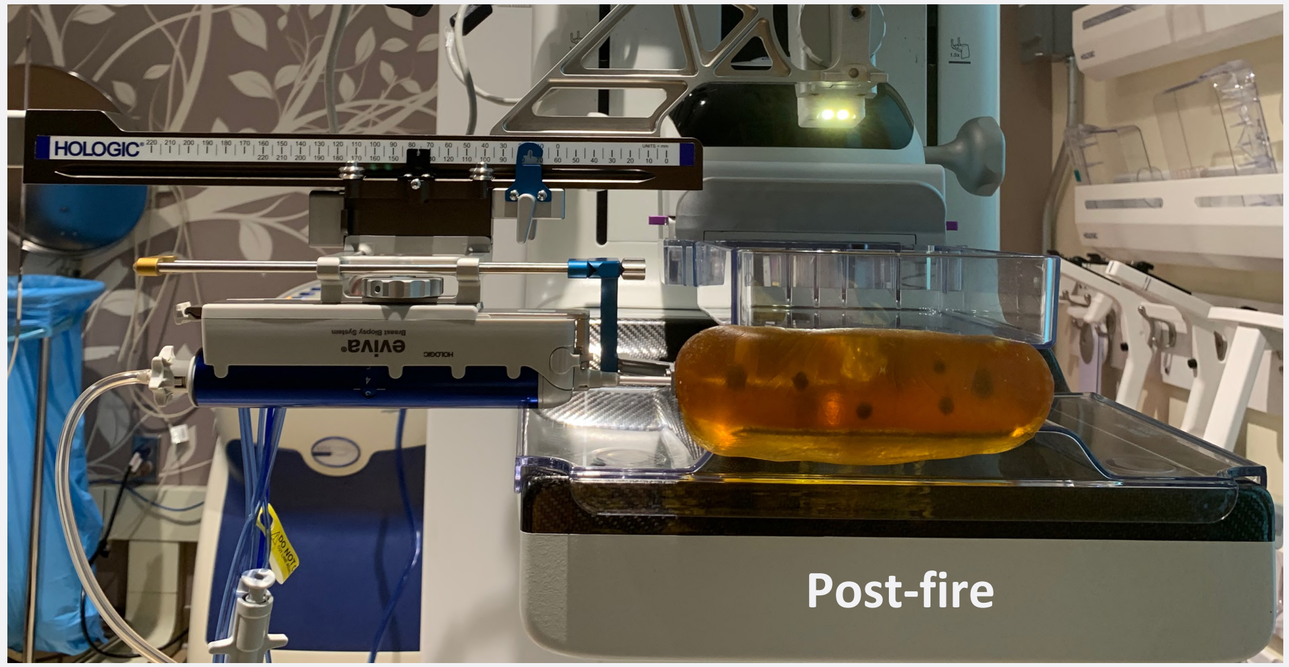
Localization accuracy test
current daily test performed by a technologist (Hologic)

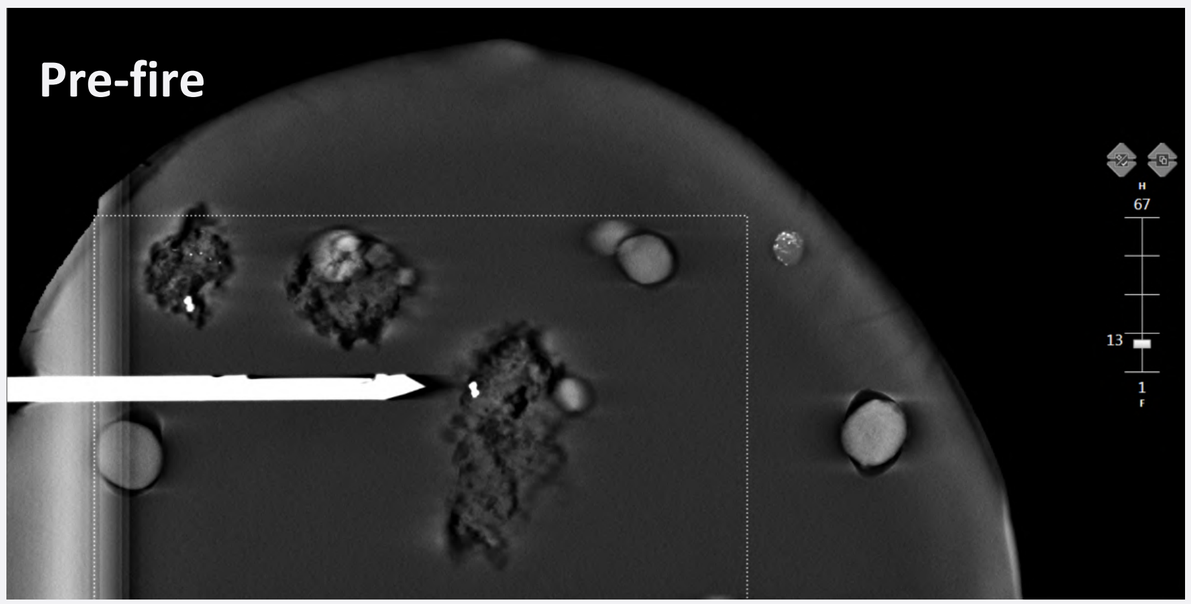


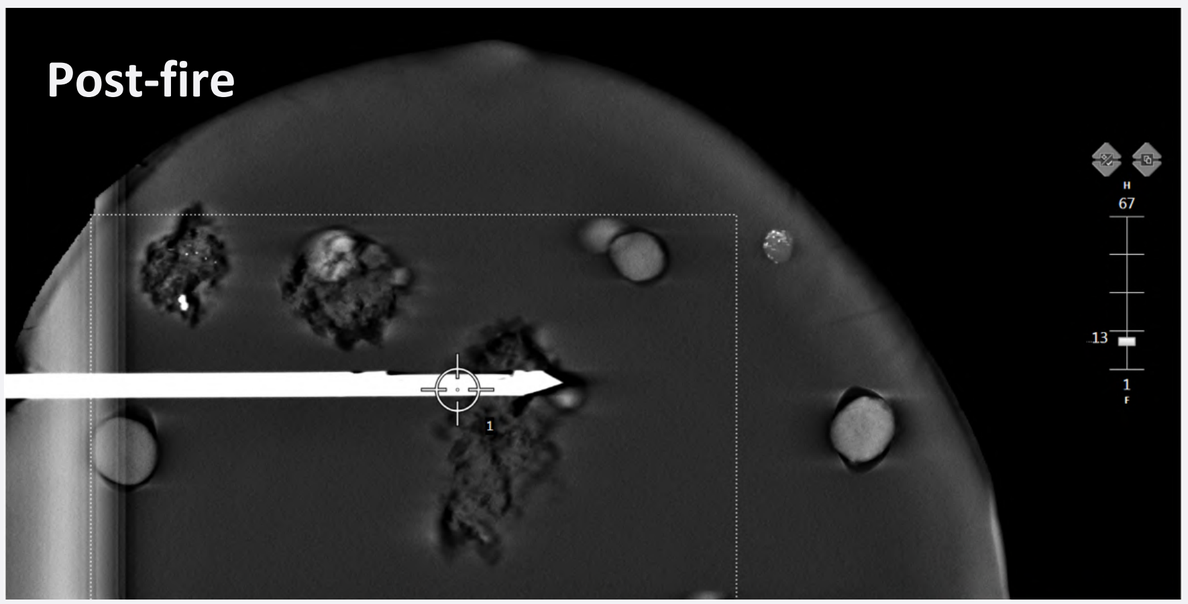


Localization accuracy test
current annual test performed by a Medical Physicist

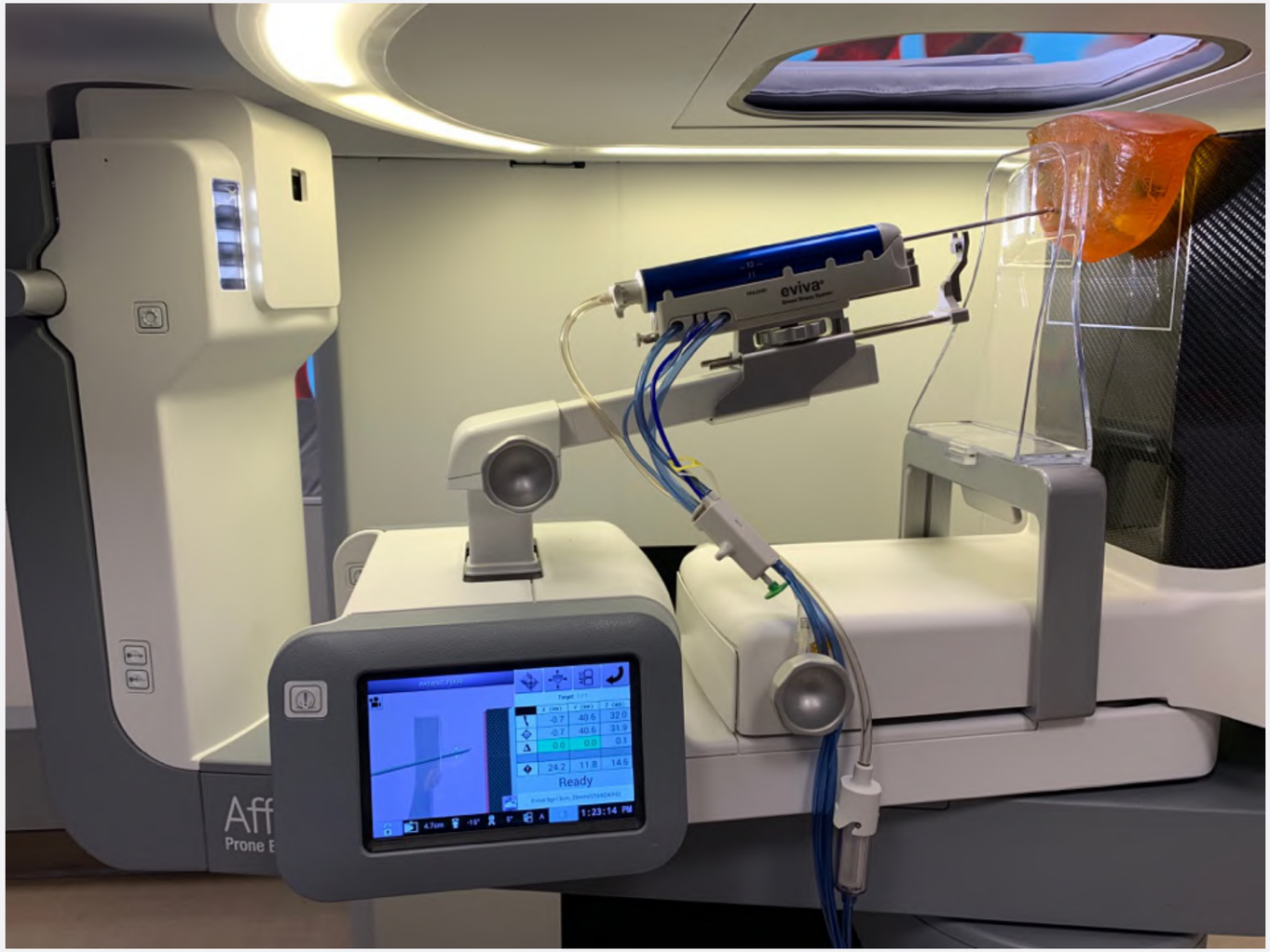


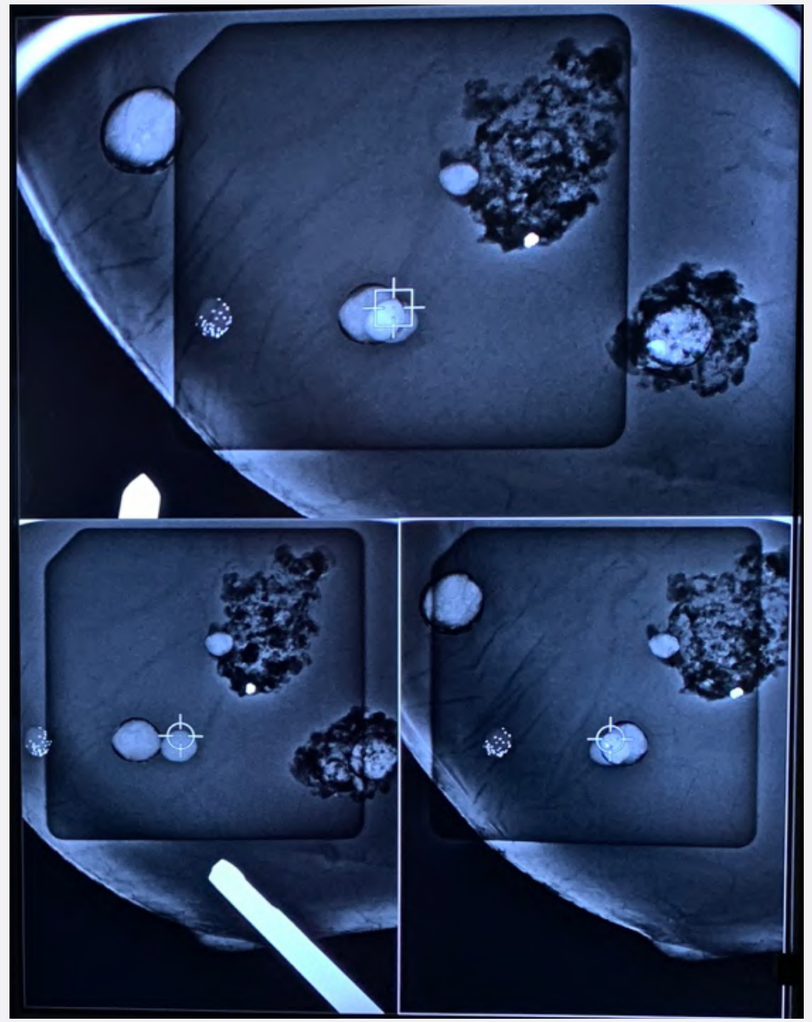




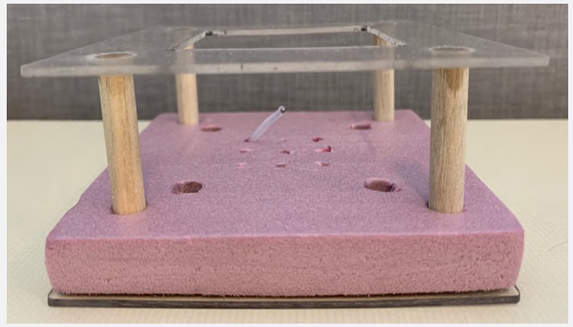


Localization accuracy test
current annual test performed by a Medical Physicist



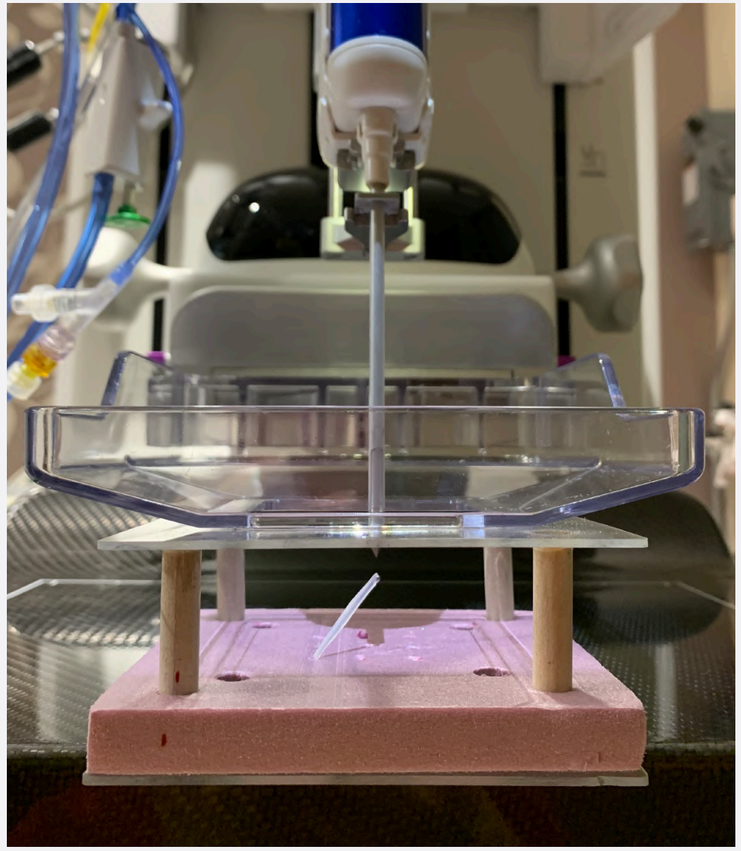


A novel approach for localization accuracy test
test setup

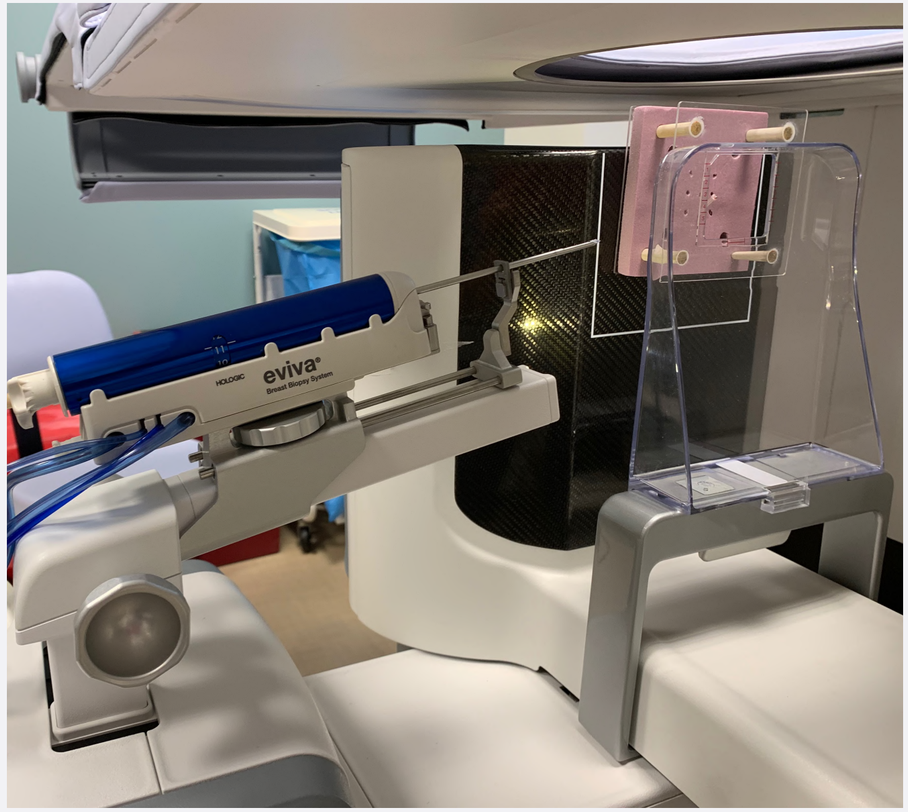


Upright unit
lateral arm biopsy

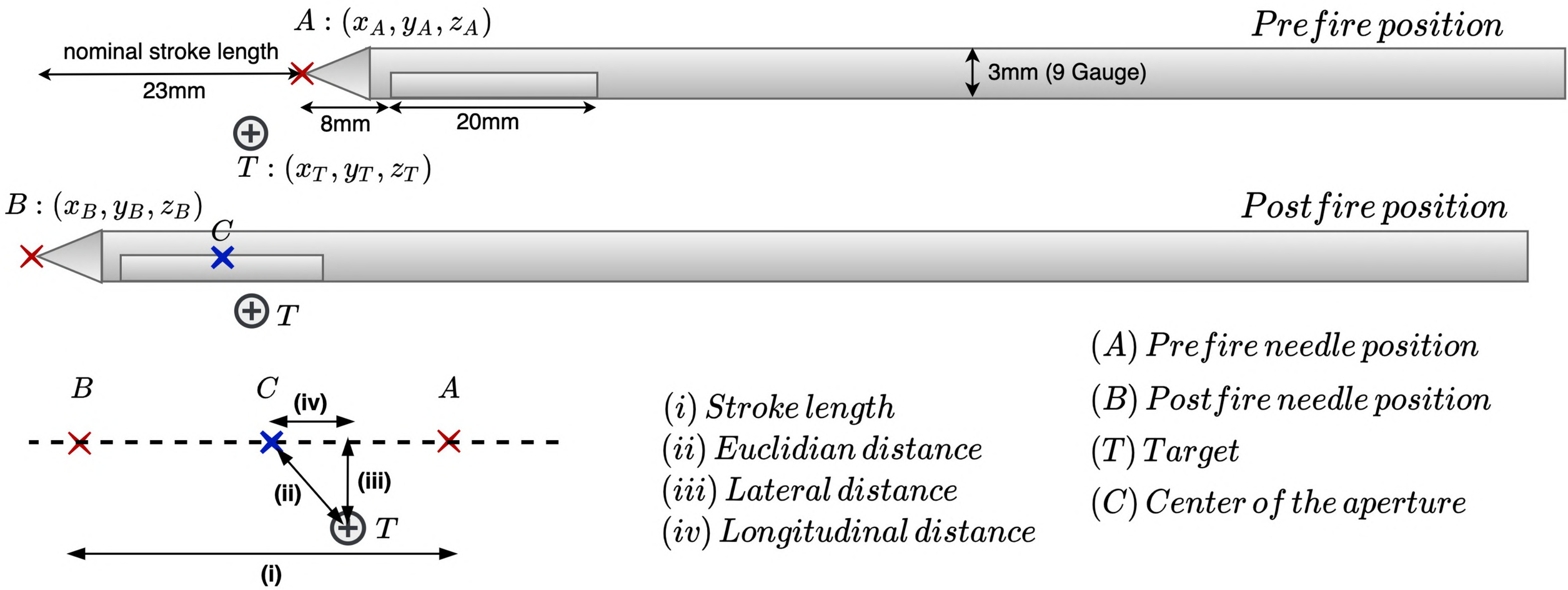
Upright unit
cranio-caudal biopsy



Prone unit
lateral arm biopsy



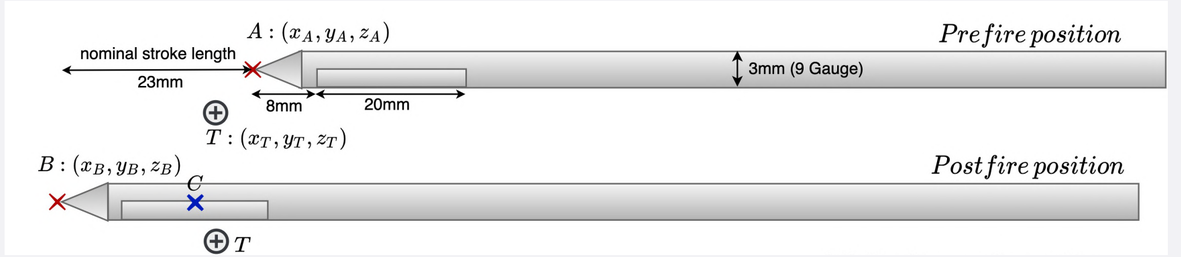
A novel approach for localization accuracy test
new localization analysis



(i) Stroke length
(ii) Euclidian distance
(iii) Lateral distance
(iv) Longitudinal distance

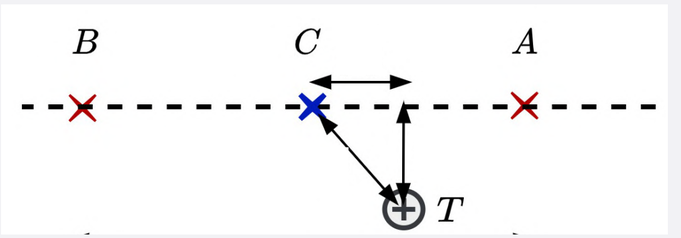
(A) Prefire needle position
(B) Postfire needle position
(T) Target
(C) Center of the aperture

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:

$$\begin{cases} x = x_A + t(x_B - x_A) \\ y = y_A + t(y_B - y_A) \\ z = z_A + t(z_B - z_A) \end{cases}$$



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

$$\left|\overrightarrow{BC}\right| = \left|\overrightarrow{AB}\right||t|$$
$$|t| = \left|\overrightarrow{BC}\right| / \left|\overrightarrow{AB}\right|$$

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

$$\begin{cases} x_C = x_A + \dfrac{d}{\left|\overrightarrow{AB}\right|}(x_B - x_A) \\ y_C = y_A + \dfrac{d}{\left|\overrightarrow{AB}\right|}(y_B - y_A) \\ z_C = z_A + \dfrac{d}{\left|\overrightarrow{AB}\right|}(z_B - z_A) \end{cases}$$

$$\left|\overrightarrow{AB}\right| = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2 + (z_B - z_A)^2}$$

A novel approach for localization accuracy test
error metrics

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

$$stroke\ length\ error = \left|\left|\overrightarrow{AB}\right| - nominal\ stroke\ length\right|$$

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

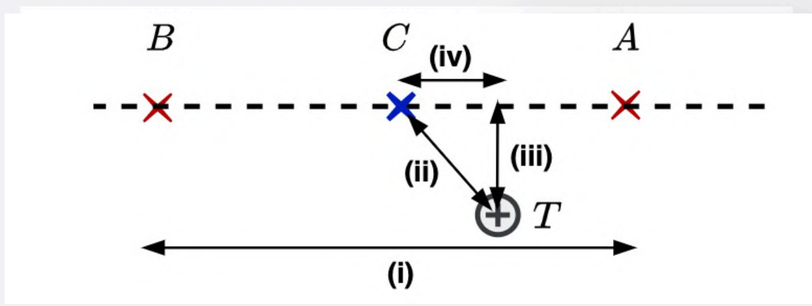
$$\left|\overrightarrow{TC}\right| = \sqrt{(x_T - x_C)^2 + (y_T - y_C)^2 + (z_B - z_A)^2}$$

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

$$\left|T \perp \overrightarrow{AB}\right| = \frac{\left|\overrightarrow{AB} \times \overrightarrow{BT}\right|}{\left|\overrightarrow{AB}\right|}$$

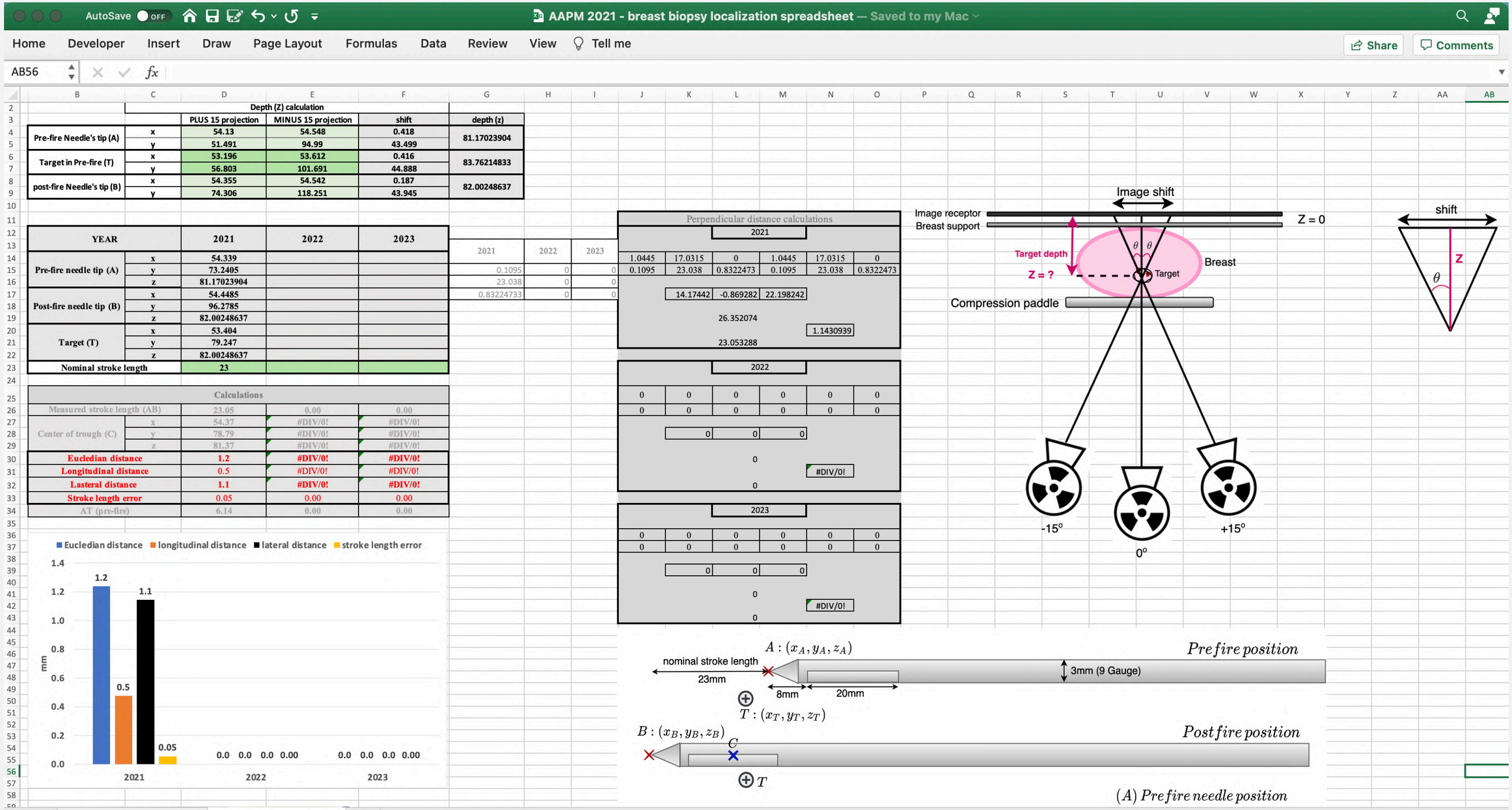
(iv) Longitudinal distance: The distance between the projection of the target on needle's trajectory and the center of the aperture:

$$longitudinal\ distance = \sqrt{\left|\overrightarrow{TC}\right|^2 - \left|T \perp \overrightarrow{AB}\right|^2}$$



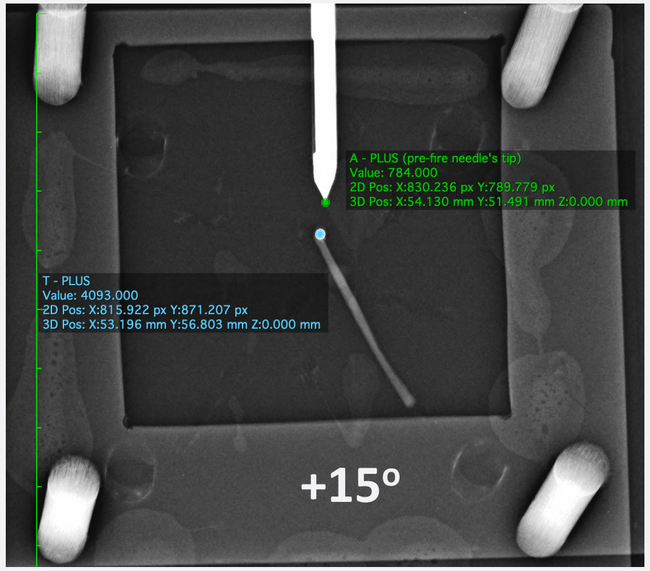
An excel spreadsheet for localization error calculations

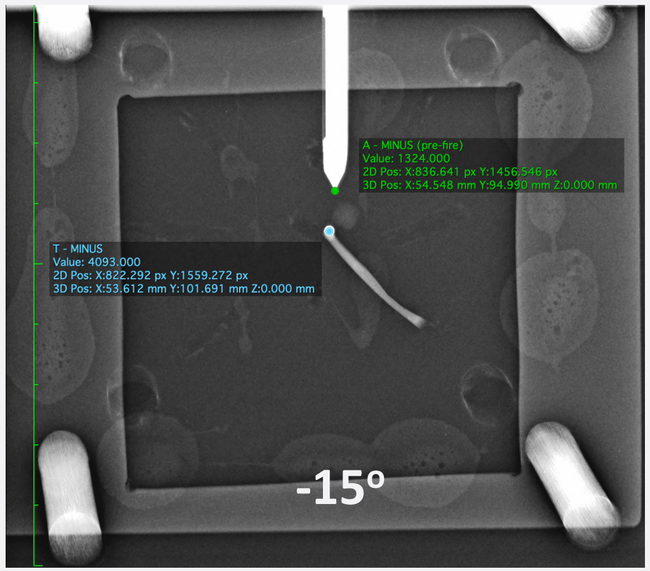
stereotactic-based error analysis



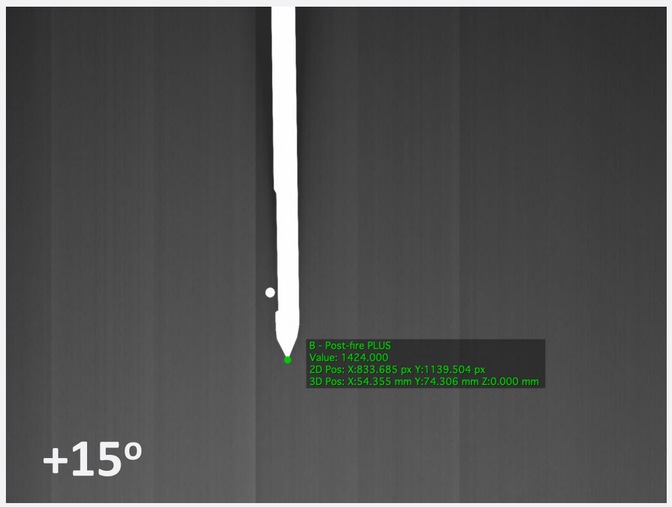
Stereotactic-guided biopsy
identification of key points on stereo pair images

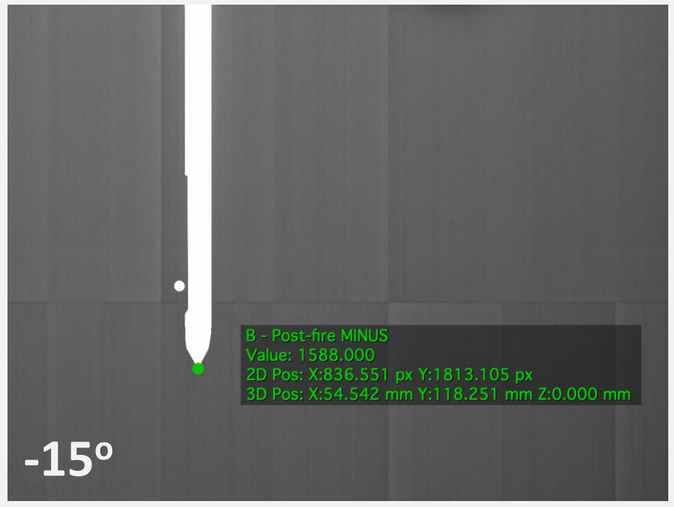
Target (T) and pre-fire needle’s tip (A) on pre-fire stereo pair images





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

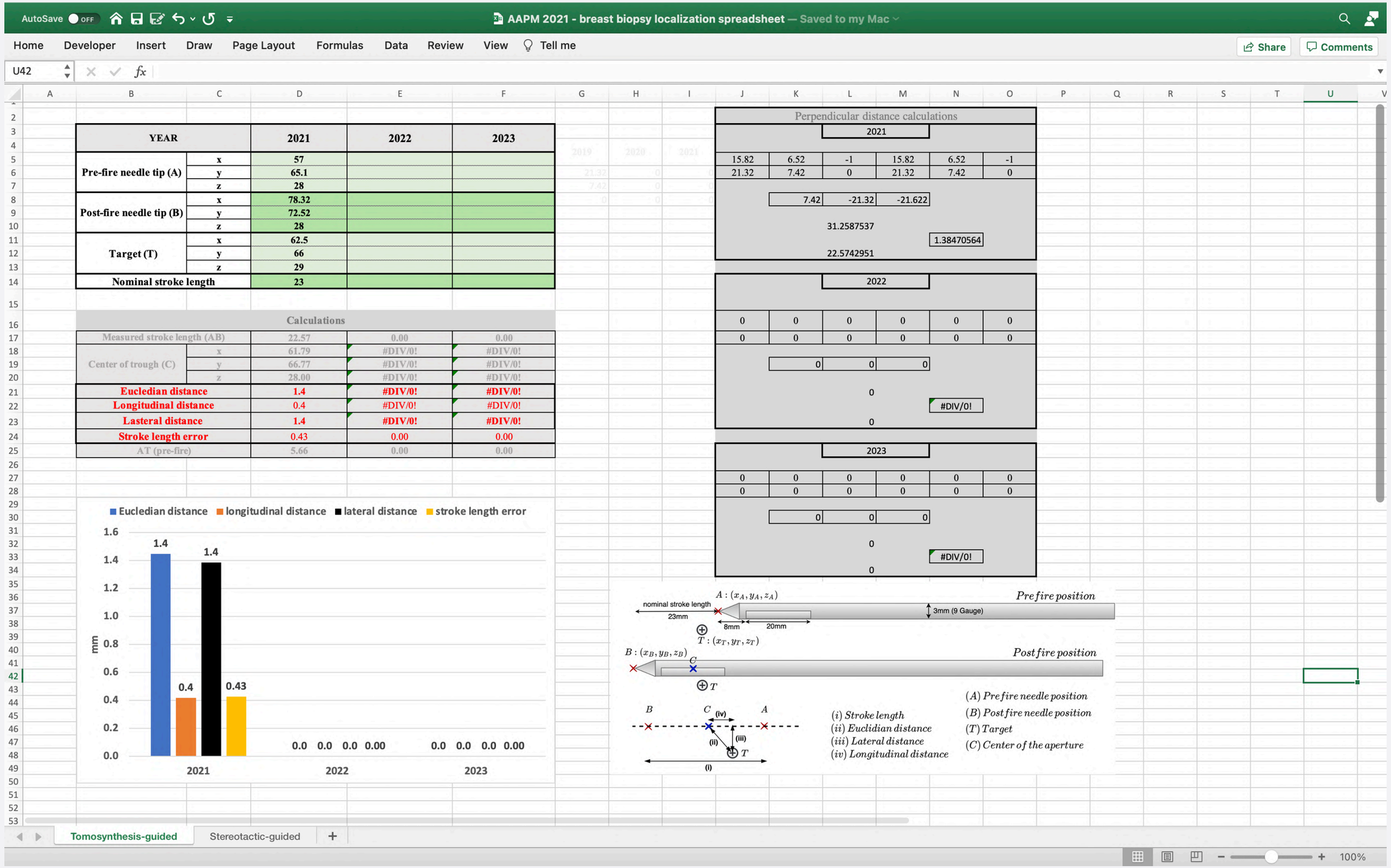




Pre/post fire images were acquired at different kVps

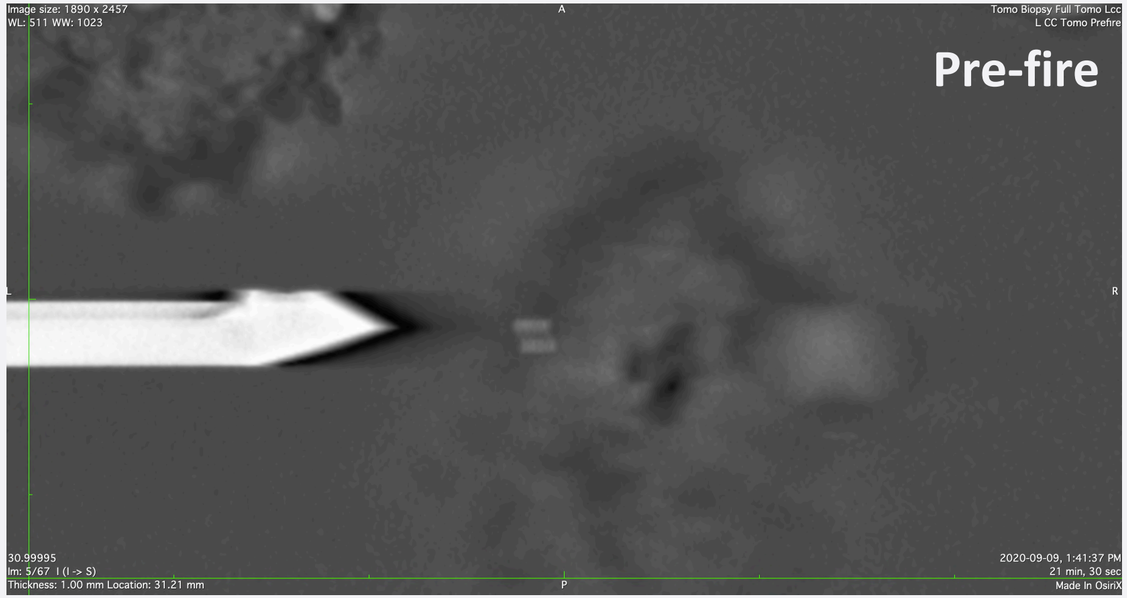
An excel spreadsheet for localization error calculations

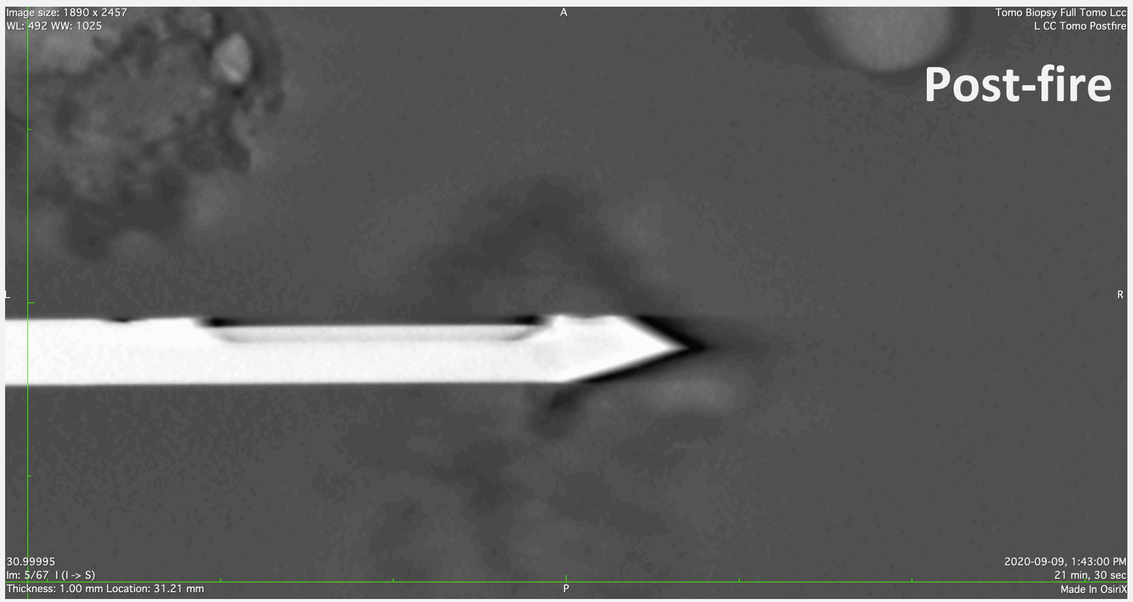
tomosynthesis-based error analysis



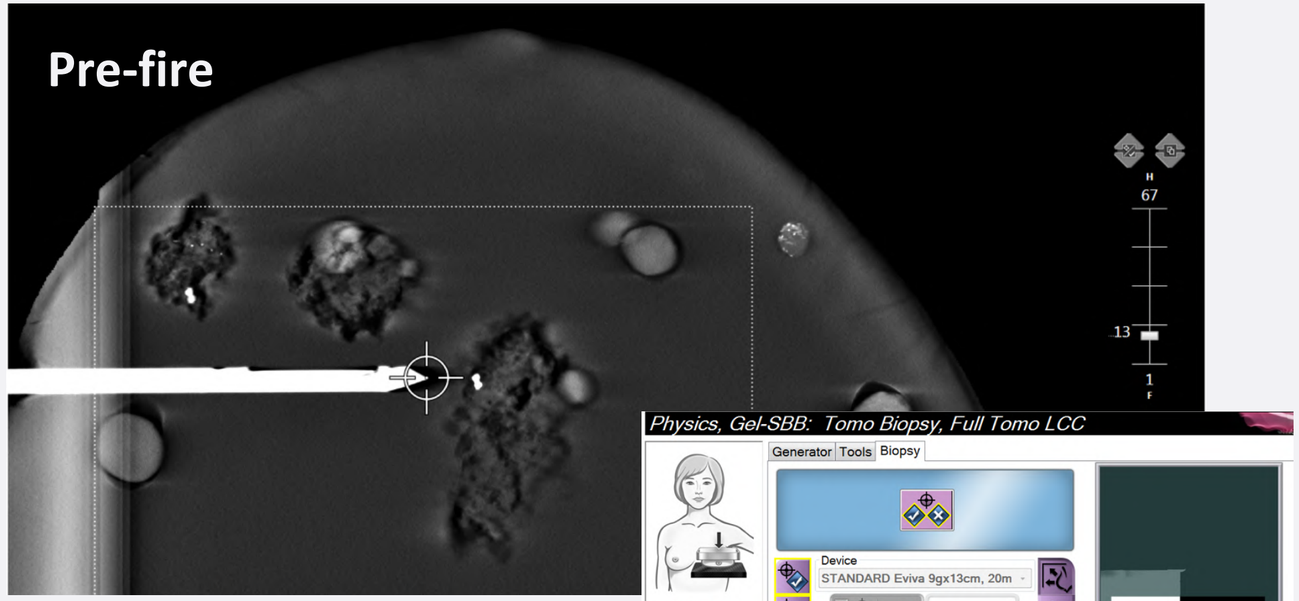
Tomosynthesis-guided biopsy
identification of key points on tomosynthesis images

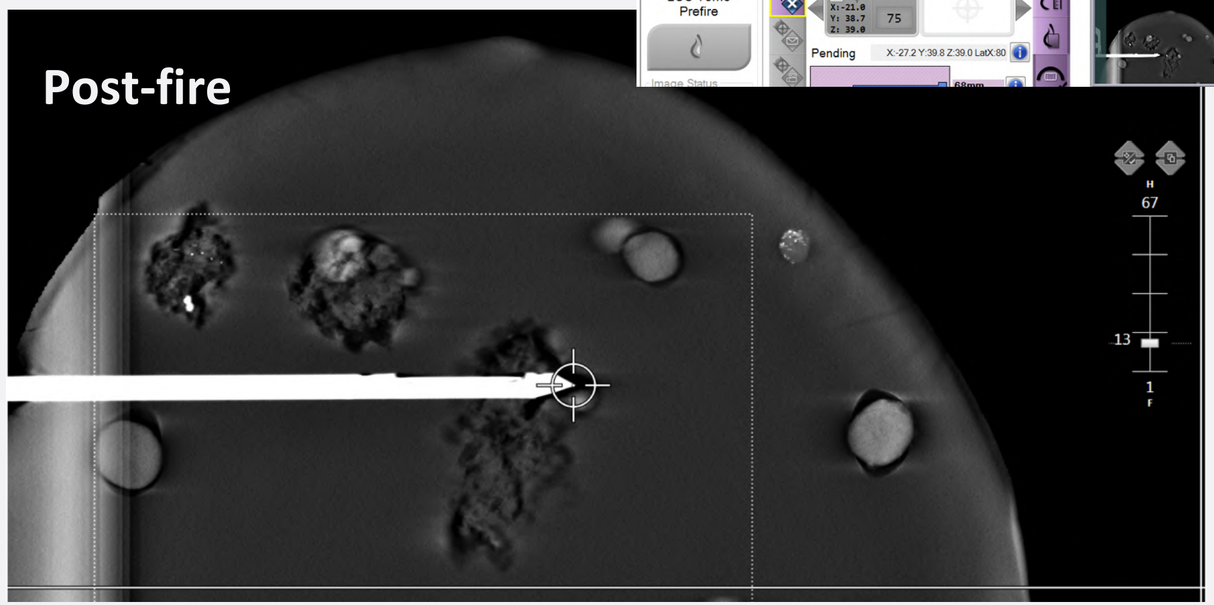
Offline analysis (e.g., on OsiriX DICOM viewer)



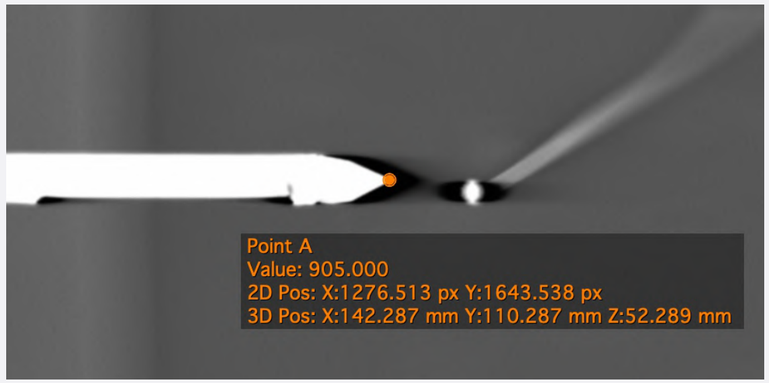
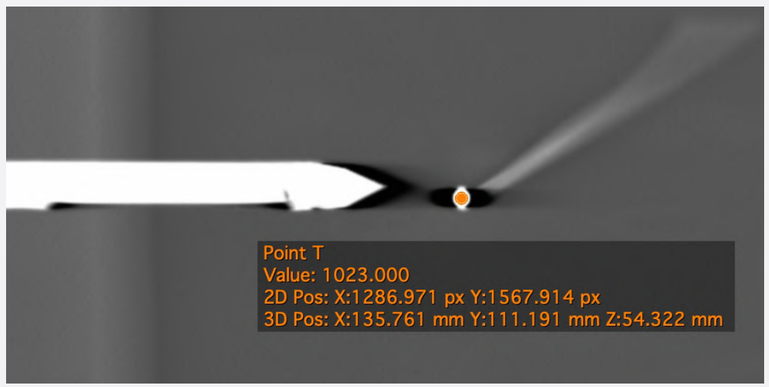
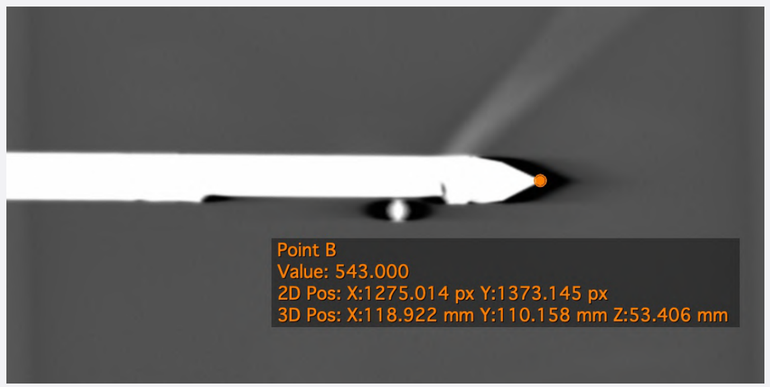
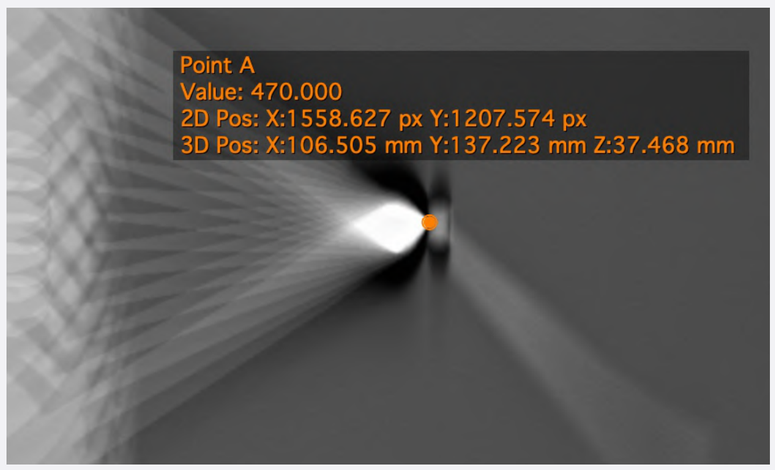
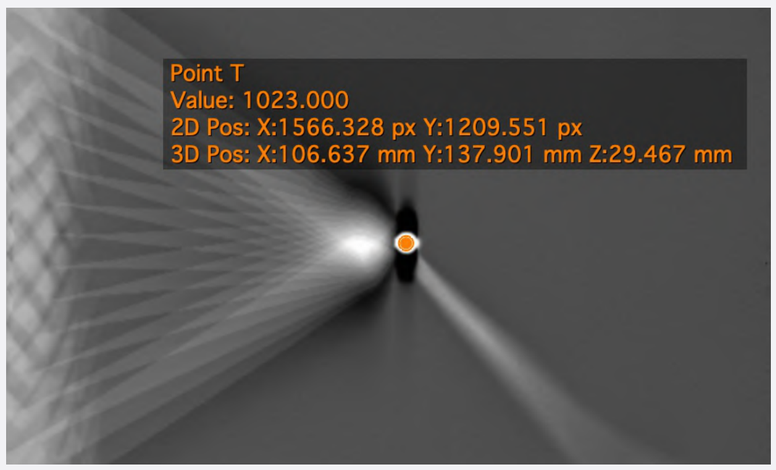
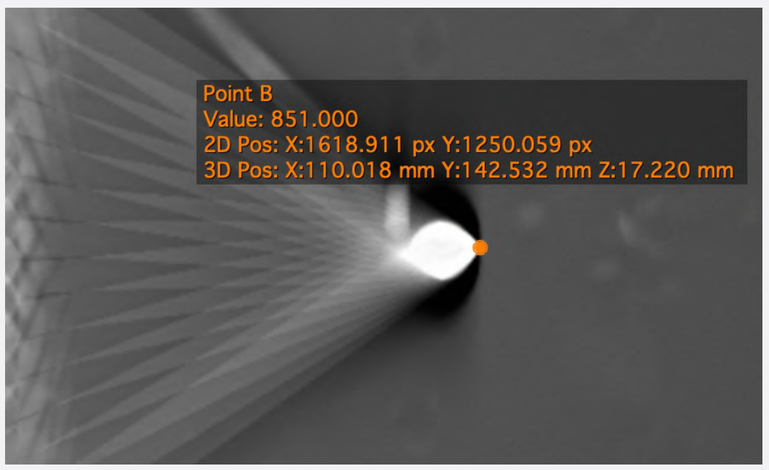


In room analysis (i.e., on biopsy unit)





Tomosynthesis-guided biopsy
identification of key points on tomosynthesis images (lateral vs. CC)

	Point A	Point T	Point B
Lateral arm			
Cranio-Caudal			

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.

Reyhaneh.Nosrati@childrens.Harvard.edu
rnosrati@mgh.Harvard.edu