

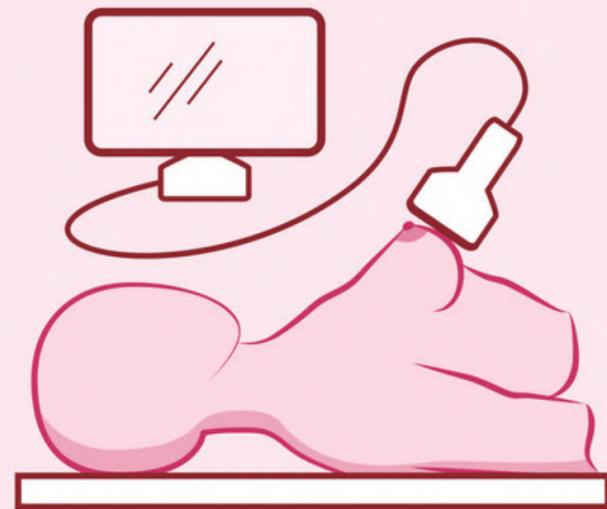
localization accuracy of mammogram-guided breast biopsy

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

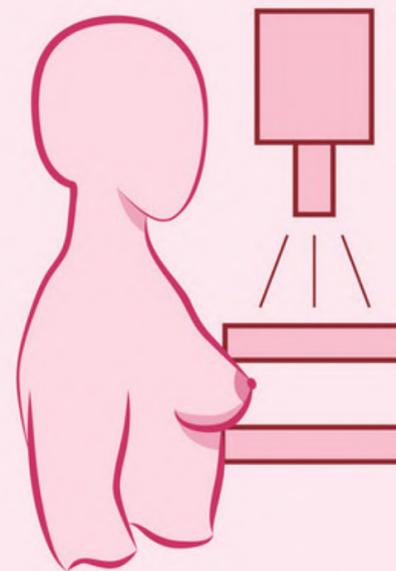
Breast cancer diagnosis



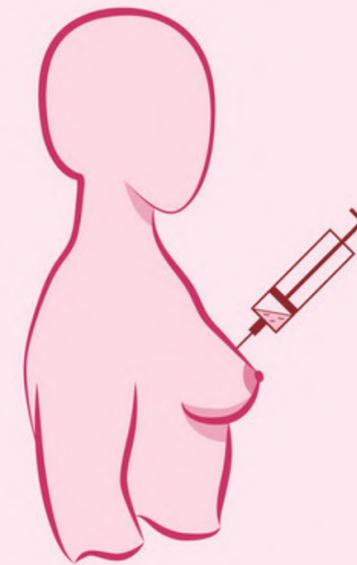
Physical inspection



ultrasound



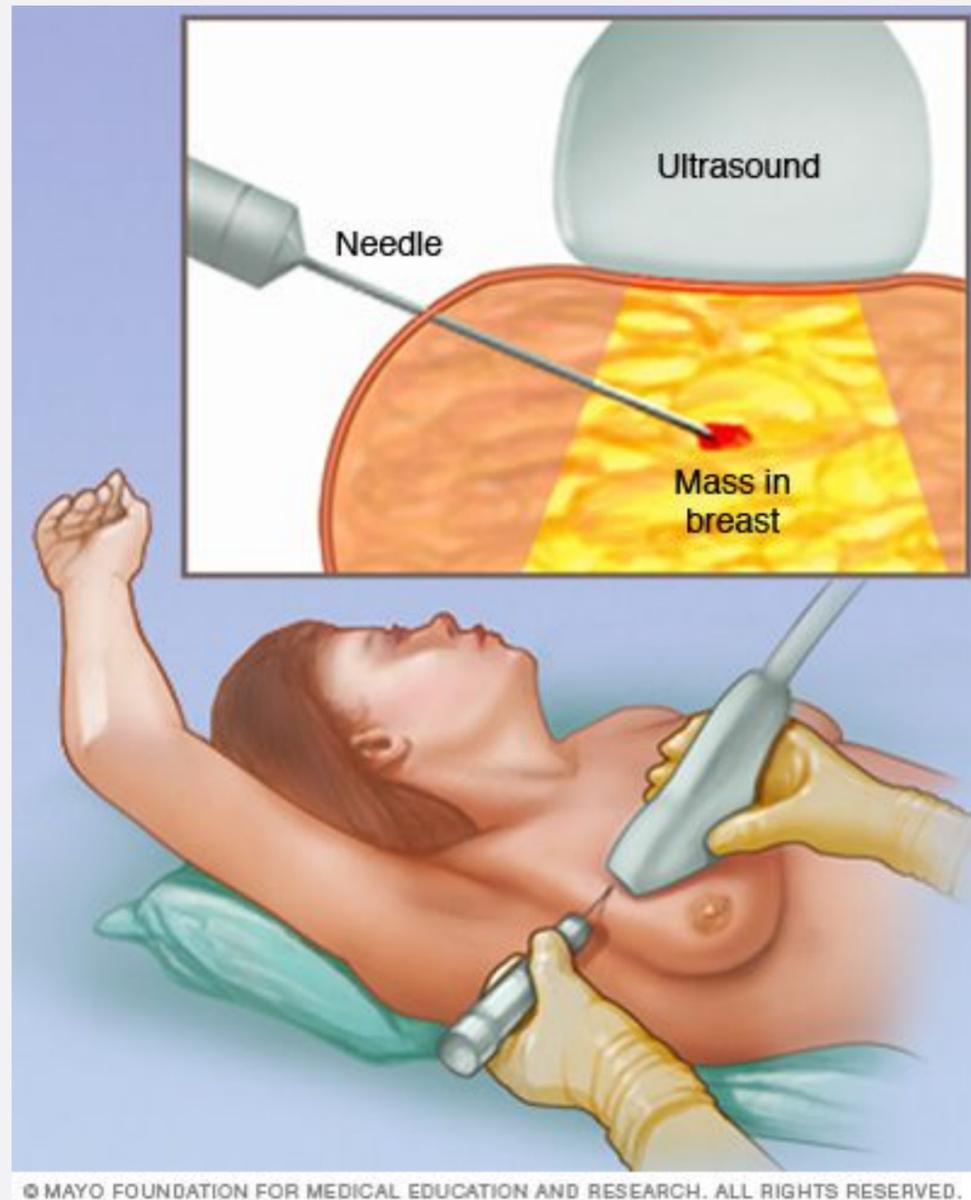
mammography



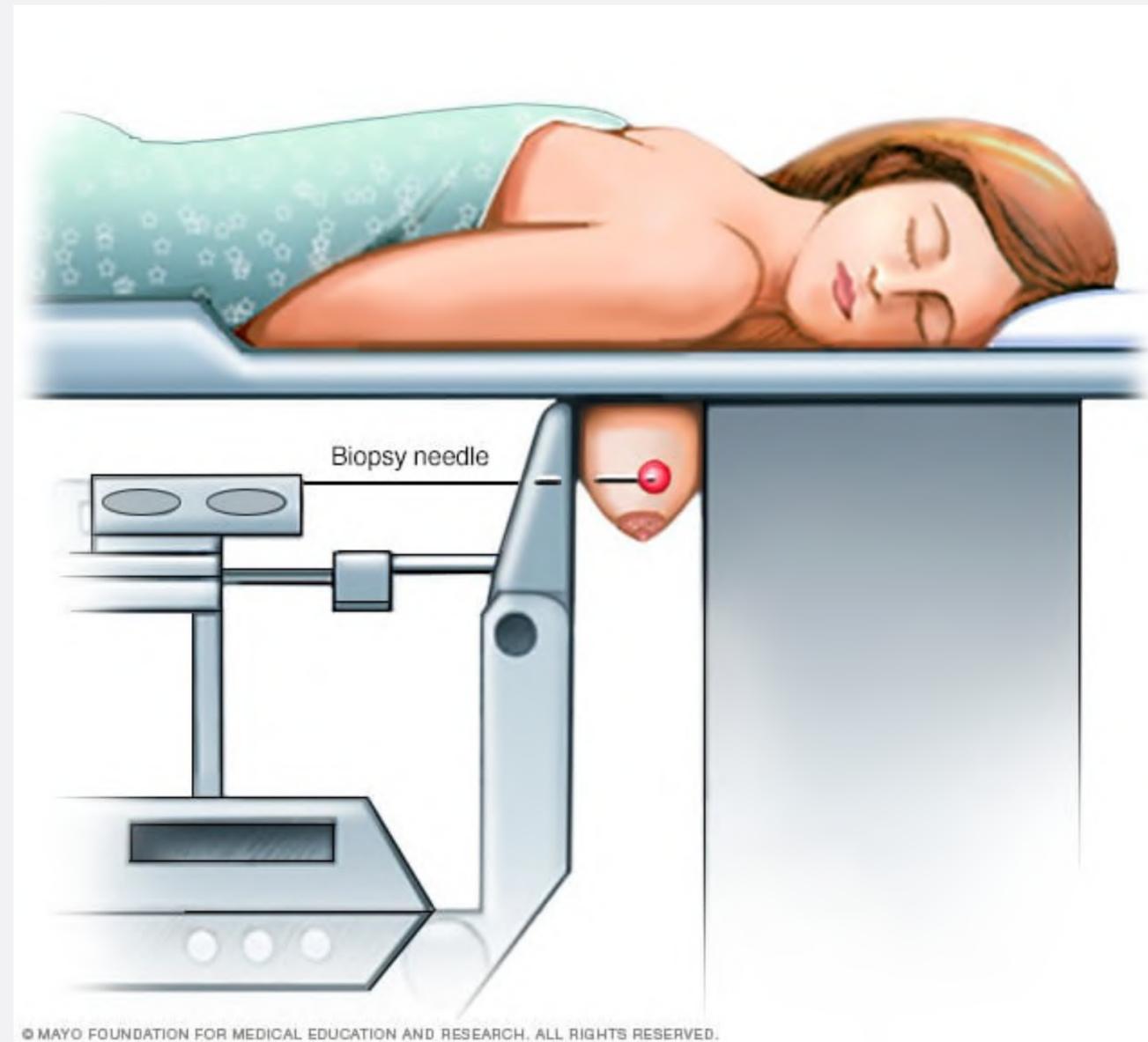
biopsy

Breast biopsy techniques

Ultrasound-guided core needle biopsy



Digital stereotactic/tomosynthesis-guided breast biopsy

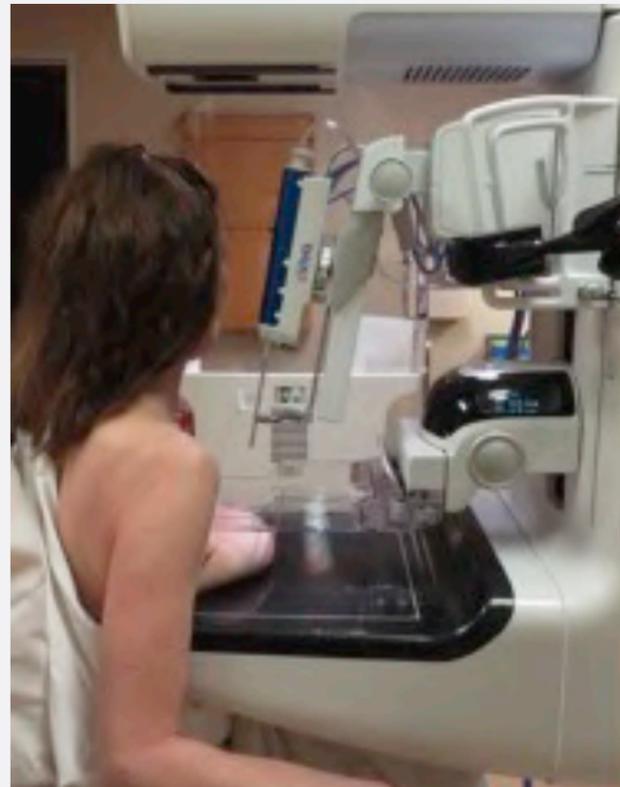


Mammogram-guided Breast Biopsy (SBB) clinical workflow

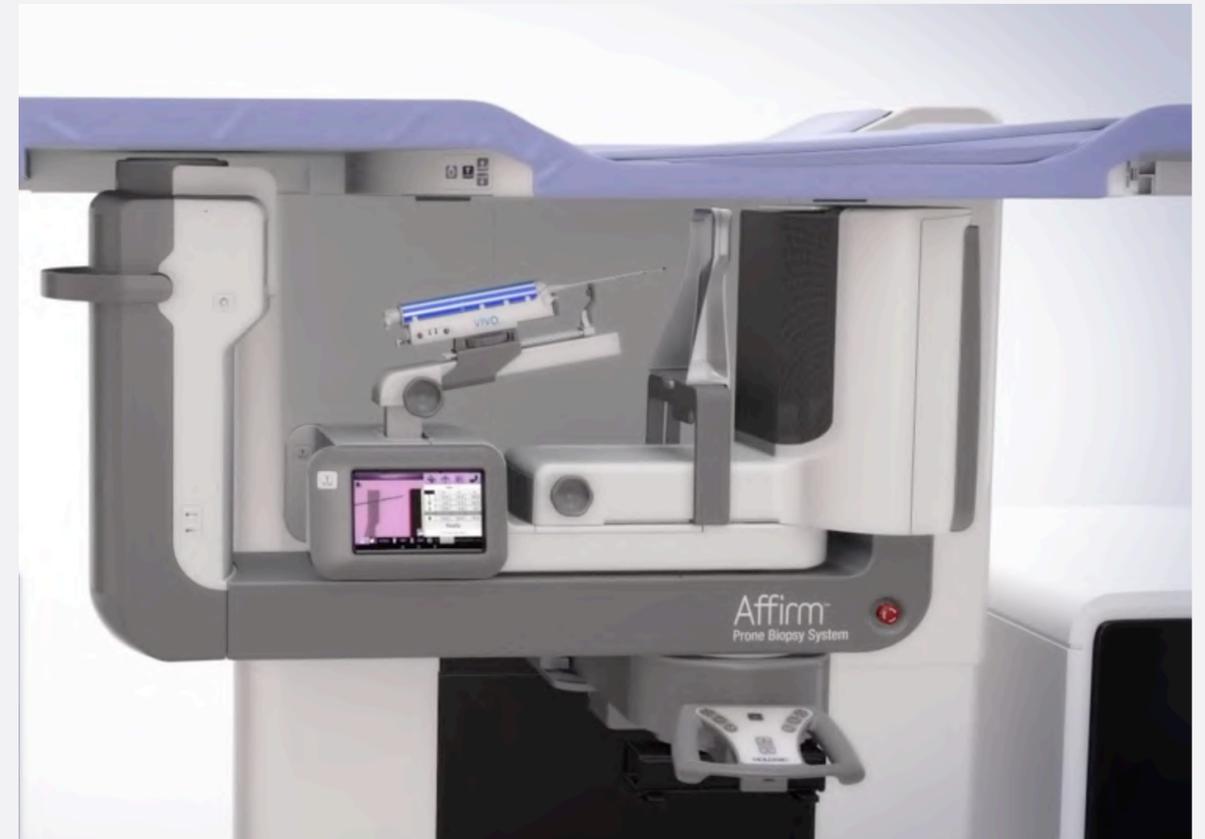
(1) The patient is positioned (prone/upright) and preliminary localization images are acquired.



Prone table cranio-caudal (CC) biopsy



Upright CC biopsy



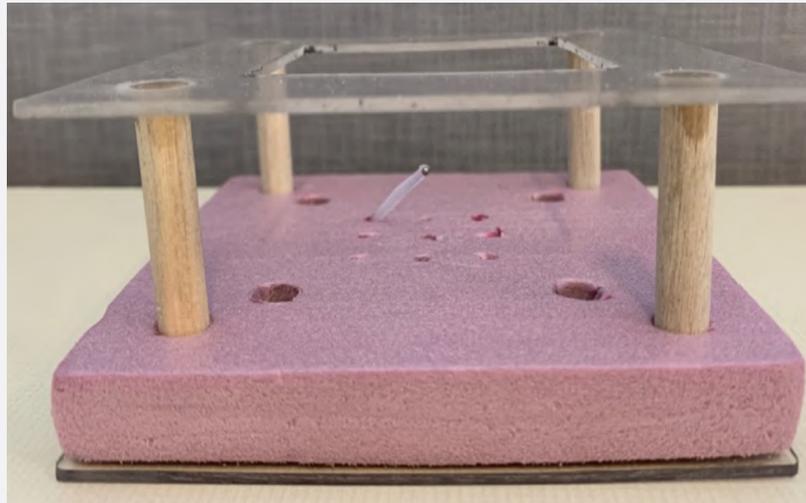
Hologic Affirm prone biopsy system
(www.youtube.com/watch?v=H0twugpEvXQ&t=3s)

Mammogram-guided Breast Biopsy (SBB)

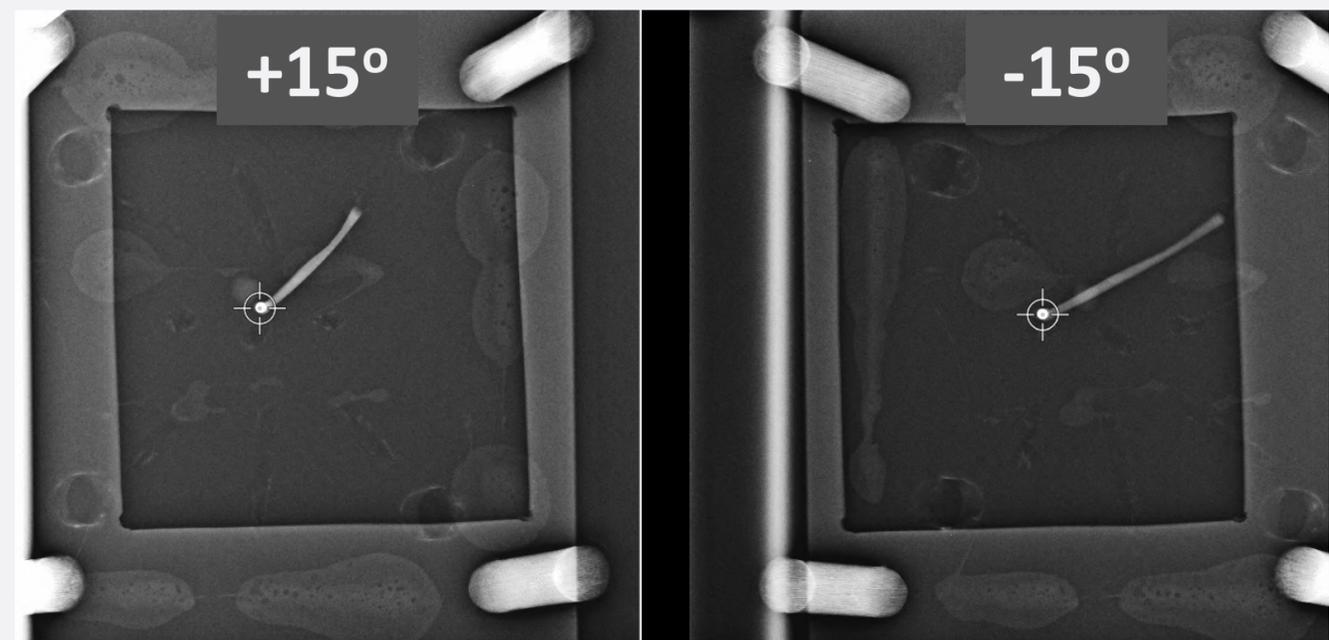
clinical workflow

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

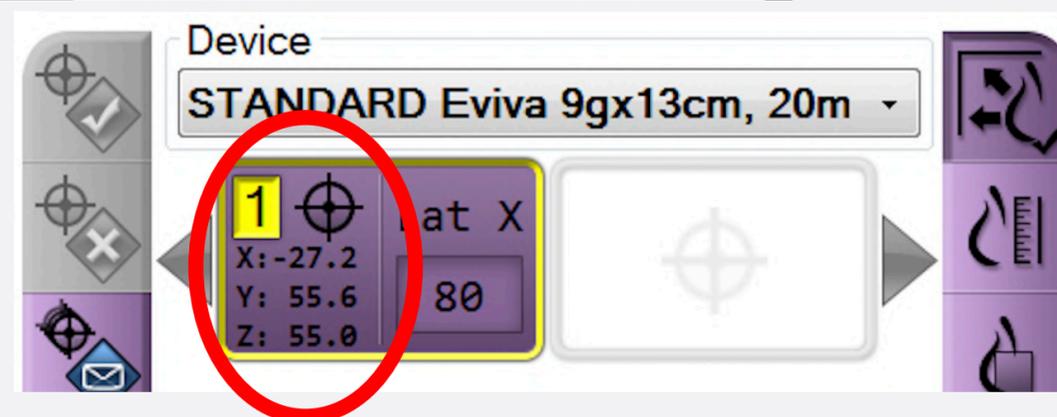
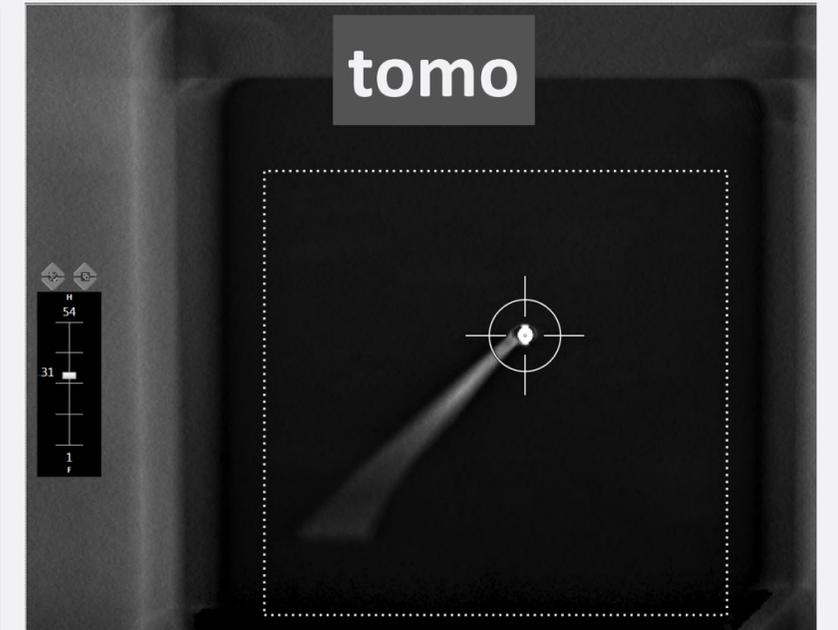
Biopsy phantom



Target identification on stereo pair



Target identification on tomo images

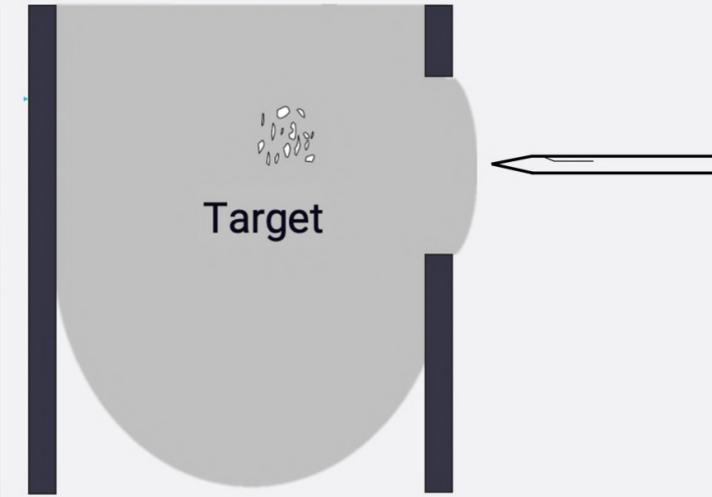
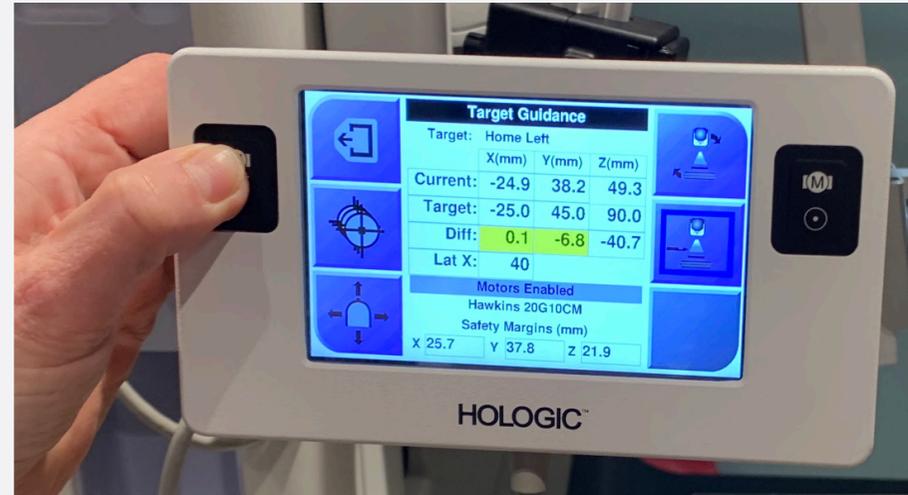


(3) Needle size is selected (standard or petite) based on the breast thickness and lesion depth.

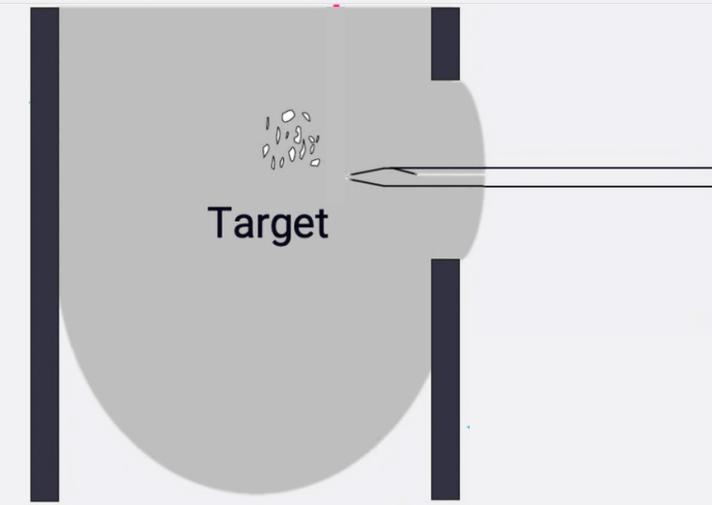
Mammogram-guided Breast Biopsy (SBB)

clinical workflow (cont'd)

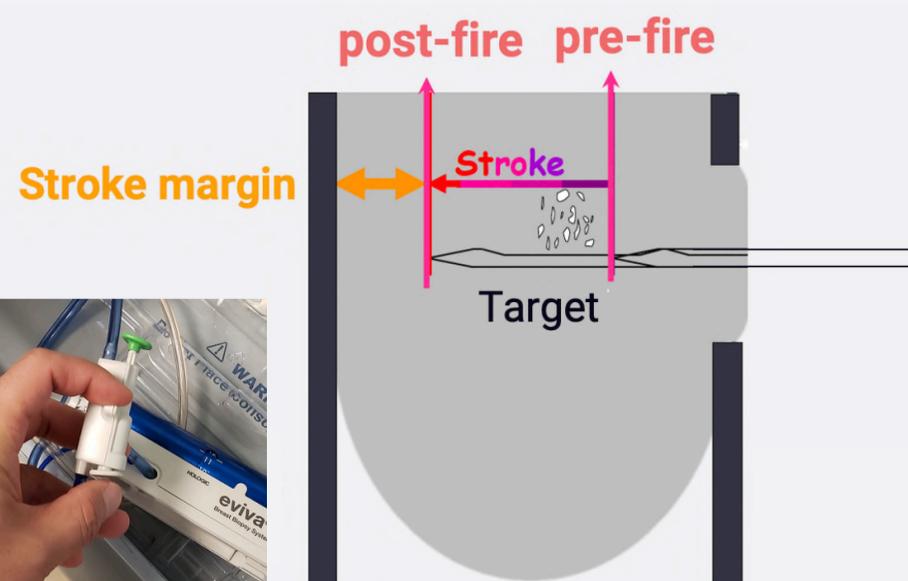
(4) Automatic targeting system is activated, and the needle is positioned outside the breast on a machine determined reference point.



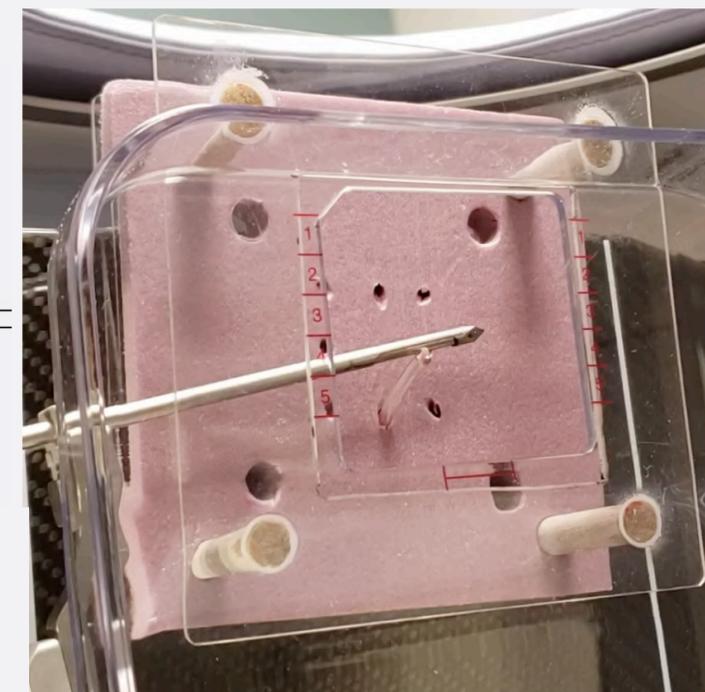
(5) The needle is manually advanced to the **pre-fire** position. Pre-fire images are acquired and appropriate positioning of the needle relative to the target is confirmed.



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



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

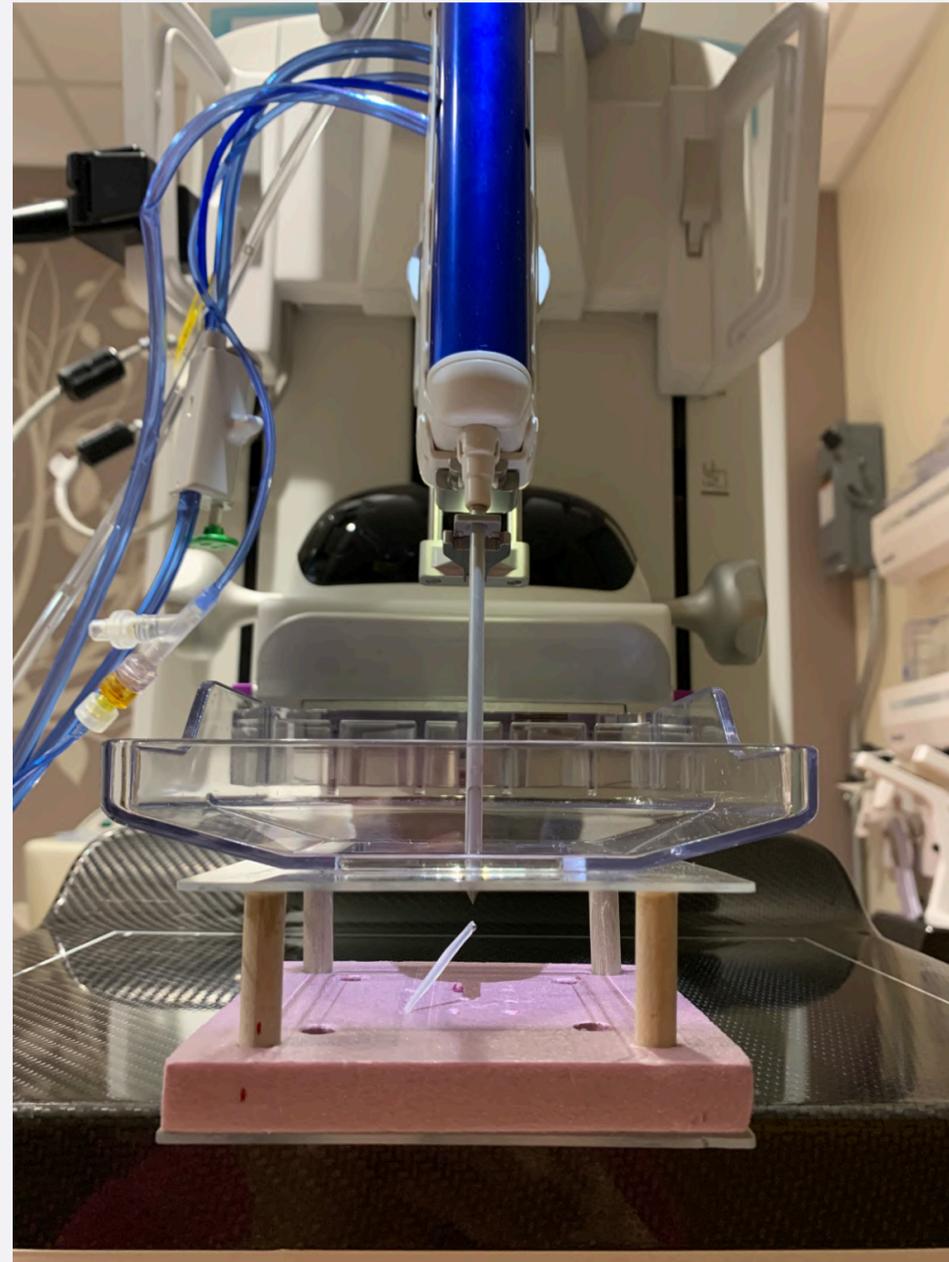


Mammogram-guided Breast Biopsy (SBB) phantom demonstration – Cranio-caudal configuration

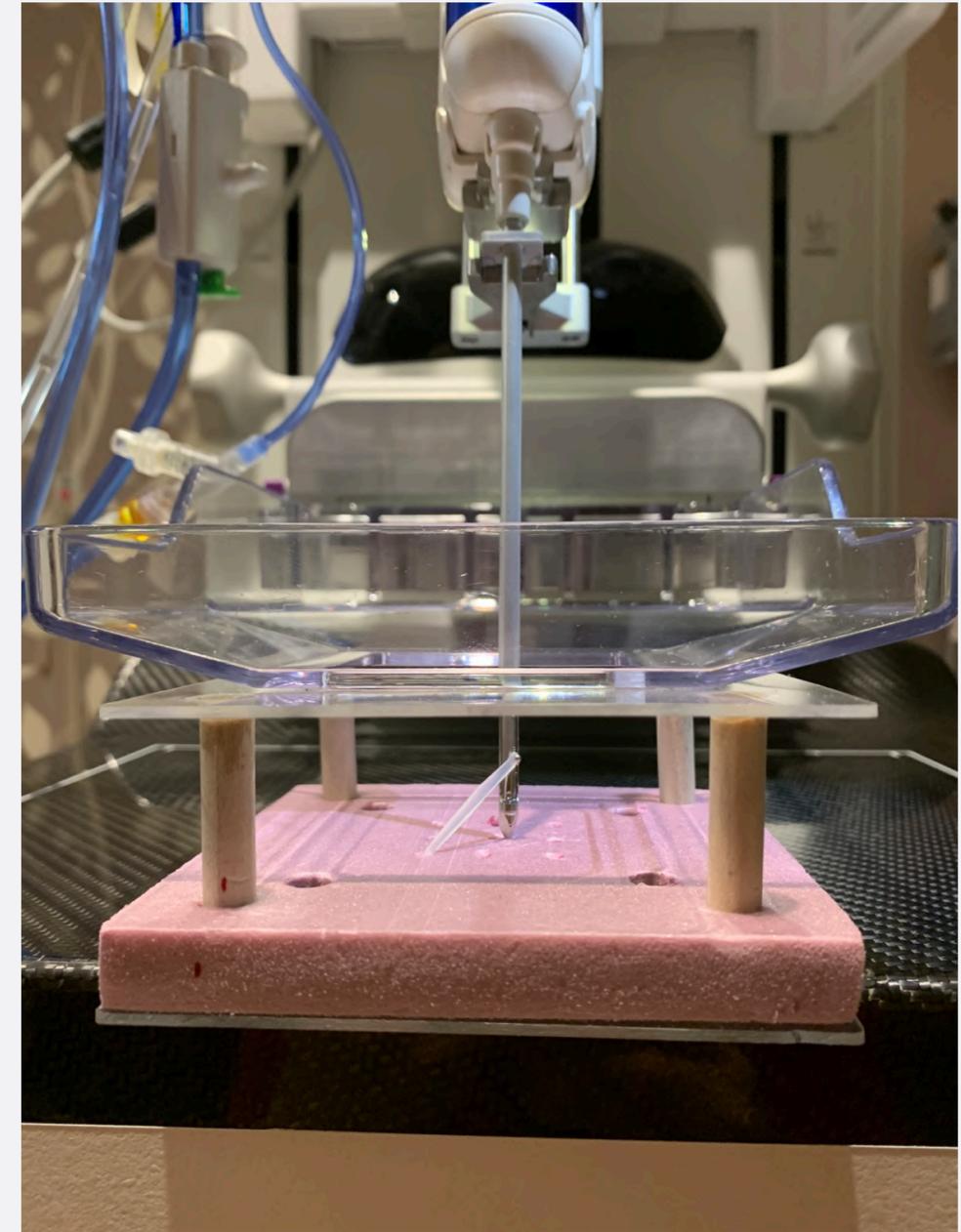
Reference point



Pre-fire position



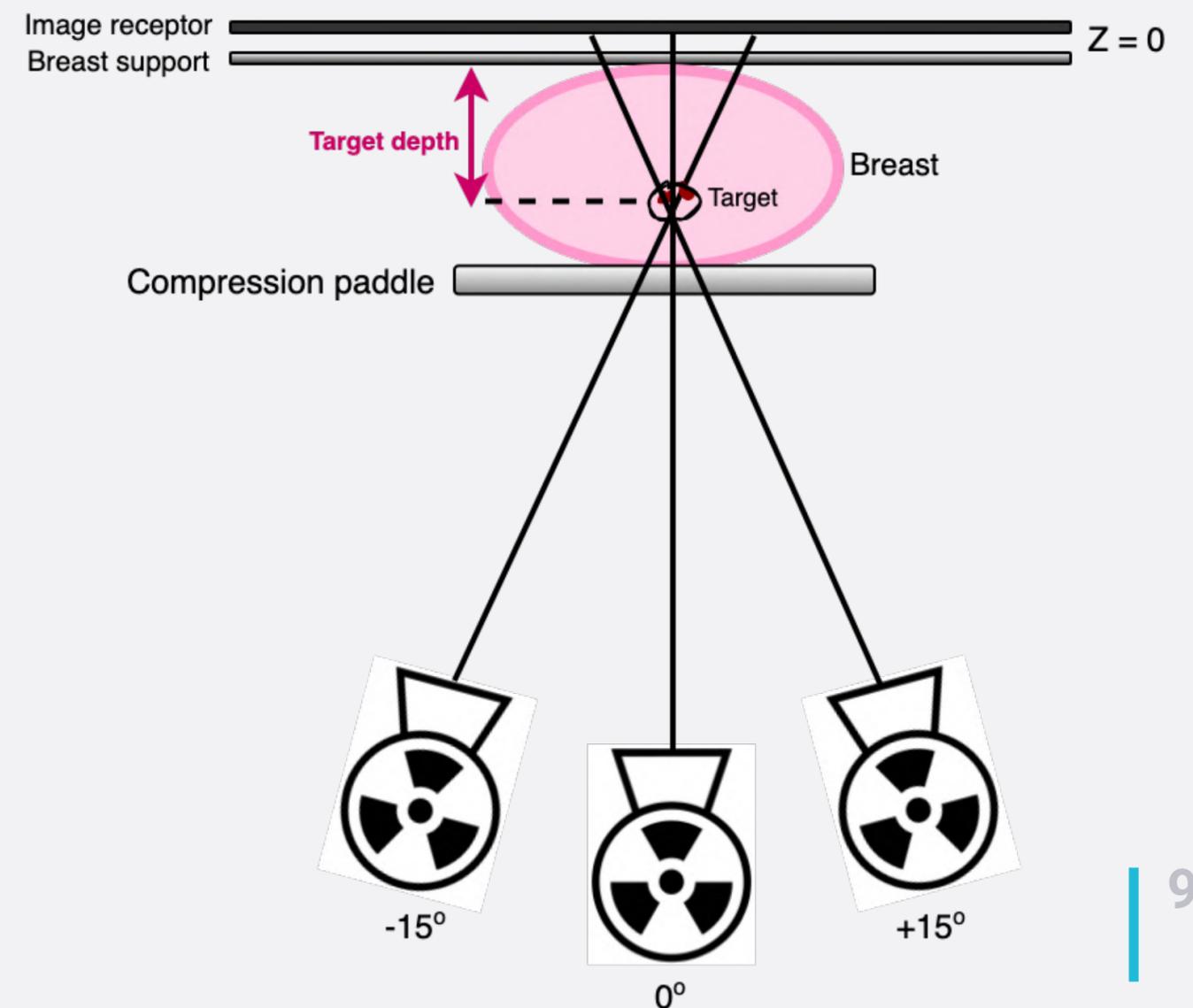
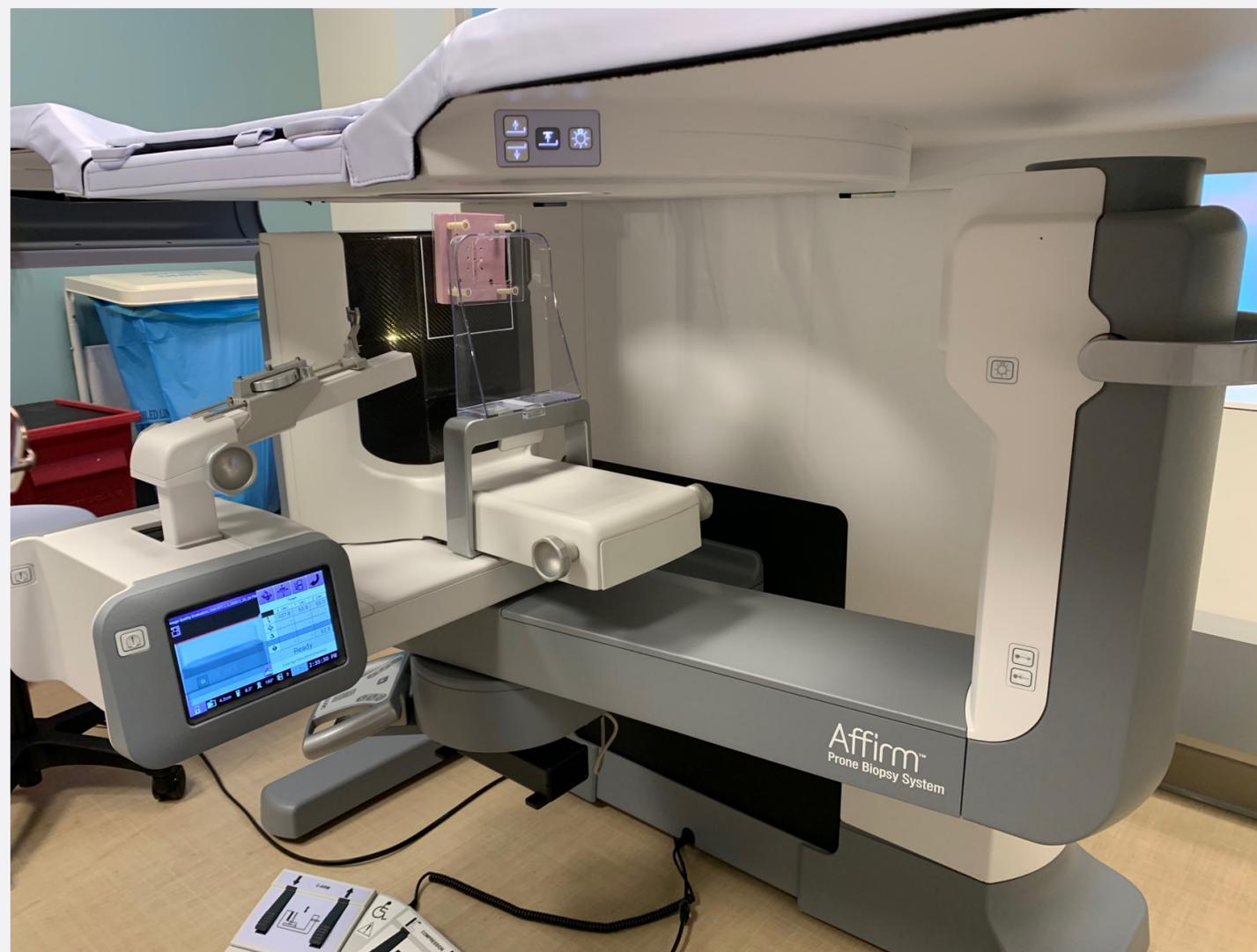
post-fire position



Stereotactic Breast Biopsy

geometric configuration of target localization: stationary detector

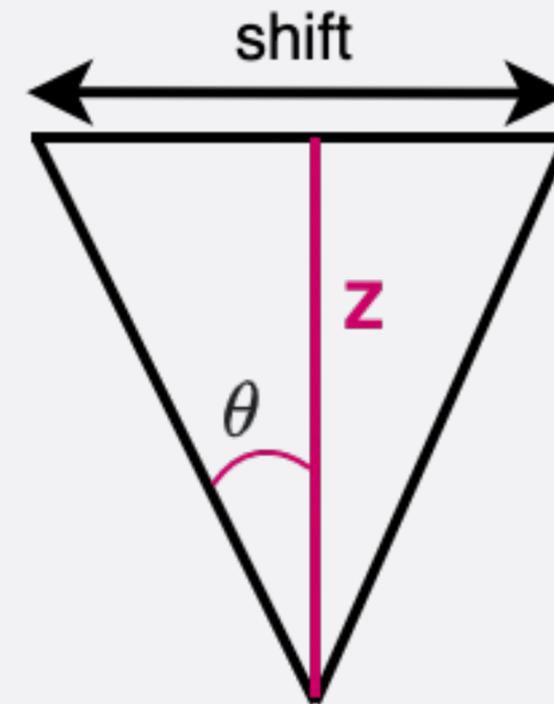
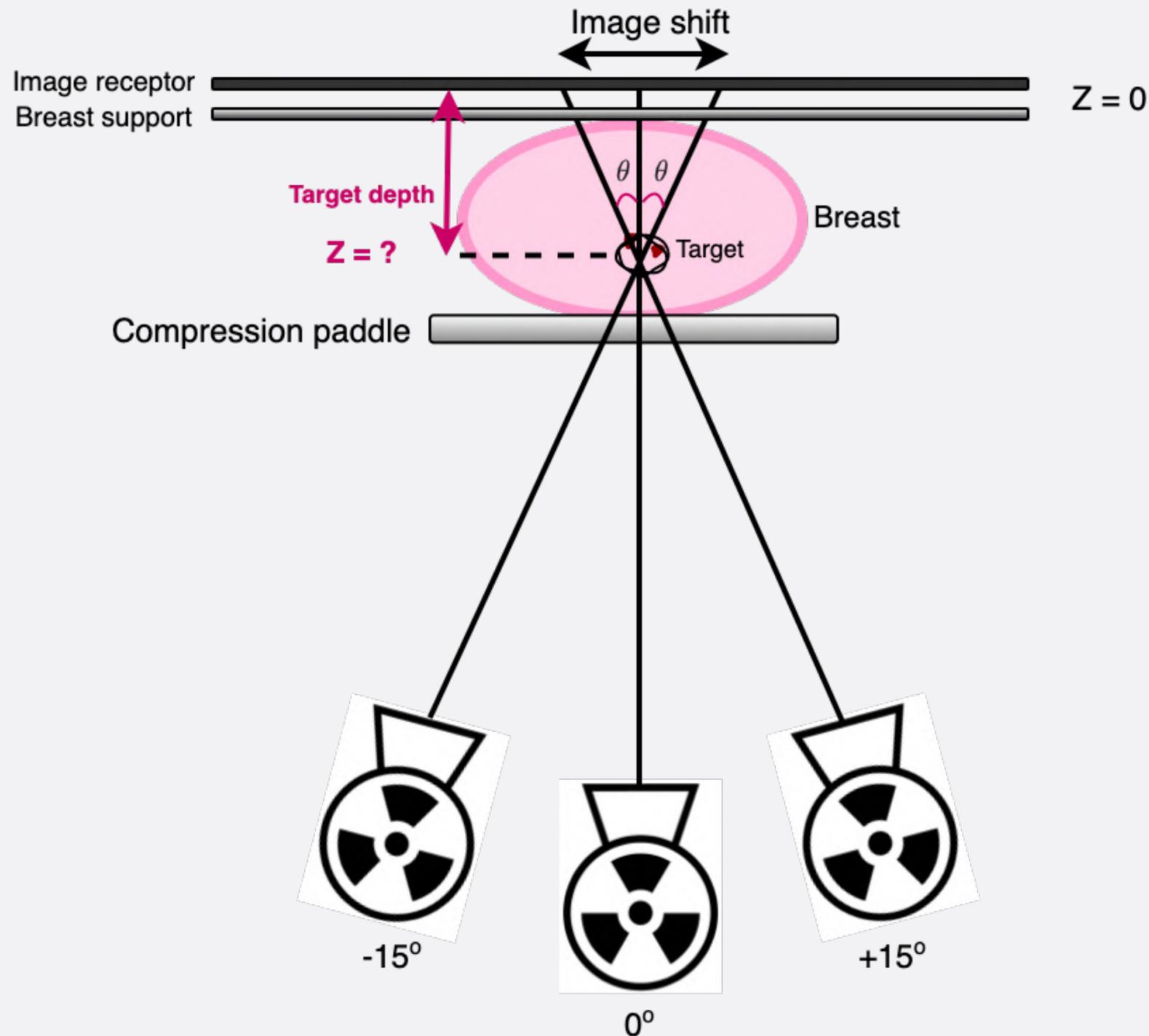
- Imaging plane remains stationary and is only perpendicular to the central x-ray at 0 degree.
- The location of $z = 0$ is posterior to the breast near the imaging plane, and z increases in value as the object approaches the x-ray source
- The center of rotation is located behind the breast near the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



Stereotactic Breast Biopsy

target localization: depth calculation

- Target location is determined using the stereo pair images:



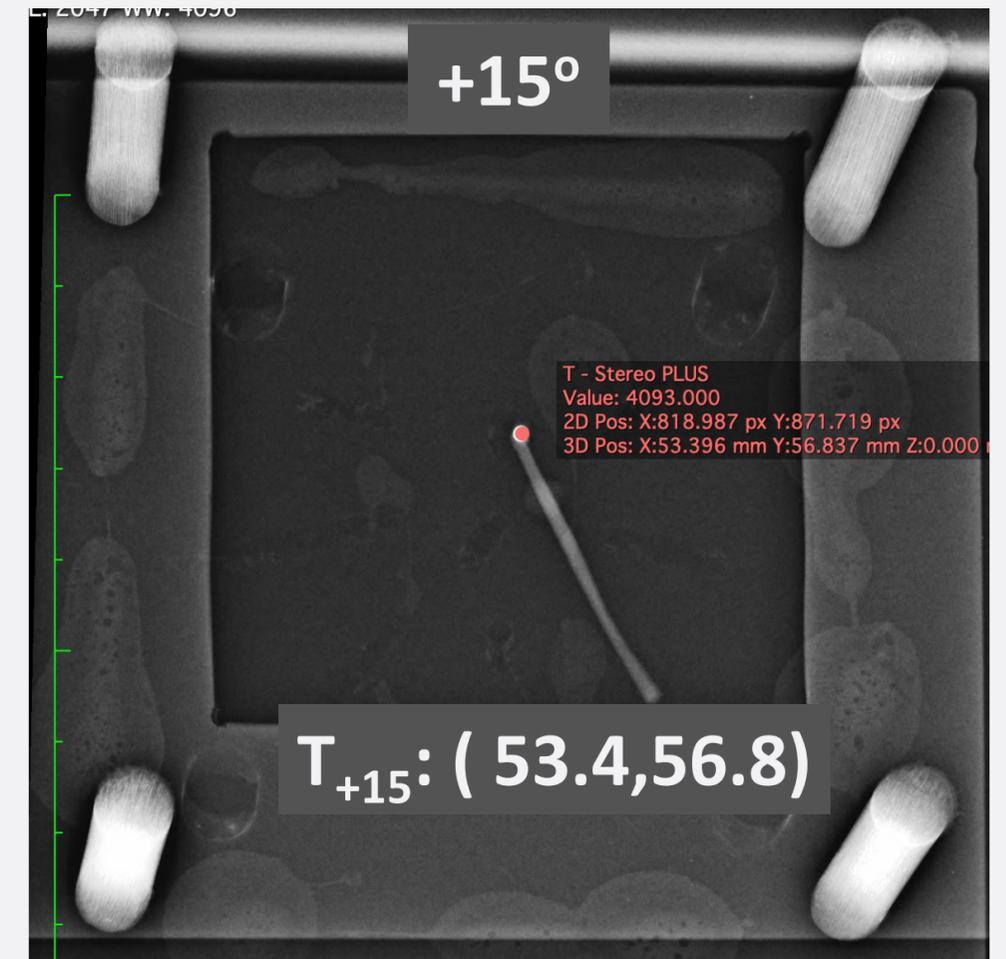
$$\tan\theta = \frac{shift/2}{Z} \quad \theta = 15^\circ$$

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

Stereotactic Breast Biopsy

target localization: phantom demonstration

- Target location is determined using the stereo pair images:



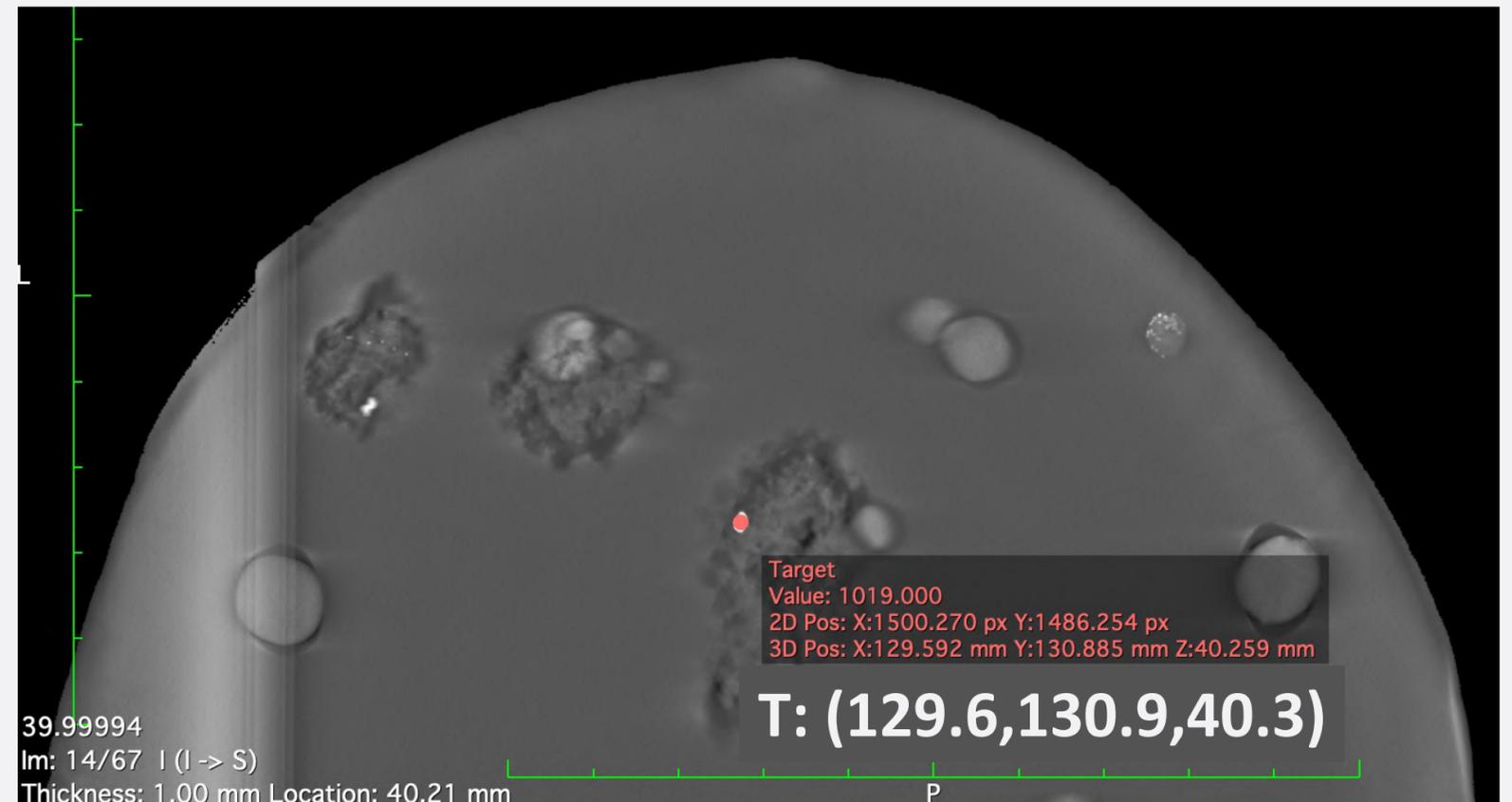
$$\textit{Shift} = 101.7 - 56.8 = 44.90 \textit{ mm}$$

$$\textit{Z} = 1.866 * \textit{shift} = 1.866 * 44.9 = 83.77 \textit{ mm}$$

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

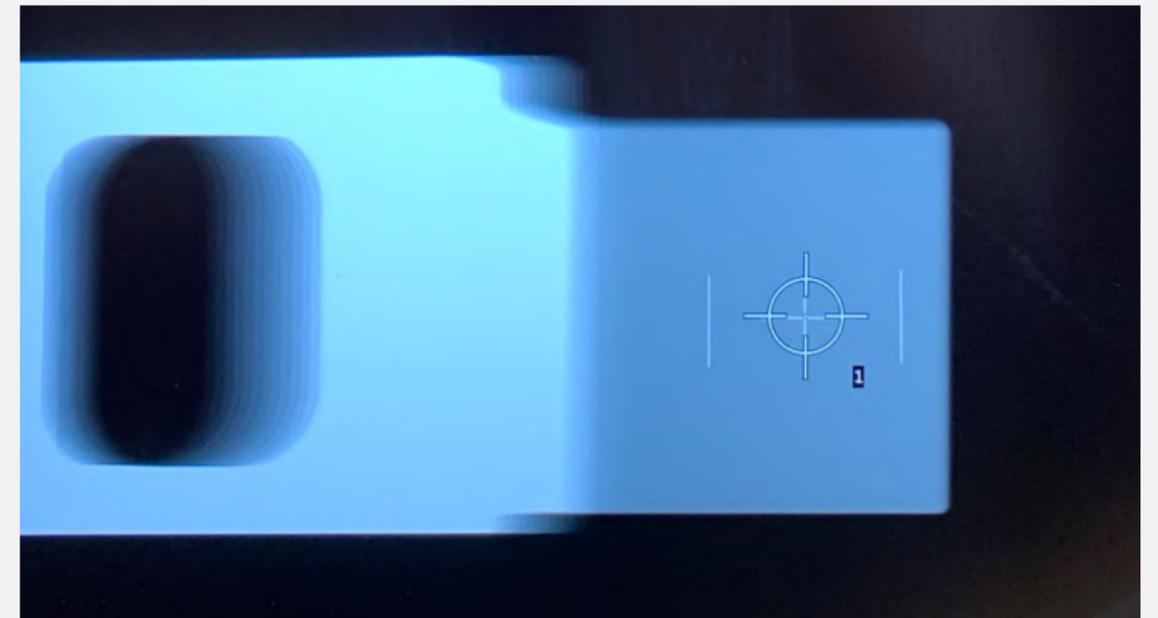
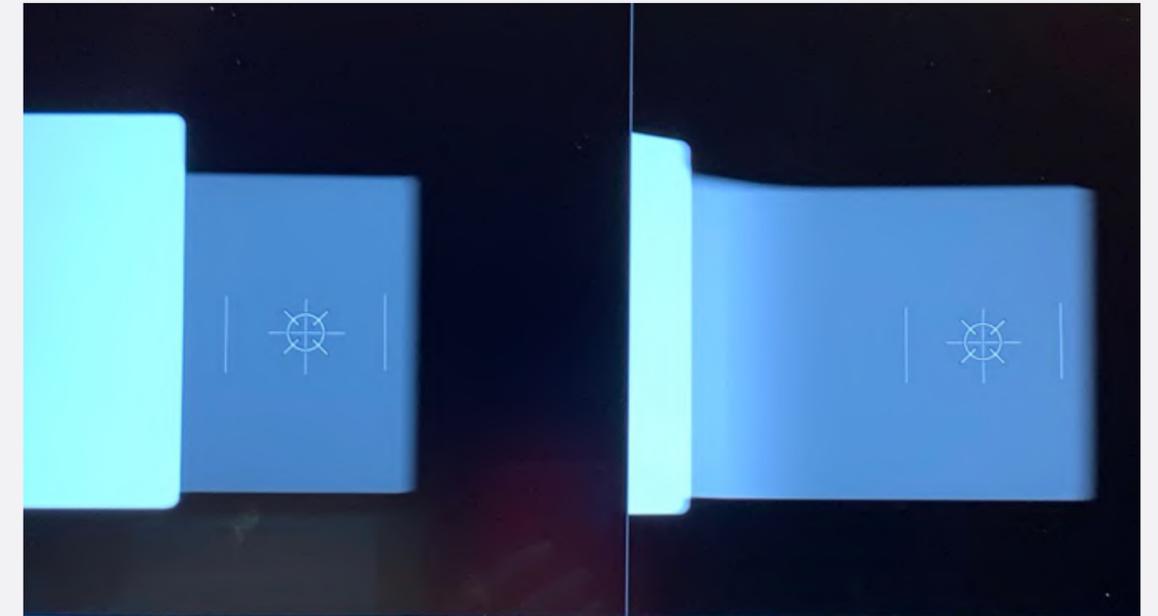
Tomosynthesis-guided breast biopsy target localization

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



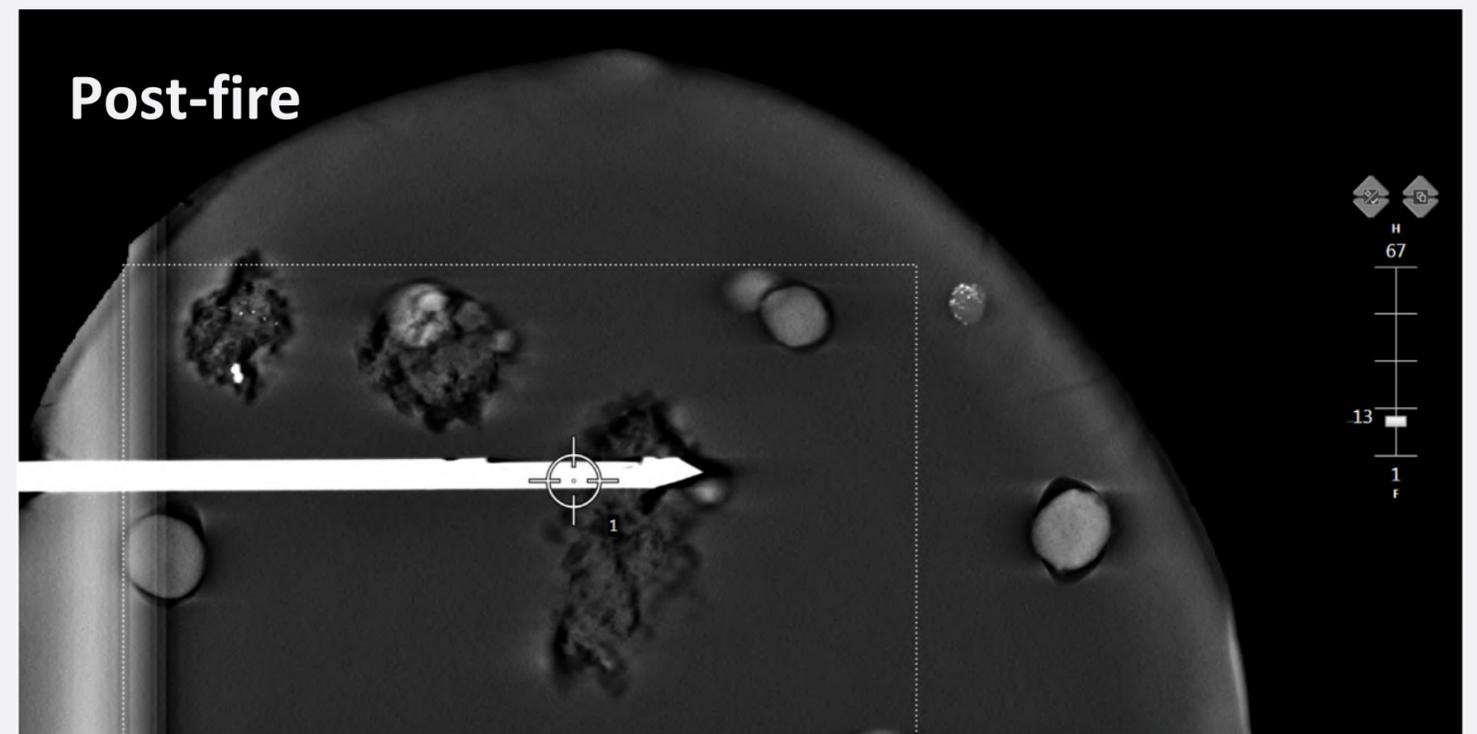
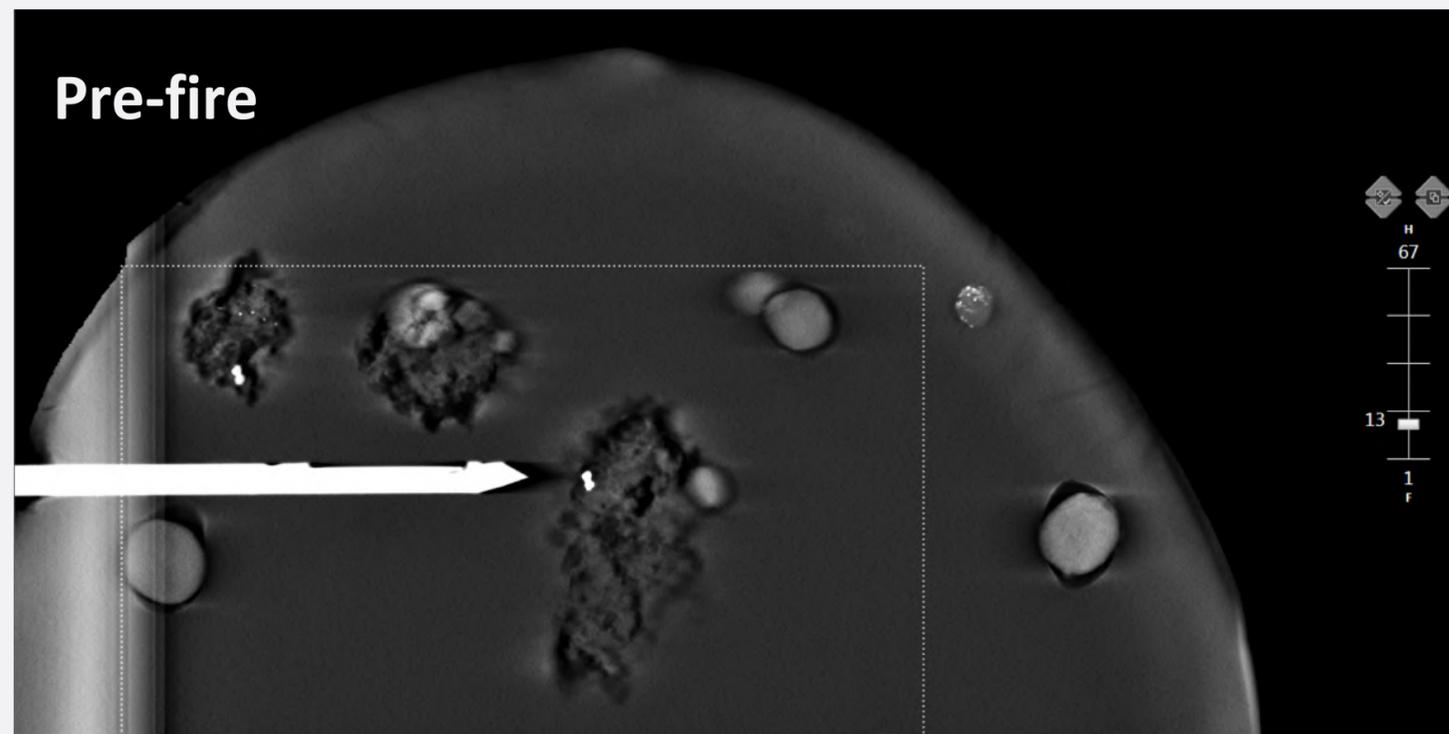
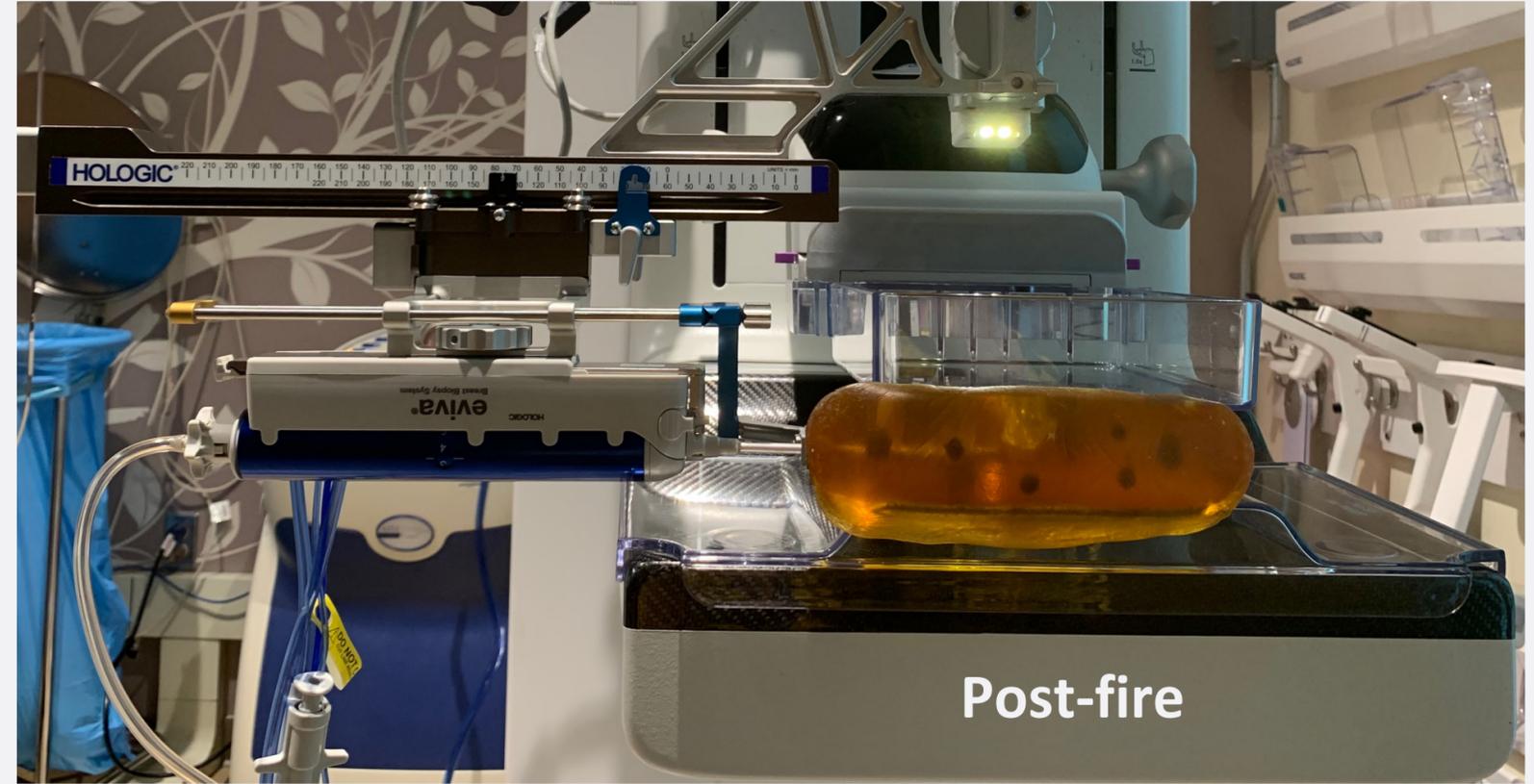
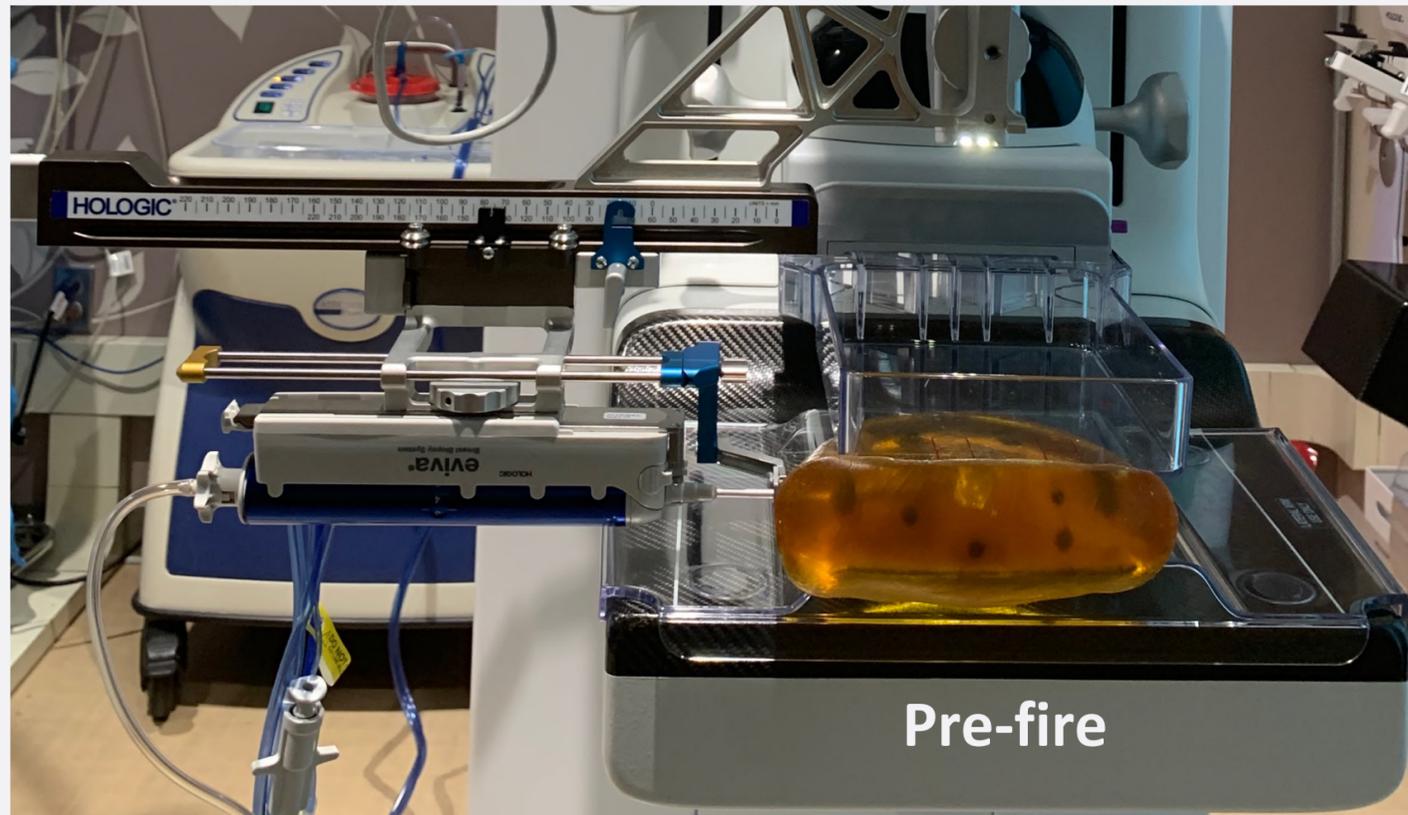
Localization accuracy test

current daily test performed by a technologist (Hologic)



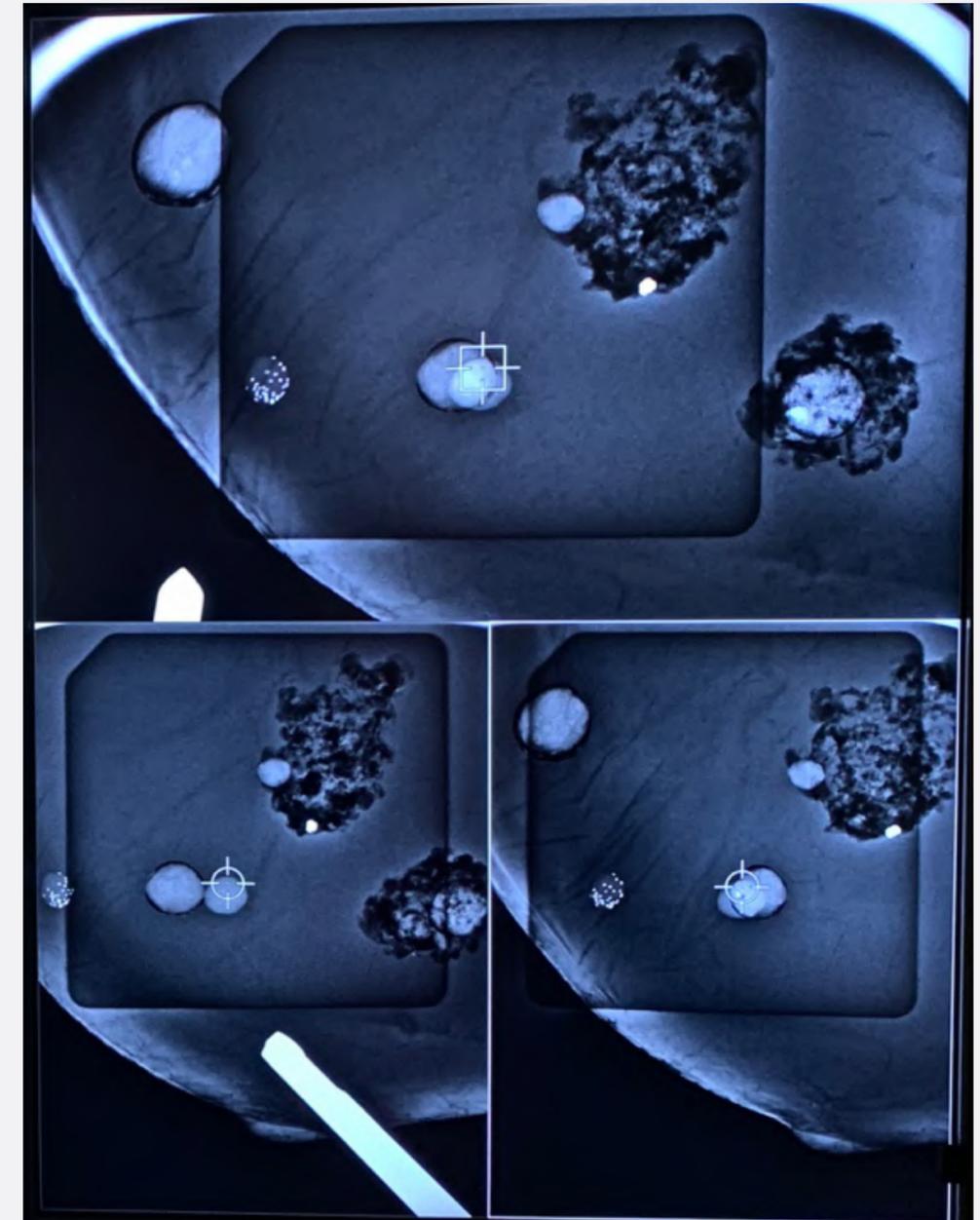
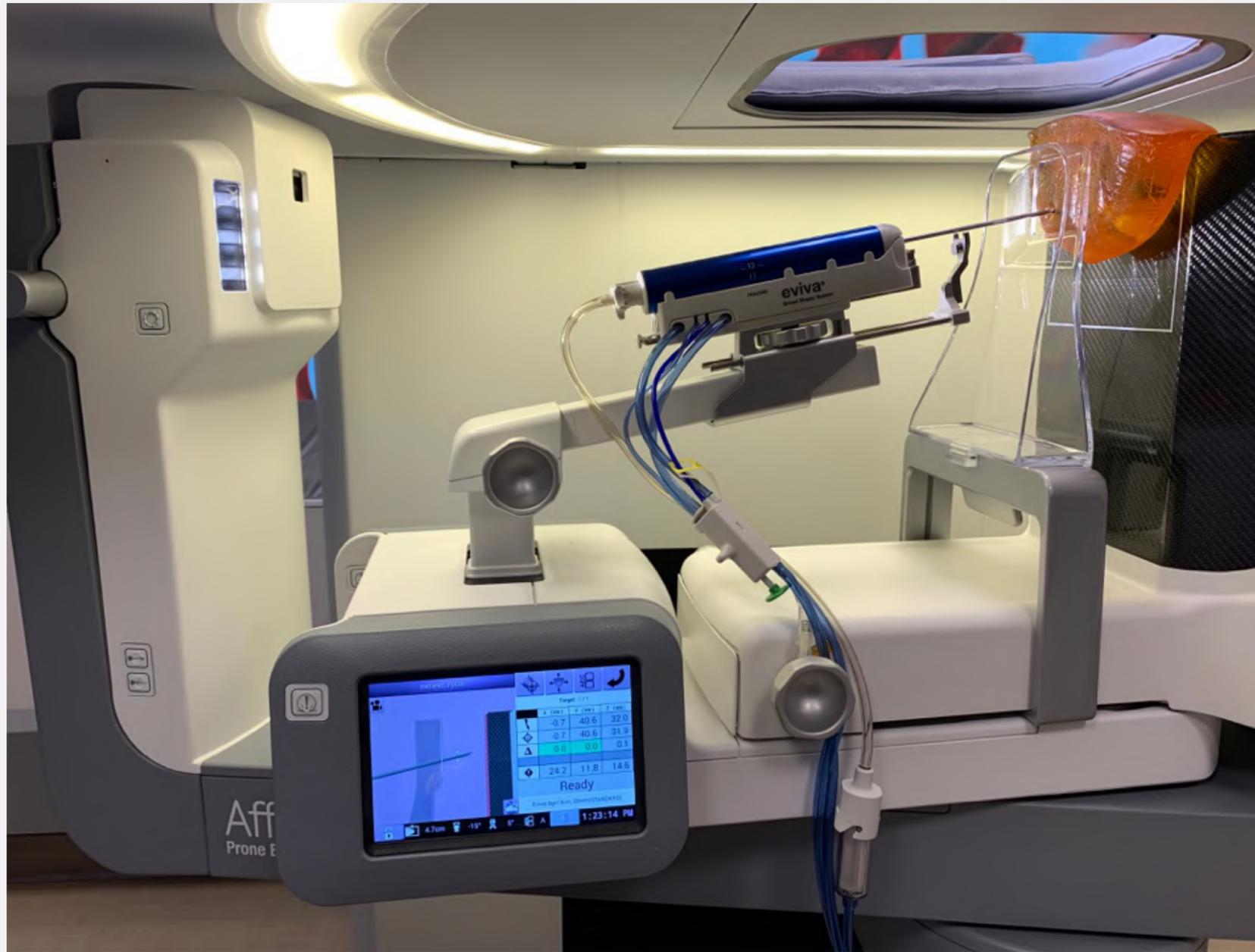
Localization accuracy test

current annual test performed by a Medical Physicist

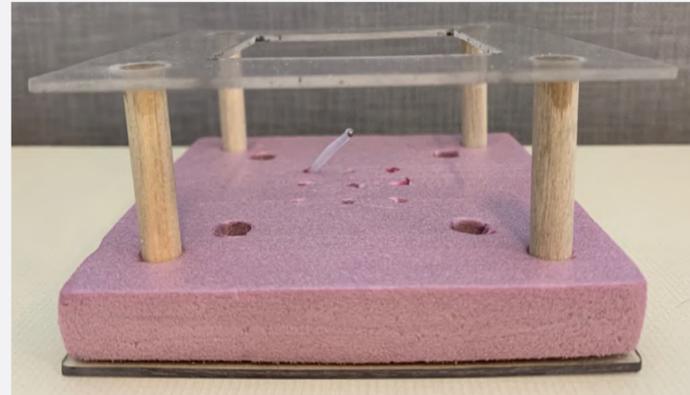


Localization accuracy test

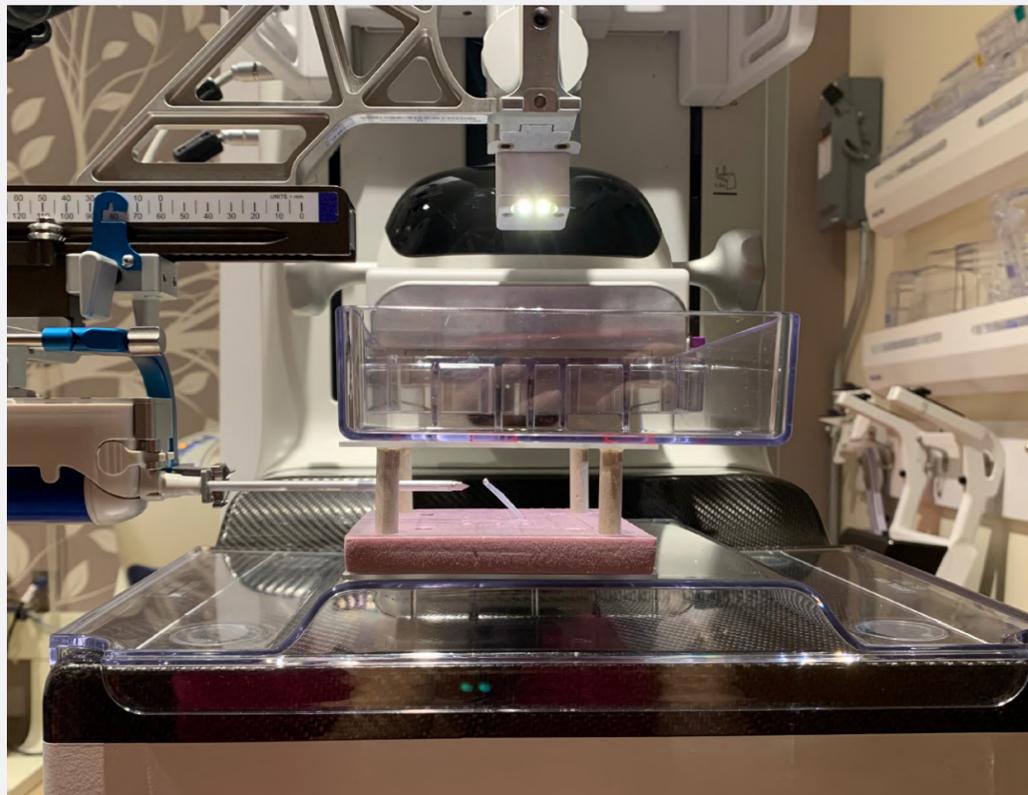
current annual test performed by a Medical Physicist



A novel approach for localization accuracy test test setup



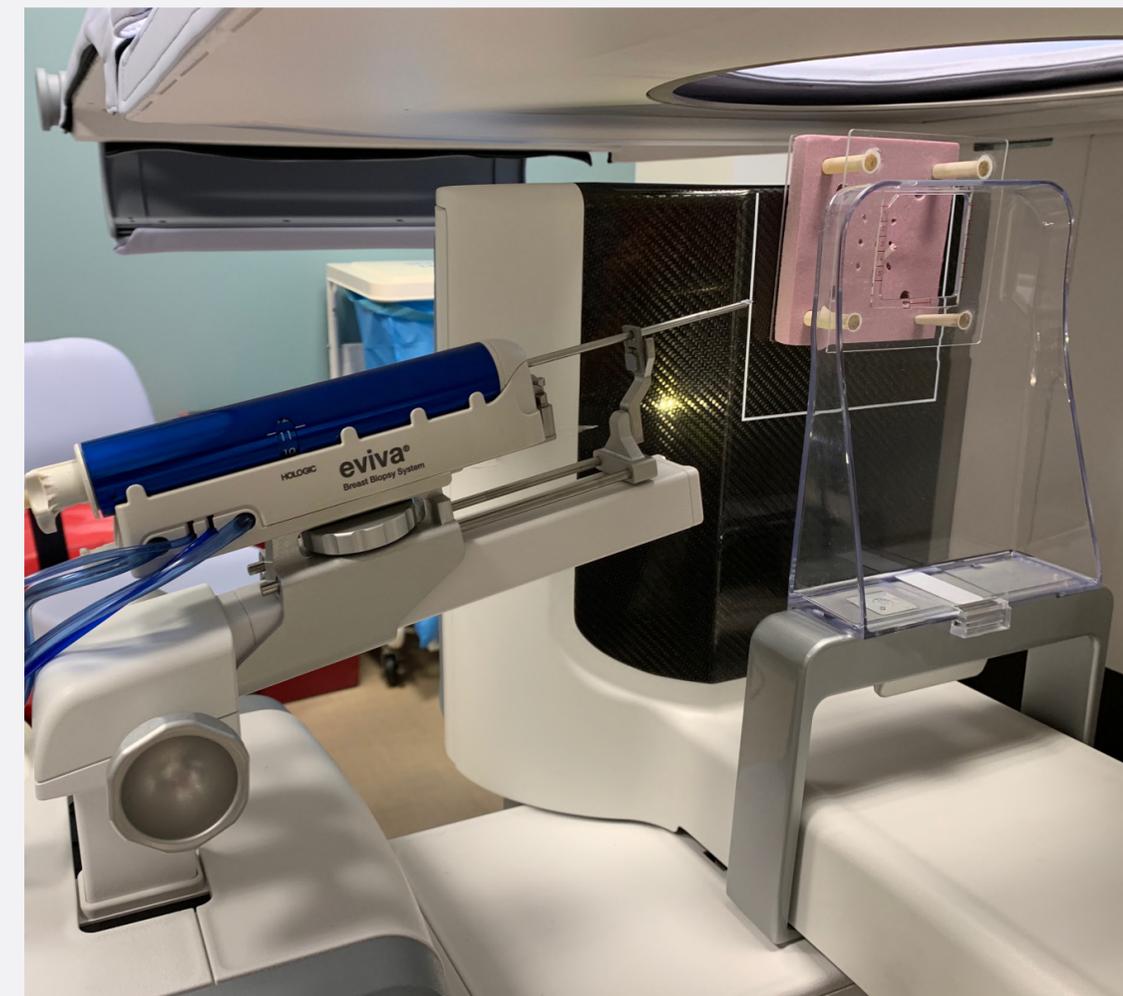
**Upright unit
lateral arm biopsy**



**Upright unit
cranio-caudal biopsy**

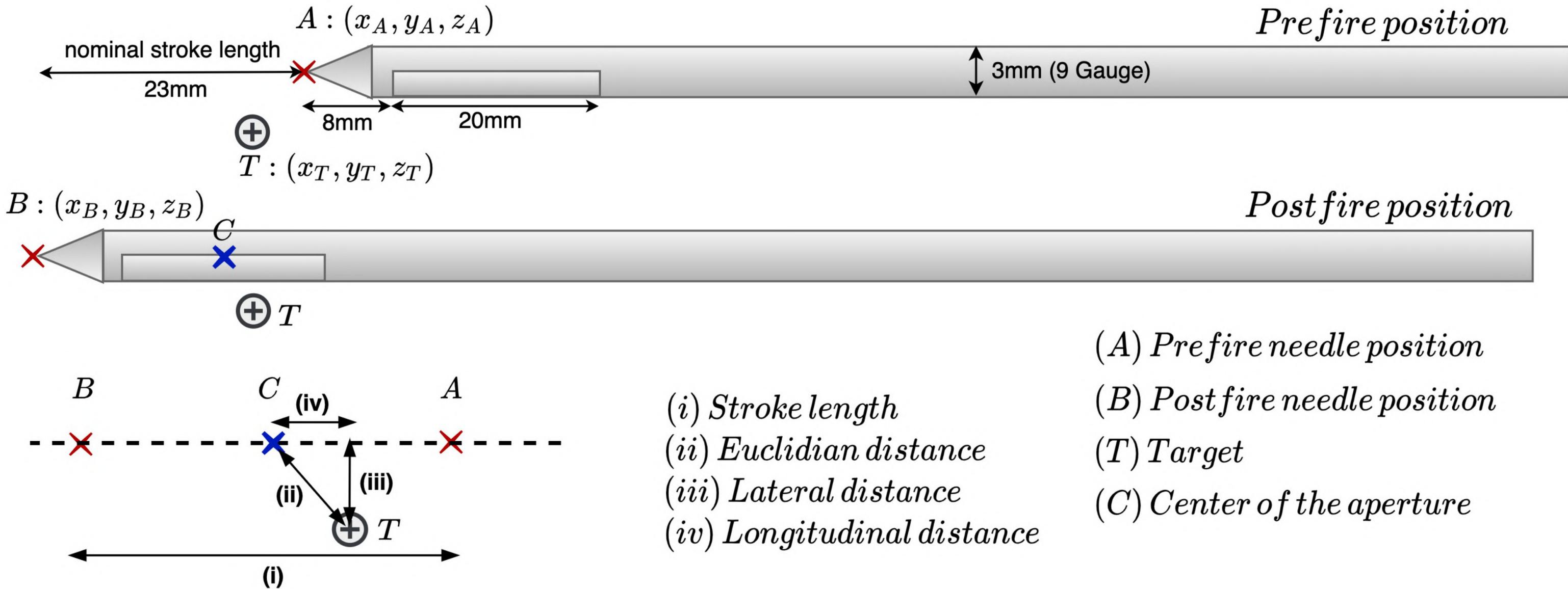


**Prone unit
lateral arm biopsy**



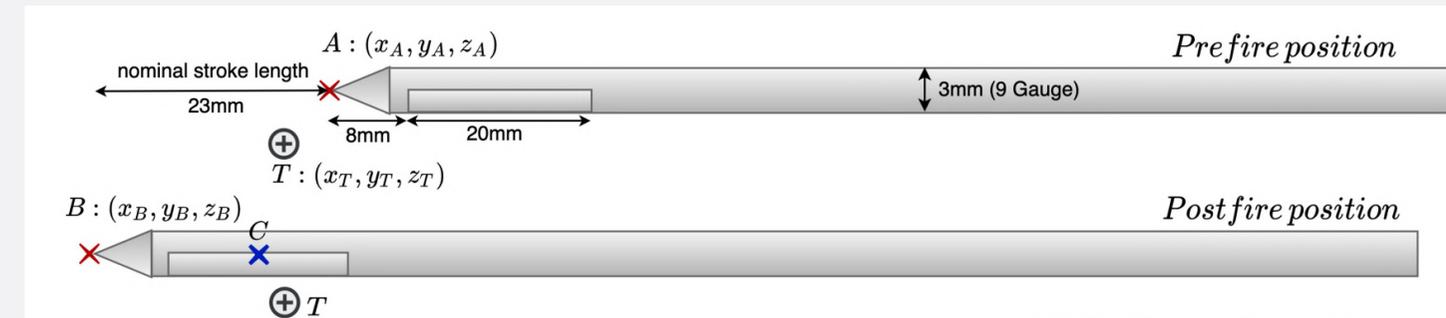
A novel approach for localization accuracy test

new localization analysis



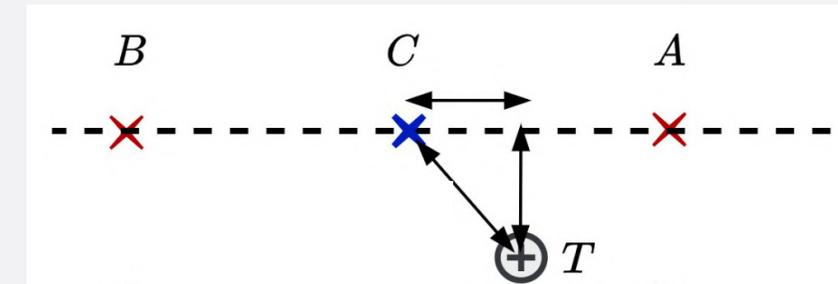
A novel localization accuracy test

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:

$$\begin{aligned} |\overrightarrow{BC}| &= |\overrightarrow{AB}| |t| \\ |t| &= |\overrightarrow{BC}| / |\overrightarrow{AB}| \end{aligned}$$

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

$$\begin{cases} x_C = x_A + \frac{d}{|\overrightarrow{AB}|} (x_B - x_A) \\ y_C = y_A + \frac{d}{|\overrightarrow{AB}|} (y_B - y_A) \\ z_C = z_A + \frac{d}{|\overrightarrow{AB}|} (z_B - z_A) \end{cases} \quad |\overrightarrow{AB}| = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2 + (z_B - z_A)^2}$$

A novel approach for localization accuracy test

error metrics

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

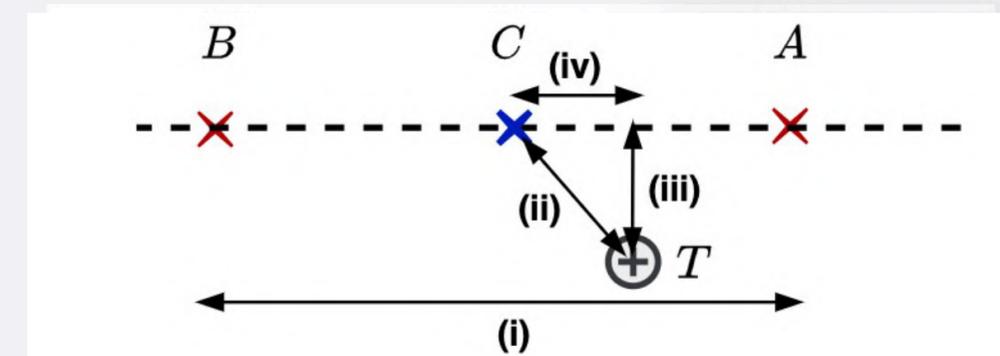
$$|\overrightarrow{TC}| = \sqrt{(x_T - x_C)^2 + (y_T - y_C)^2 + (z_B - z_A)^2}$$

(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

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AB56 | fx

Depth (Z) calculation					
		PLUS 15 projection	MINUS 15 projection	shift	depth (z)
Pre-fire Needle's tip (A)	x	54.13	54.548	0.418	81.17023904
	y	51.491	94.99	43.499	
Target in Pre-fire (T)	x	53.196	53.612	0.416	83.76214833
	y	56.803	101.691	44.888	
post-fire Needle's tip (B)	x	54.355	54.542	0.187	82.00248637
	y	74.306	118.251	43.945	

YEAR	2021	2022	2023	
Pre-fire needle tip (A)	x	54.339		
	y	73.2405		
	z	81.17023904		
Post-fire needle tip (B)	x	54.4485		
	y	96.2785		
	z	82.00248637		
Target (T)	x	53.404		
	y	79.247		
	z	82.00248637		
Nominal stroke length	23			

Calculations			
Measured stroke length (AB)	23.05	0.00	0.00
Center of trough (C)	x	54.37	#DIV/0!
	y	78.79	#DIV/0!
	z	81.37	#DIV/0!
Euclidian distance	1.2	#DIV/0!	#DIV/0!
Longitudinal distance	0.5	#DIV/0!	#DIV/0!
Lateral distance	1.1	#DIV/0!	#DIV/0!
Stroke length error	0.05	0.00	0.00
AT (pre-fire)	6.14	0.00	0.00

Perpendicular distance calculations					
2021					
1.0445	17.0315	0	1.0445	17.0315	0
0.1095	23.038	0.8322473	0.1095	23.038	0.8322473
14.17442	-0.869282	22.198242			
26.352074			1.1430939		
23.053288					
2022					
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0			
0			#DIV/0!		
0					
2023					
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0			
0			#DIV/0!		
0					

mm	2021	2022	2023
Euclidian distance	1.2		
Longitudinal distance	0.5		
Lateral distance	1.1		
stroke length error	0.05	0.00	0.00

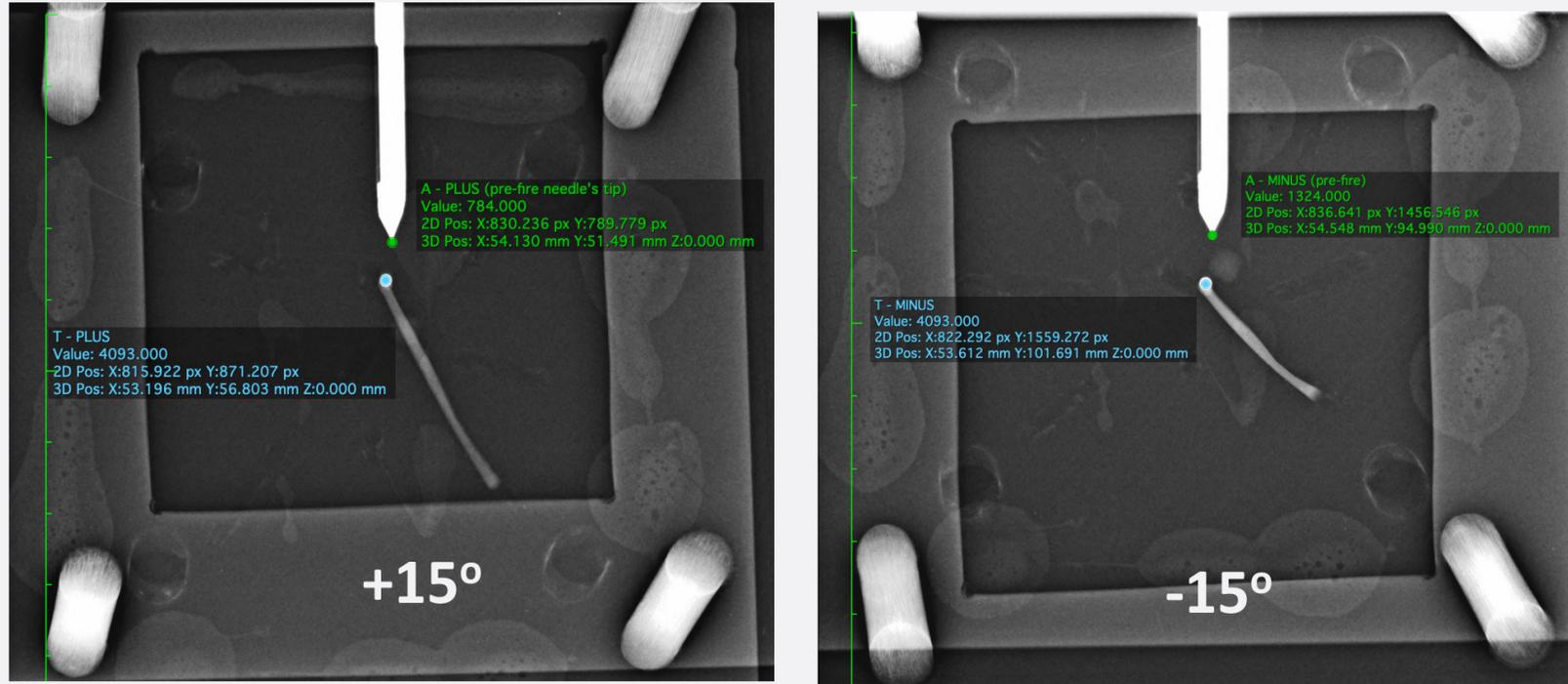
Tomosynthesis-guided | Stereotactic-guided

80%

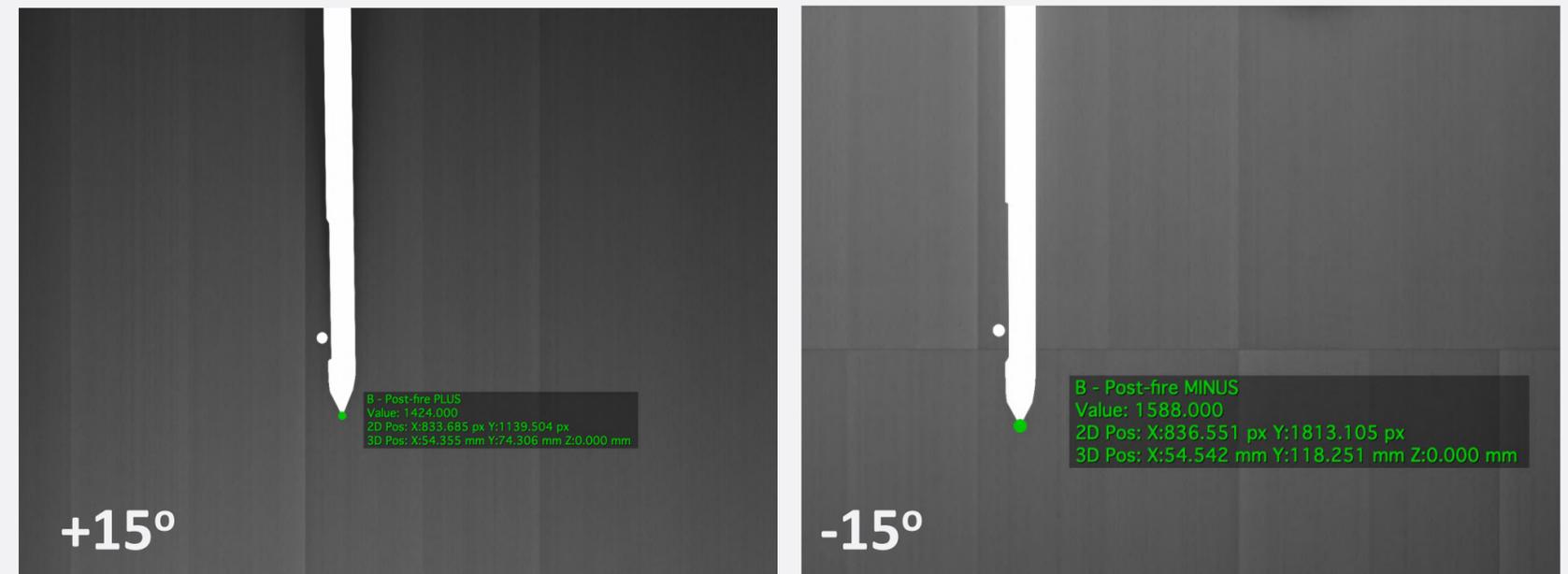
Stereotactic-guided biopsy

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

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U42 | fx

YEAR	2021	2022	2023
Pre-fire needle tip (A)	x	57	
	y	65.1	
	z	28	
Post-fire needle tip (B)	x	78.32	
	y	72.52	
	z	28	
Target (T)	x	62.5	
	y	66	
	z	29	
Nominal stroke length	23		

Calculations			
Measured stroke length (AB)	22.57	0.00	0.00
Center of trough (C)	x	61.79	#DIV/0!
	y	66.77	#DIV/0!
	z	28.00	#DIV/0!
Euclidian distance	1.4	#DIV/0!	#DIV/0!
Longitudinal distance	0.4	#DIV/0!	#DIV/0!
Lateral distance	1.4	#DIV/0!	#DIV/0!
Stroke length error	0.43	0.00	0.00
AT (pre-fire)	5.66	0.00	0.00

Year	Euclidian distance	longitudinal distance	lateral distance	stroke length error
2021	1.4	0.4	1.4	0.43
2022	0.00	0.00	0.00	0.00
2023	0.00	0.00	0.00	0.00

Perpendicular distance calculations

2021

15.82	6.52	-1	15.82	6.52	-1
21.32	7.42	0	21.32	7.42	0
7.42	-21.32	-21.622			
31.2587537					
22.5742951					
1.38470564					

2022

0	0	0	0	0	0
0	0	0	0	0	0
0	0	0			
0					
#DIV/0!					

2023

0	0	0	0	0	0
0	0	0	0	0	0
0	0	0			
0					
#DIV/0!					

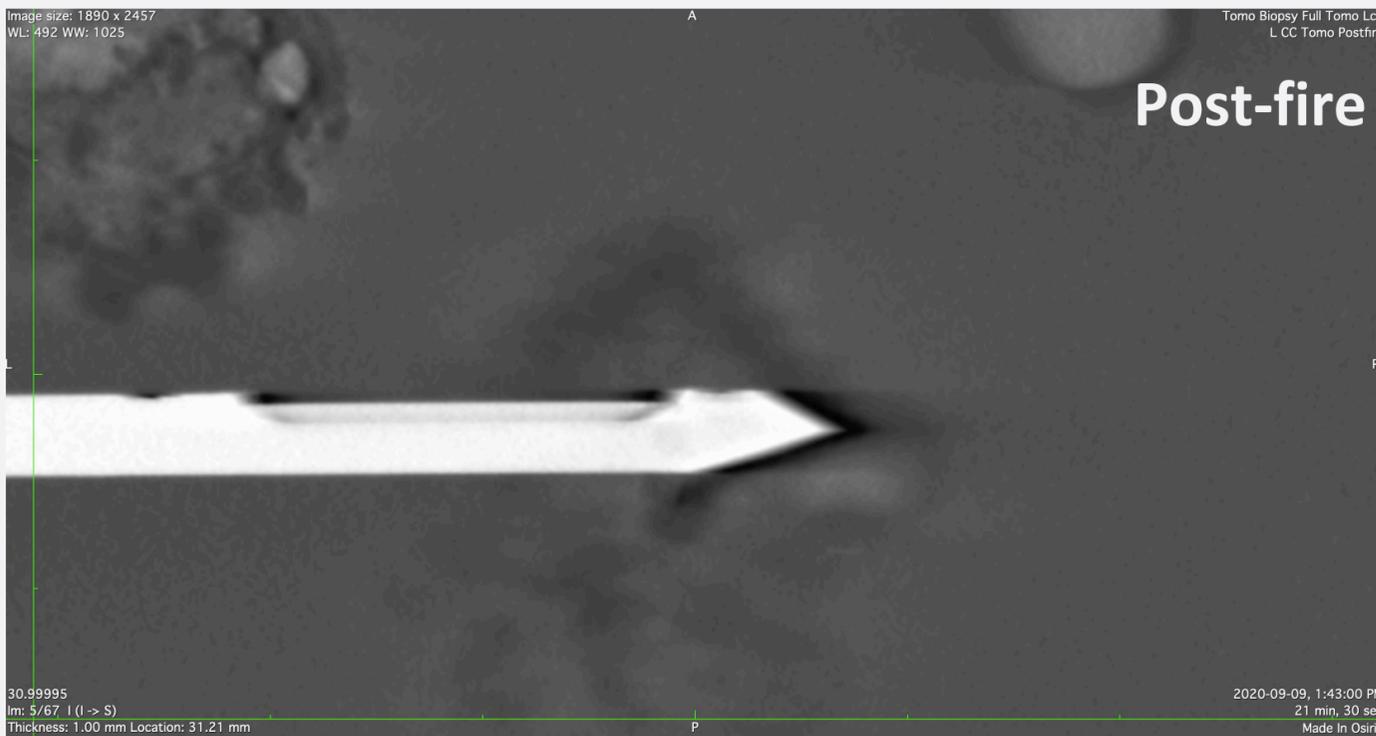
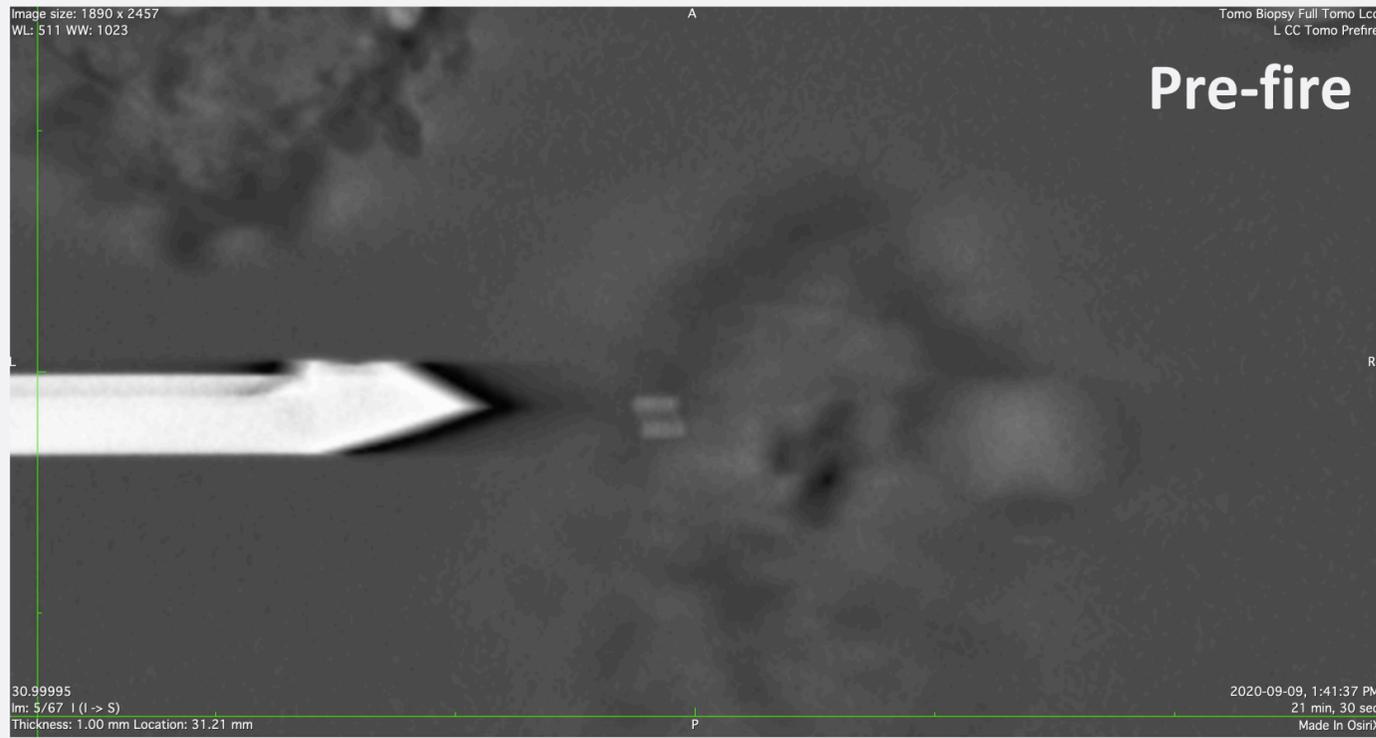
(A) Pre fire needle position
 (B) Post fire needle position
 (T) Target
 (C) Center of the aperture

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

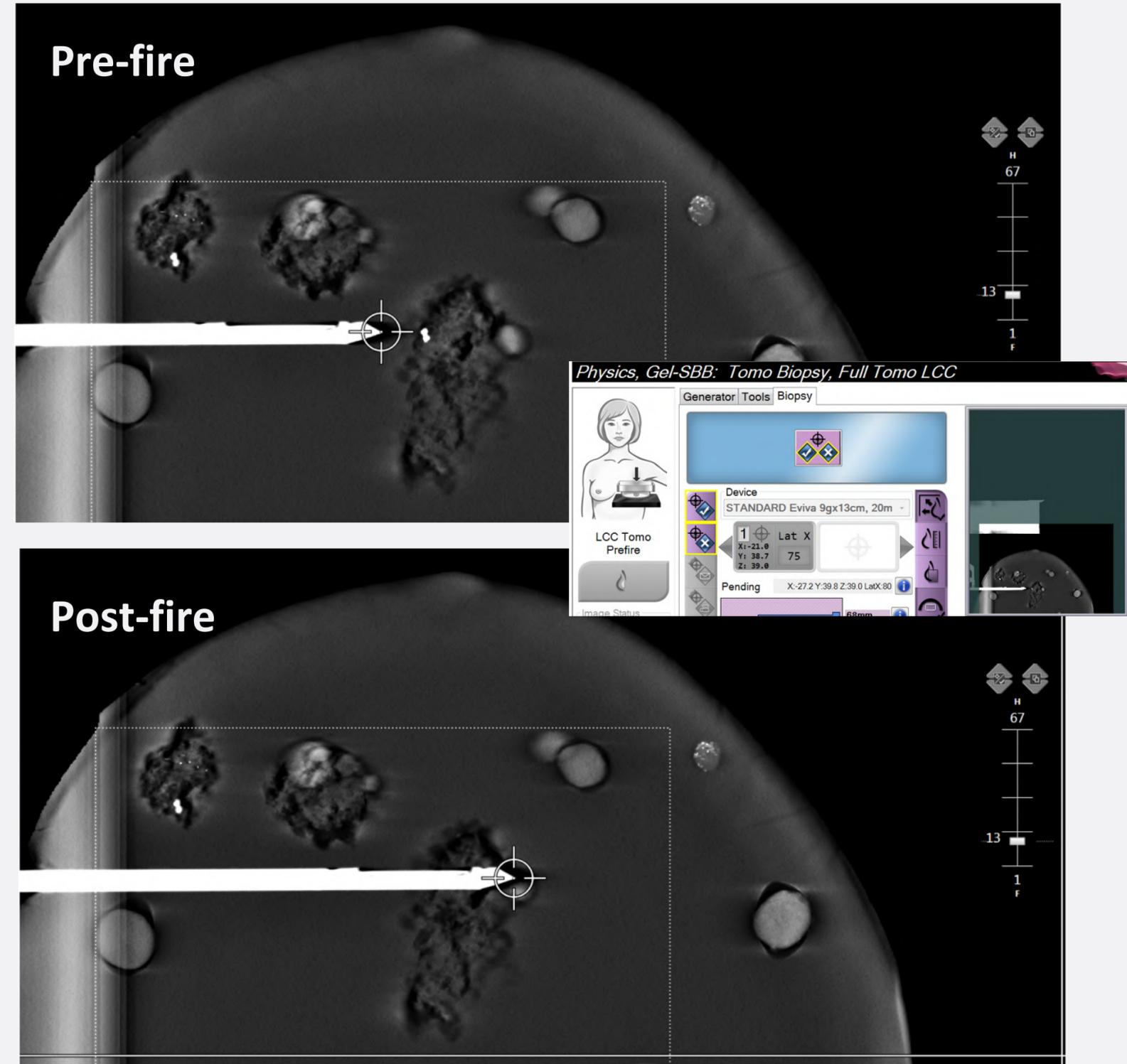
Tomosynthesis-guided biopsy

identification of key points on tomosynthesis images

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



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

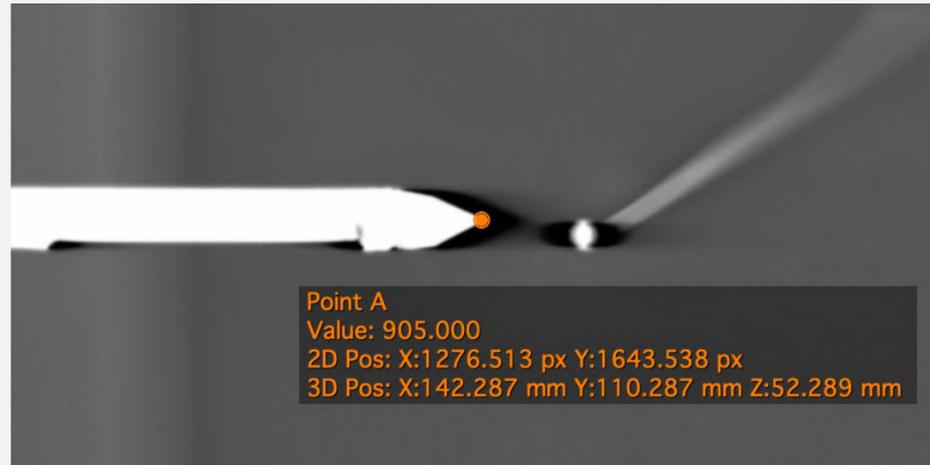


Tomosynthesis-guided biopsy

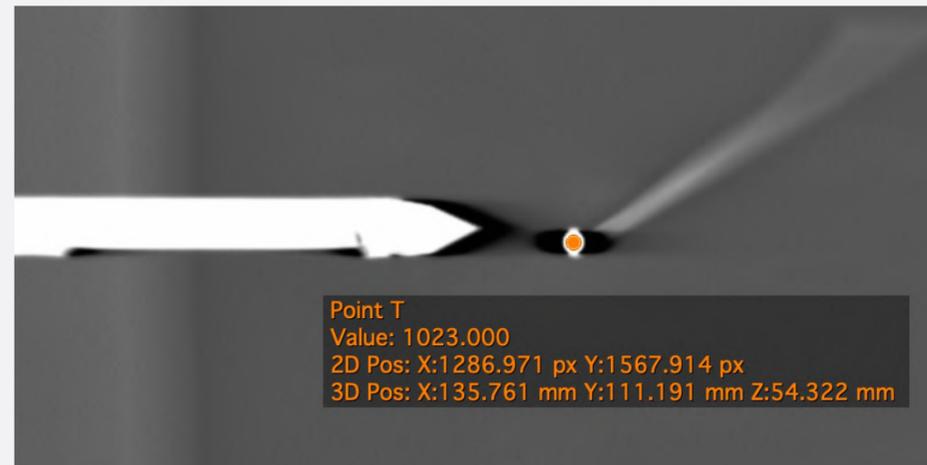
identification of key points on tomosynthesis images (lateral vs. CC)

Lateral arm

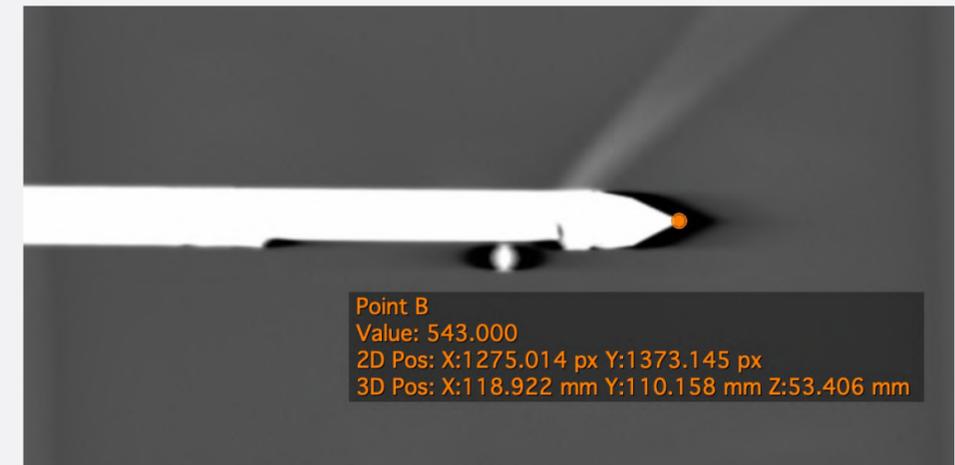
Point A



Point T

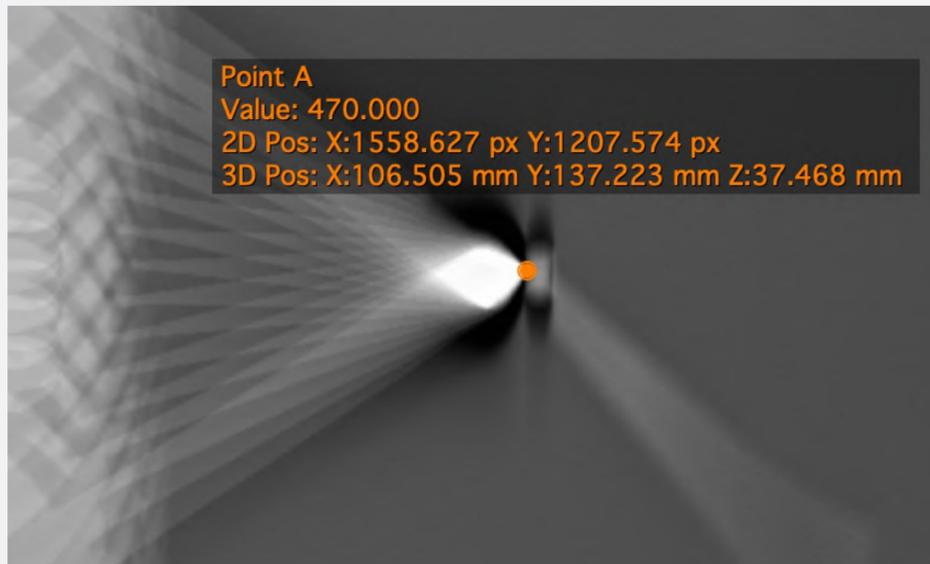


Point B

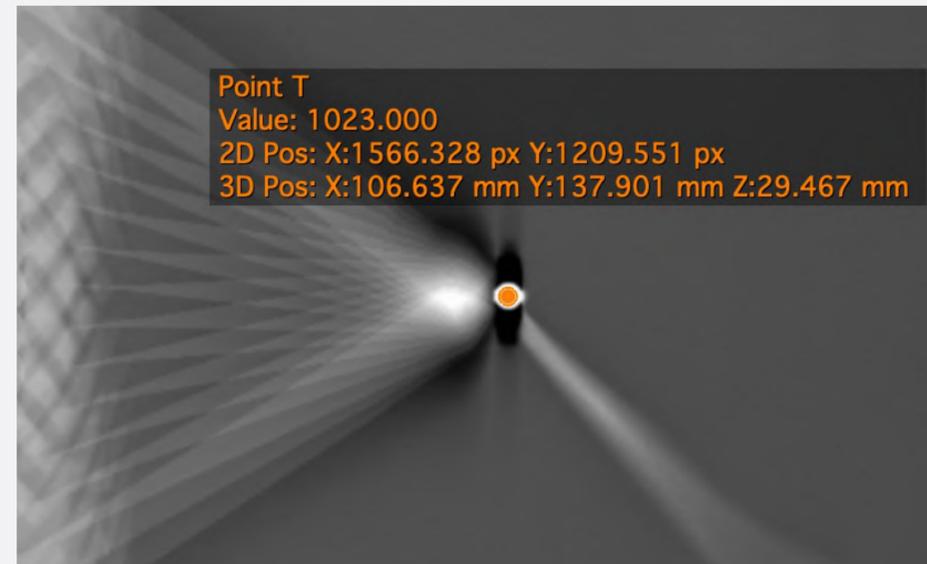


Cranio-Caudal

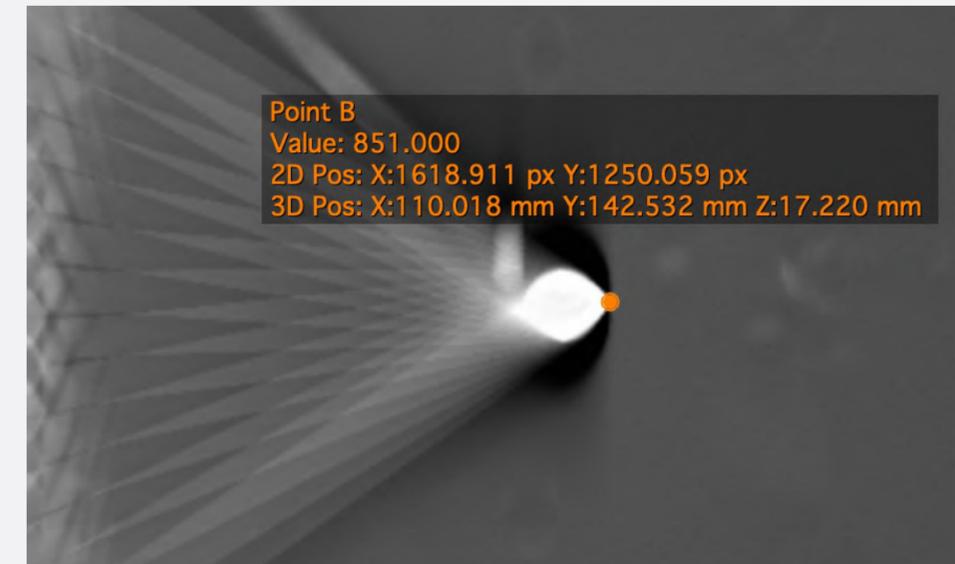
Point A
Value: 470.000
2D Pos: X:1558.627 px Y:1207.574 px
3D Pos: X:106.505 mm Y:137.223 mm Z:37.468 mm



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.

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