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Robot-assisted MRI-guided prostate biopsy using 3D Slicer

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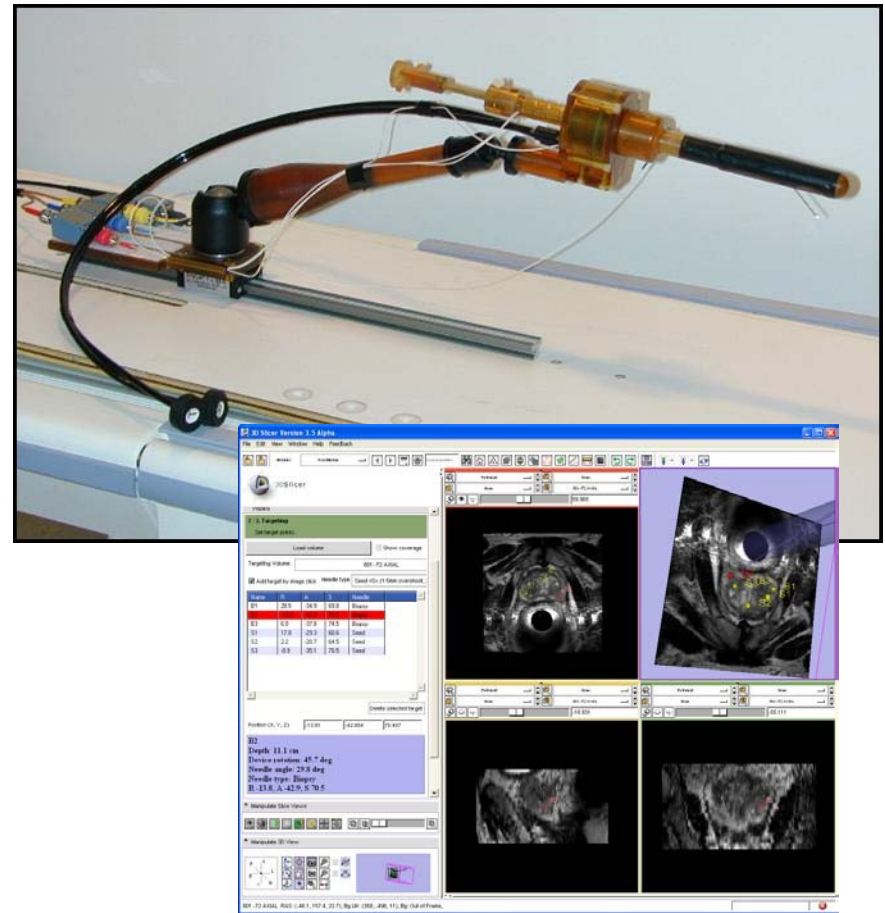
NA-MIC Tutorial Contest: Summer 2010



Learning Objective

This tutorial demonstrates how to perform a MRI-guided robot-assisted prostate biopsy and seed placement using 3D Slicer.

It is not necessary to have access to a robotic device or an MRI scanner to complete the tutorial.





Pre-requisite

This tutorial assumes that you have already completed the **Slicer3 Visualization Tutorial** (by Sonia Pujol)

The tutorial is available at:

<http://www.slicer.org/slicerWiki/index.php/Slicer3.6:Training>



Material

- This tutorial requires the installation of the **Slicer3.6 release** and the tutorial dataset.

They are available at the following locations:

- **Slicer3.6** download page
<http://www.slicer.org/pages/Downloads/>
- **Tutorial dataset:**
ProstateNavData_TutorialContestSummer2010
http://wiki.na-mic.org/Wiki/index.php/File:ProstateNav_TutorialContestSummer2010.pdf

Disclaimer: *It is the responsibility of the user of Slicer to comply with both the terms of the license and with the applicable laws, regulations, and rules.*



Platform

- The tutorial has been developed and tested on Windows XP and Windows 7 platforms.



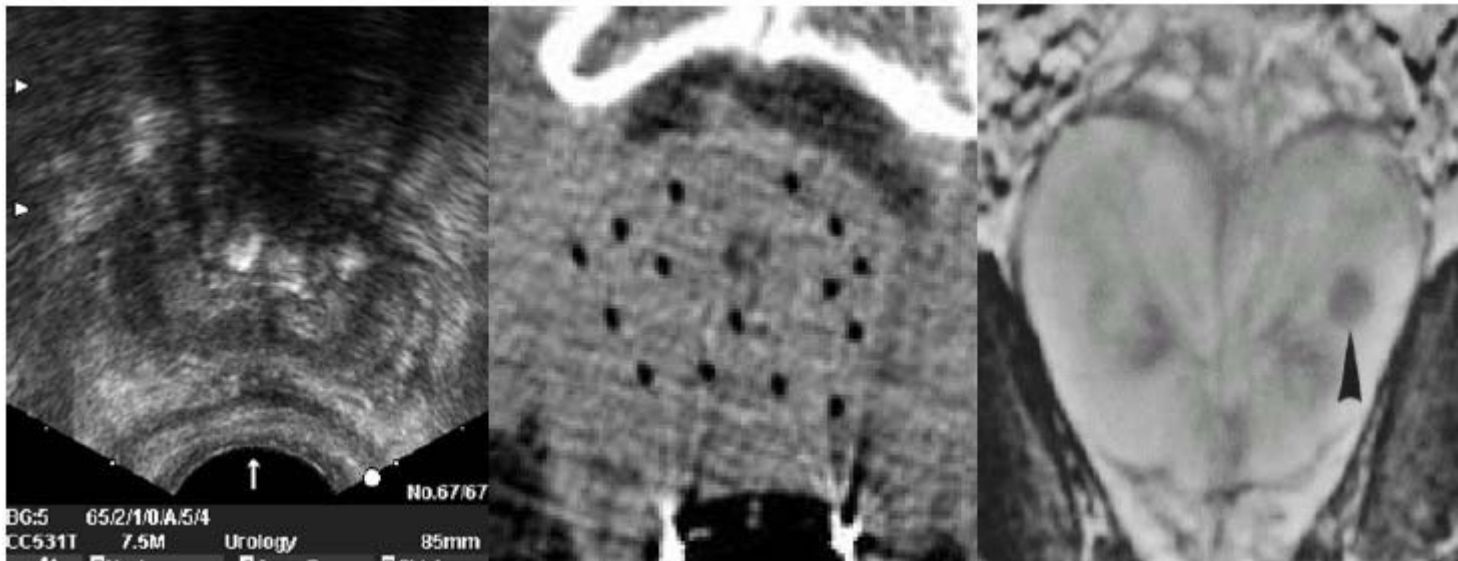
Overview

- MRI-guided prostate biopsy: clinical background
- Systems overview
- Clinical workflow
 - Set up and calibration
 - Target planning and needle insertion
 - Verification
- Conclusion



MRI-guided prostate biopsy: clinical background

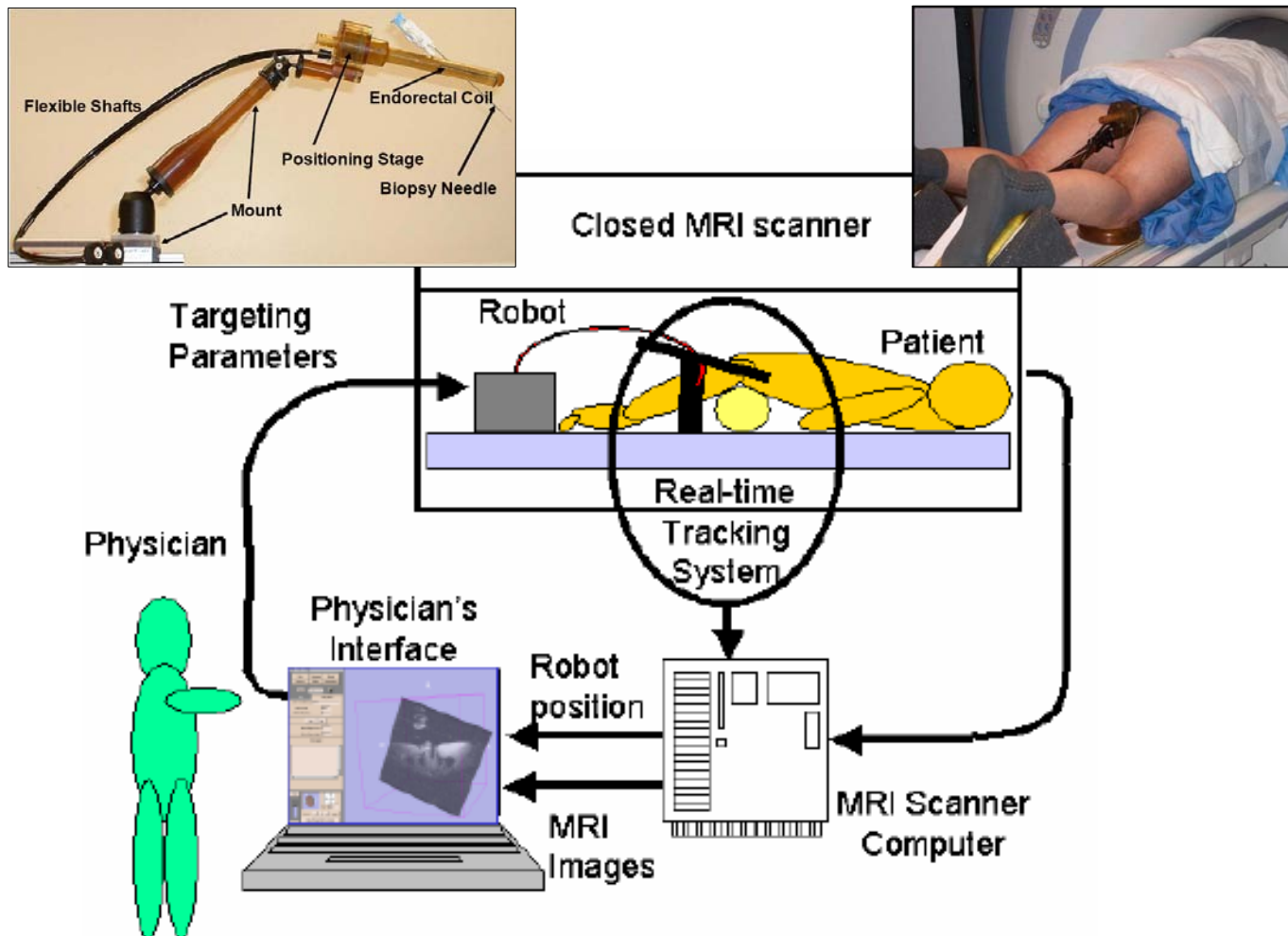
- Prostate cancer, most common cancer in men
- Core needle biopsy definitive diagnostic for prostate cancer
- TRUS has been “Gold standard” for guiding biopsy
- MRI/MRS offers high sensitivity for localizing tumor
- Robotic access required inside scanner^{1,2}



Prostate images from ultrasound, CT, and MRI



Systems overview





More information

Detailed information about the transrectal procedure:

- [1] Krieger A, Susil RC, Ménard C, Coleman JA, Fichtinger G, Atalar E, Whitcomb LL, Design of A Novel MRI Compatible Manipulator for Image Guided Prostate Intervention, IEEE Trans. Biomed. Eng. 2005; 52(2):306-313
- [2] Susil RC, Ménard C, Krieger A, Coleman JA, Camphausen K, Choyke P, Ullman K, Smith S, Fichtinger G, Whitcomb LL, Coleman NC, Atalar E, Transrectal Prostate Biopsy and Fiducial Marker Placement in a Standard 1.5T MRI Scanner, J Urol. 2006 Jan;175(1):113-20



Clinical workflow

- Acquire a calibration volume (high resolution image of the calibration object)
- Calibrate/register robot to MR coordinate system
- Acquire targeting volume (high-resolution image of the patient anatomy)
- Pick/mark biopsy or seed targets
- Perform needle insertion
- Acquire verification volume (quick, low-resolution image with needle still in place)
- Verify the needle position



Set up and calibration

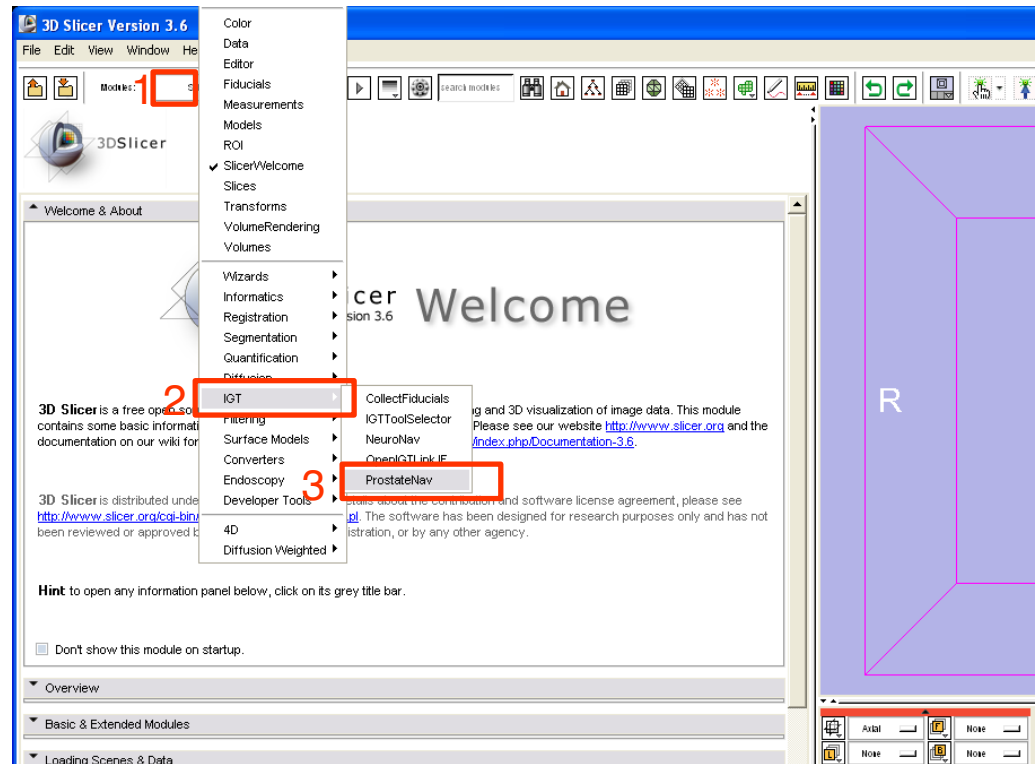


Start the ProstateNav module

When 3D Slicer is started it shows the Welcome window on the left.

To see the user interface of the prostate biopsy navigation module:

- 1 –Click on the “Modules” list
- 2 –Click on the “IGT”
- 3–Click on the “ProstateNav”



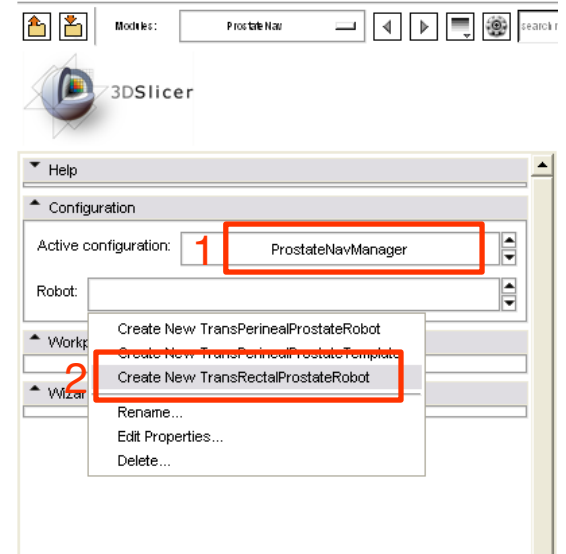


Select a robot device

Before starting the procedure the needle guidance device has to be set up.

- 1 – Click on the “Active configuration” list and select “Create New ProstateNavManager” to create a new ProstateNavManager node. All the calibration, planning, targeting, and verification information will be saved into this node.
- 2 – Click on the “Robot” list and select the device that will be used for the needle insertion. This tutorial presents the workflow for the transrectal robotic device, so choose the “Create New TransRectalProstateRobot” item

When the robotic device is selected then the Workphase and Wizard windows are updated to show the transrectal procedure workflow steps.





Load calibration image

- 1 – Click on the “Load volume” button
- 2 – Select the image folder in the folder tree
- 3 – Click on “Parse directory”
- 4 – Select the calibration image: “701 Sag 3Pt Plan”
- 5 – Click “Apply”

The screenshot shows the 3DSlicer software interface. The 'Add Volume' dialog box is open, displaying a file tree with a folder named '0701_SAG_3POINT_PLAN' selected. The 'Parse Directory' button is highlighted with a red box. The 'DCOM Information' panel on the right shows the selected folder's details, including '701 -SAG 3POINT PLAN (18 files)'. The 'Apply' button at the bottom right of the dialog is also highlighted with a red box.

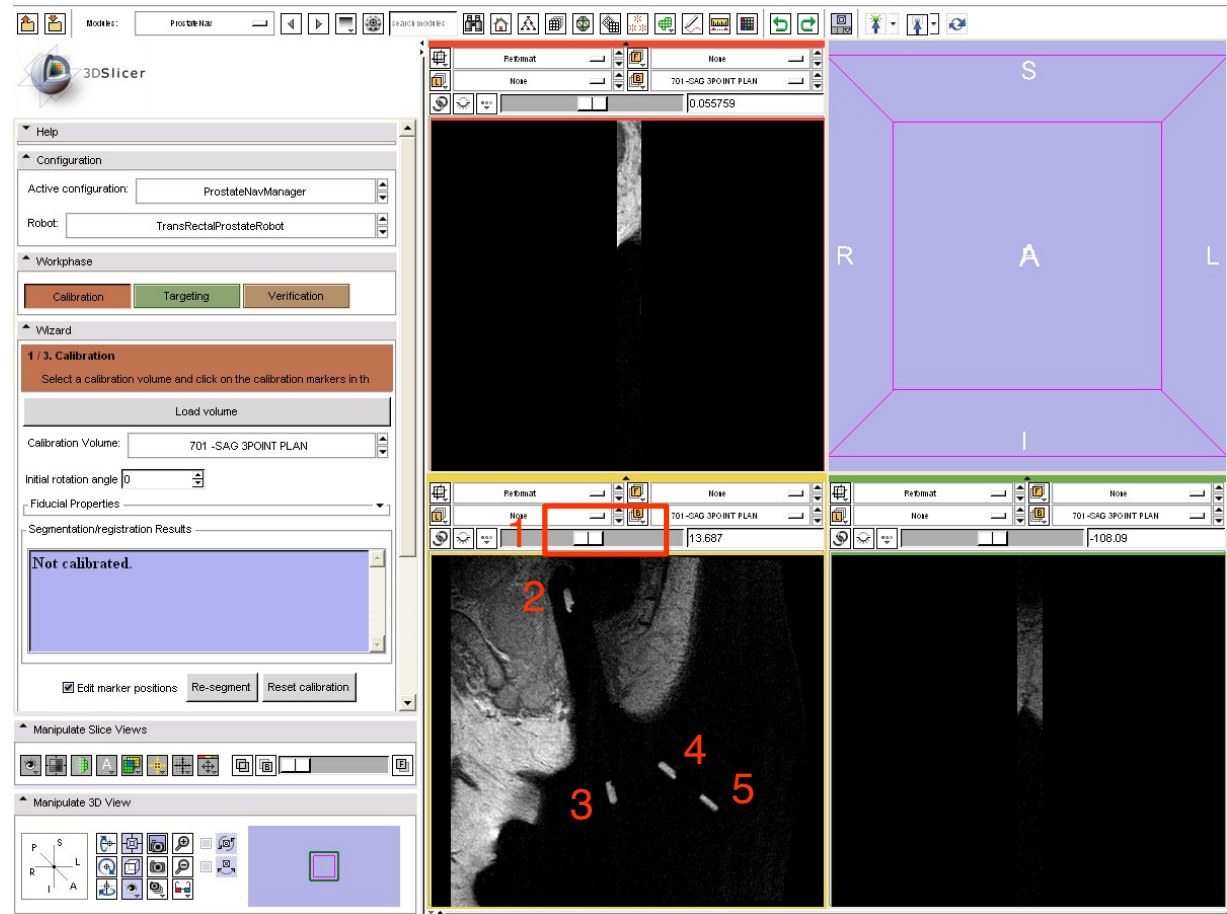
Name	Size	Modified time
f0001.dcm	519 KB	08/07/09 18:00:41
f0002.dcm	519 KB	08/07/09 18:00:41
f0003.dcm	519 KB	08/07/09 18:00:42
f0004.dcm	519 KB	08/07/09 18:00:42
f0005.dcm	519 KB	08/07/09 18:00:42
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f0016.dcm	519 KB	08/07/09 18:00:43
f0017.dcm	519 KB	08/07/09 18:00:43
f0018.dcm	519 KB	08/07/09 18:00:43

Description	Value
Patient's Name	PI39_0
Patient ID	
Modality	MR
Study Date	20090408
Study Description	MR2.ACF
Institution Name	MR2.ACF
Series Number	701
Series Description	SAG 3PD
Specific Character Set	ISO_IR_1
Image Type	ORIGINA
Instance Creation Date	20090408



Mark calibration fiducials

- 1 – Select a slice where the fiducials are visible by using the slider above the image and/or using the mouse wheel
- 2..5 – In any of slice views, click near the center of each marker





Review calibration results

- 1 – Numerical results displayed (axes angle, distance)
- 2 – The segmented fiducials are shown in the 3D viewer window.

The screenshot displays the 3D Slicer Version 3.6 interface. The left sidebar contains the 'Configuration' panel with 'Active configuration: ProstateNavManager' and 'Robot: TransRectalProstateRobot'. Below it is the 'Wizard' section, currently on '1 / 3. Calibration', with instructions to 'Load calibration image and click on the markers'. The 'Segmentation/registration Results' panel is highlighted with a red box and contains the following text:

1
Calibration results:
Axes angle: 38.8 deg
Axes distance: 0.7 mm
Initial rotation angle: 0.0 deg
Segmentation results:

Below the results are buttons for 'Edit marker positions', 'Re-segment', and 'Reset calibration', along with a status message: 'Calibration is successfully completed.' The main 3D viewer window is divided into three views: a top view showing a segmented blue rod with four markers (Marker 1, 2, 3, 4) and axes labeled P, R, L; a bottom-left view showing a grayscale image of the prostate with the four markers; and a bottom-right view showing a grayscale image of the prostate with a red box indicating the calibration volume. A red box highlights the 3D viewer window, and a red box highlights the calibration results panel.



Refine calibration results

If either the numerical results or the displayed marker segmentation indicates that the calibration might be inaccurate (large axes distance, axes angle different from 37 deg, marker contours are uneven or incomplete), then calibration can be refined:

A – Click on the small arrow next to “Fiducial Properties” to show the segmentation parameters

B – Segmentation parameters

Fiducial size: W/H/D = width/height/depth of the region around the clicked point where automatic marker detection is performed.

Fiducial radius: only voxels that are closer to the axis than this radius will be included in the automatic marker detection region.

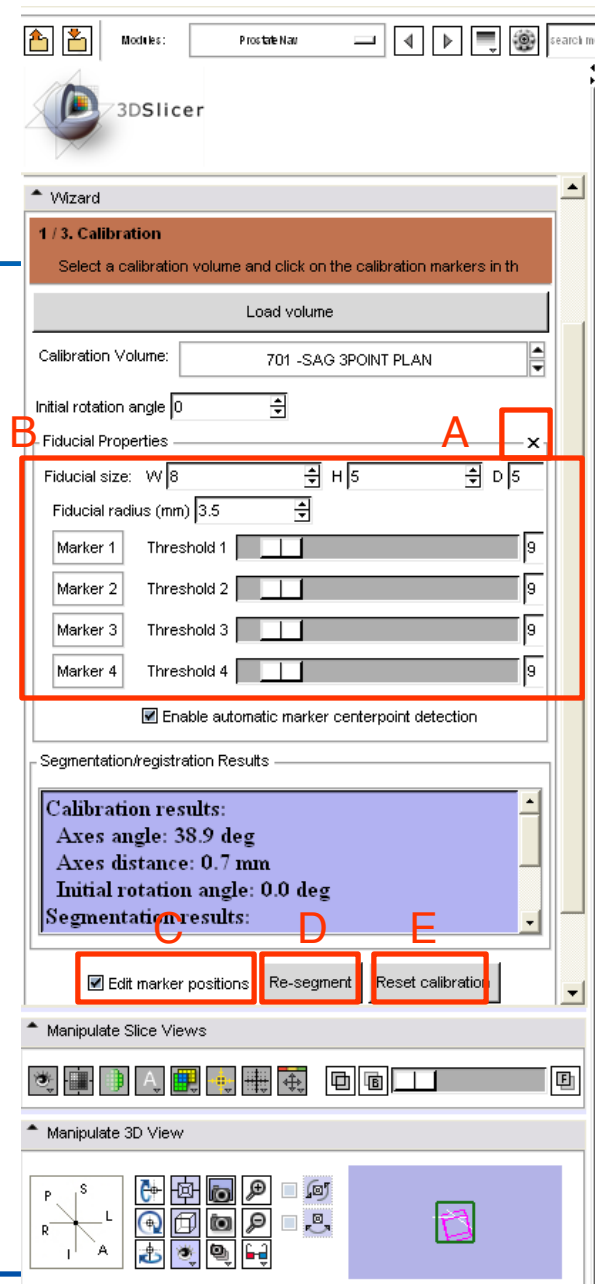
Threshold: marker segmentation threshold

Enable automatic marker centerpoint detection: If enabled, then marker center will be automatically detected, near the clicked position, using the fiducial size, radius, and threshold parameters. If disabled then the clicked positions will be used as marker centerpoint positions.

C – Edit marker positions: enable this checkbox to set the mouse mode so that clicks on the image places fiducial markers

D – Re-segment: click to re-run automatic marker detection algorithm after changing segmentation parameters

E – Reset calibration: removes calibration markers





Target planning and needle insertion



Load targeting image

- 1 – Click on the “Targeting” button to move to the planning and targeting workflow step
- 1 – Click on the “Load volume” button
- 2 – Select the image folder in the folder tree
- 3 – Click on “Parse directory”
- 4 – Select the targeting image:
“801 -T2 AXIAL Plan”
- 5 – Click “Apply”

The screenshot shows the 3DSlicer interface with the 'Add Volume' dialog box open. The 'Targeting' button in the 'Workphase' section is highlighted in red (1). The 'Load volume' button in the 'Add Volume' dialog is highlighted in red (2). The folder tree shows the selected folder '0801_T2_AXIAL' highlighted in red (3). The 'Parse Directory' button in the 'DICOM Information' section is highlighted in red (4). The '801 -T2 AXIAL (26 files)' folder is highlighted in red (5). The 'Apply' button at the bottom right of the dialog is highlighted in red (6).

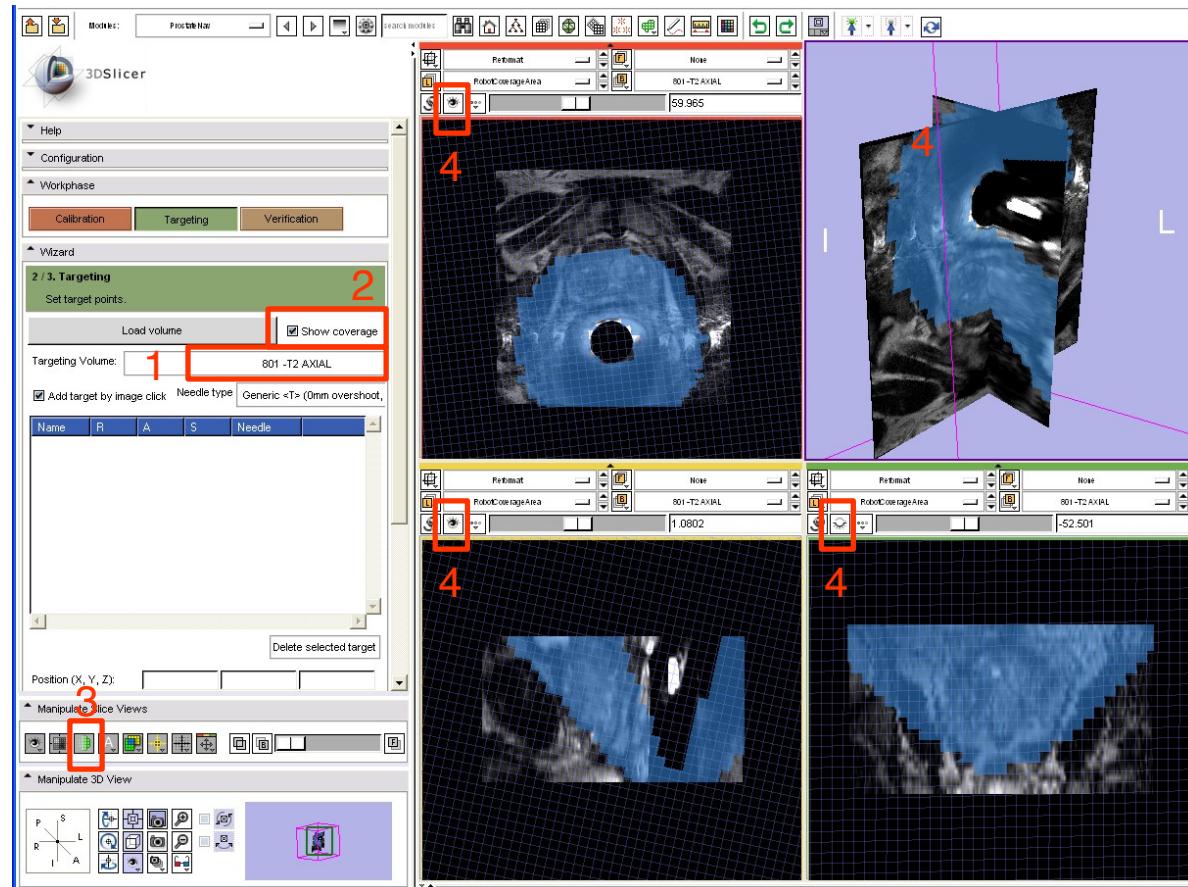
Name	Size	Modified time
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I0024.dcm	519 KB	08/07/09 18:00:47
I0025.dcm	519 KB	08/07/09 18:00:47
I0026.dcm	519 KB	08/07/09 18:00:47

Description	Value
Patient's Name	Pt39_0
Patient ID	
Modality	MR
Study Date	2009
Study Description	MRI
Institution Name	MR2
Series Number	801
Series Description	T2A
Specific Character Set	ISO_
Image Type	ORIG
Instance Creation Date	2009



Prepare target planning

- 1 – Select the targeting volume: “801 –T2 AXIAL”
- 2 – Click “Show coverage” and browse through the slices to verify that the device can reach all the desired target areas (displayed as a blue overlay)
- 3 – Click on the label layer opacity icon and move the slider to adjust coverage area display opacity
- 4 – Click the “eye” icons to show/hide a slice in the 3D viewer

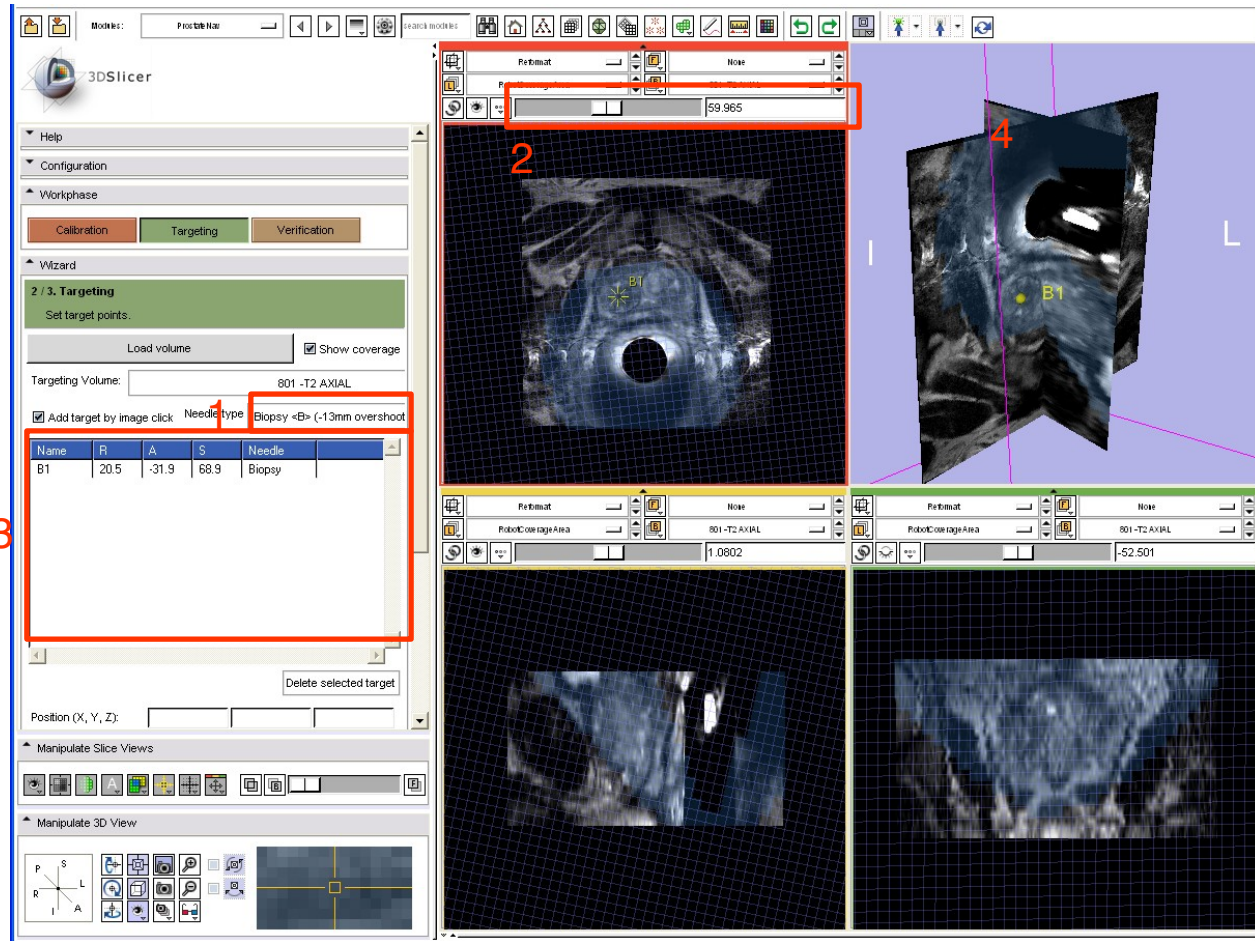




Define targets

Perform the following steps for each target:

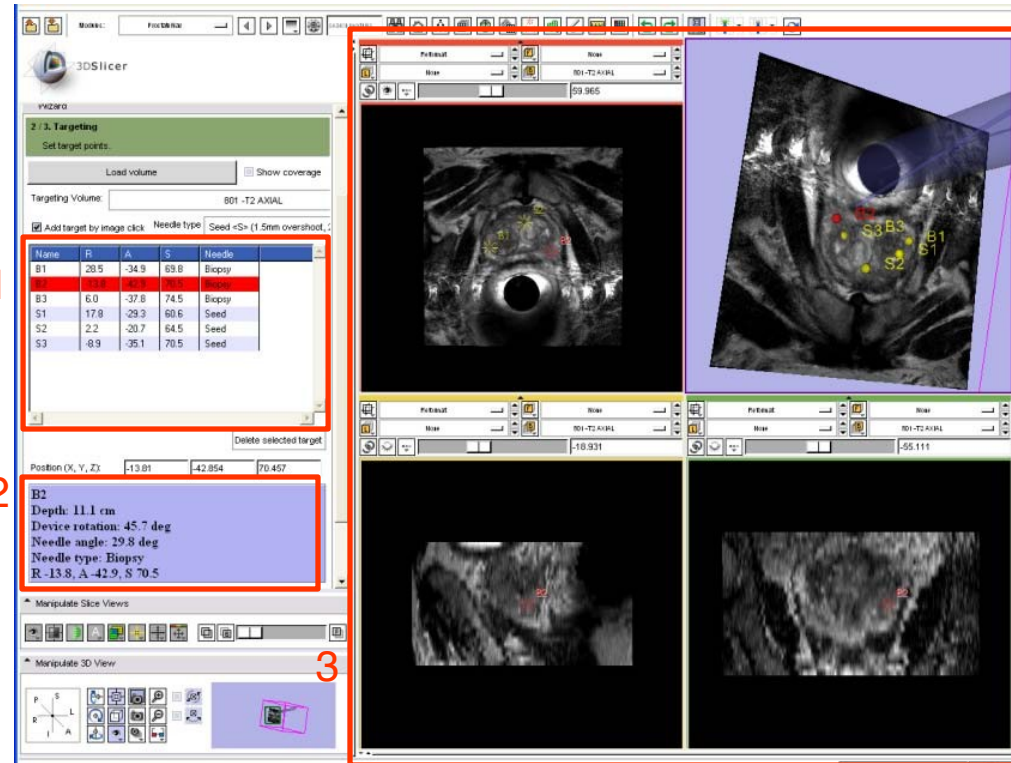
- 1 - Select the needle type
- 2 - Navigate to desired slice in any of three views, and pick a target by clicking
- 3 - Target and its targeting parameters populated in the list (double-click on any of the position value to enter a specific R/A/S coordinate value)
- 4 - Target point is displayed in the 3D view





Needle insertion

- 1 – Click on a target in the target list
- 2 – Targeting parameters are shown below the target list
- 3 – The target and needle trajectory is displayed in all the slice views and in the 3D view
- 4 – 3D view and targeting parameters are displayed in the secondary (procedure room) monitor



The robot is motorized, one has to manually set the displayed targeting parameters on the robot manipulator and insert the needle.

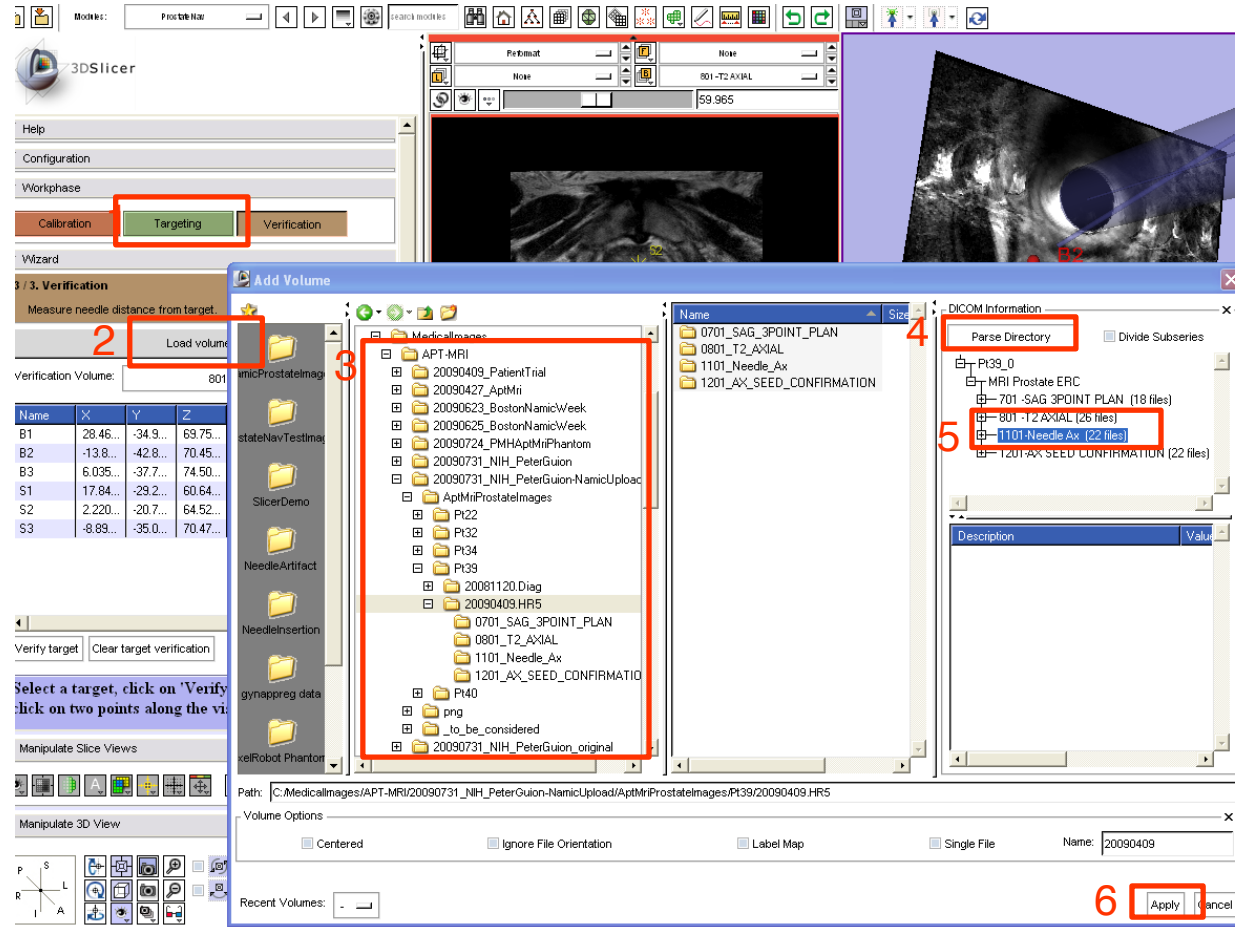


Verification



Load verification image

- 1 – Click on the “Verification” button to move to the verification workflow step
- 1 – Click on the “Load volume” button
- 2 – Select the image folder in the folder tree
- 3 – Click on “Parse directory”
- 4 – Select the verification image: **“1101-Needle Ax”**
- 5 – Click “Apply”





Verify target visually

- 1 – Select the verification image (where the needle is visible)
- 2 – Click on the target in the target list that corresponds to the needle in the image
- 3 – Three orthogonal slices are shown in the slice viewers, reformatted to be aligned with the planned needle trajectory

3DSlicer

3 / 3. Verification

Measure needle distance from target.

Load volume

Verification Volume: 1101-Needle Ax

Name	X	Y	Z	Needle	Over.	LR	Er.
B1	28.46...	-34.9...	63.75...	Biopsy			
B2	43.6...	42.0...	70.45...	Biopsy			
B3	-2.17...	36.2...	81.35...	Biopsy			
S1	17.04...	43.2...	100.04...	Seed			
S2	2.220...	-20.7...	64.52...	Seed			
S3	-8.89...	-35.0...	70.47...	Seed			

Verify target Clear target verification

Select a target, click on 'Verify target' button, then click on two points along the visible needle line.

Manipulate Slice Views

Manipulate 3D View



Verify a target quantitatively

To quantitatively evaluate the targeting error:

- 1 – Click on “Verify target”
- 2, 3 – Click on the centerline of the needle at two different positions (anywhere along the needle, as far as possible from each other)
- 4 – The distance of the needle centerline from the target point is displayed in the target list

3DSlicer

3 / 3. Verification

Measure needle distance from target.

Load volume

Verification Volume: 1101-Needle Ax

Name	X	Y	Z	Needle	Overall Error
B1	28.46...	-34.9...	69.75...	Biopsy	
B2	-13.8...	-42.8...	70.45...	Biopsy	
B3	6.80	-38.6	80.95	Biopsy	4.608932
S1	17.84...	-29.2...	60.64...	Seed	
S2	2.220...	-20.7...	64.52...	Seed	
S3	-8.89...	-35.0...	70.47...	Seed	

Verify target Clear target verification

Select a target, click on 'Verify target' button, then click on two points along the visible needle line.

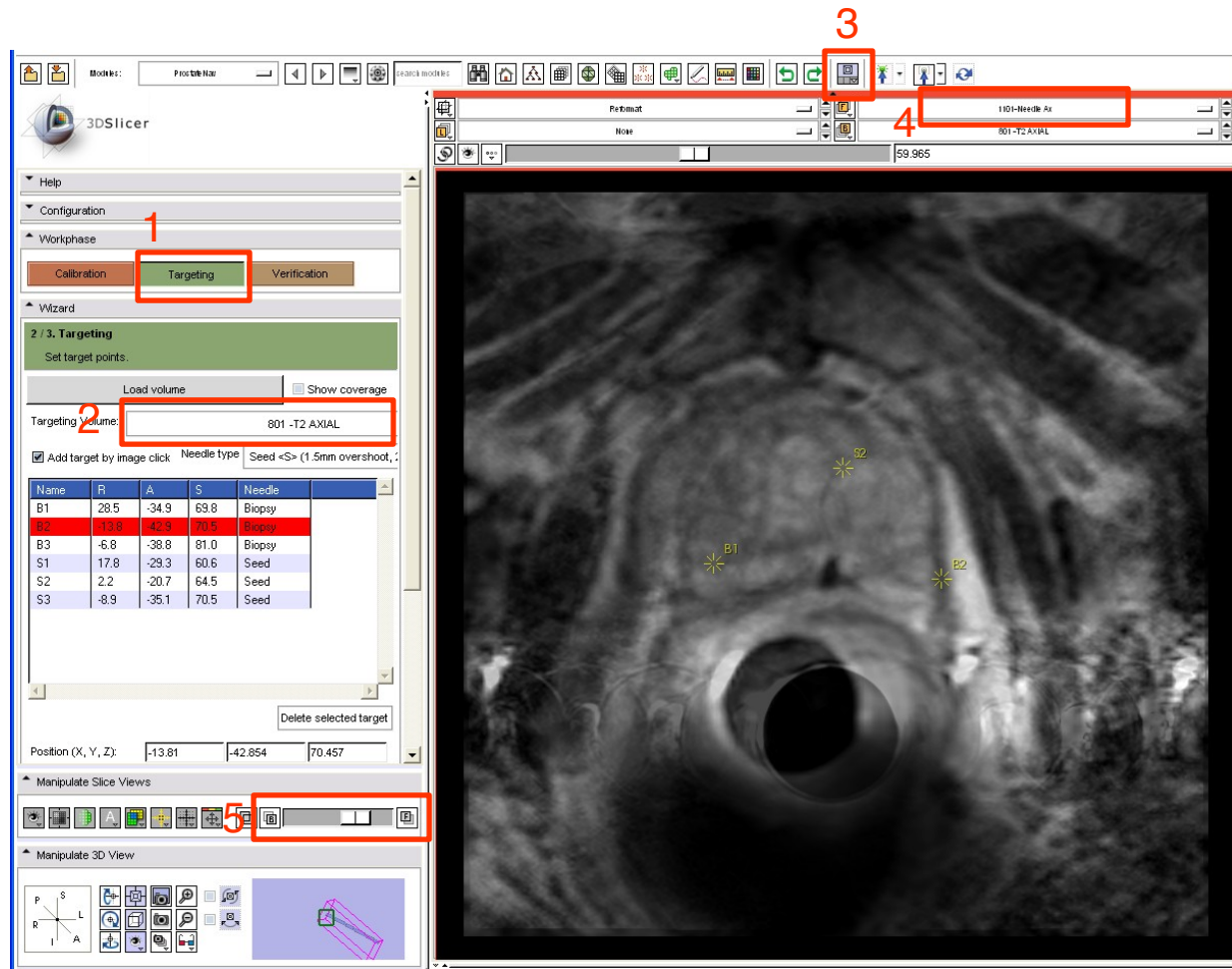
Manipulate Slice Views

Manipulate 3D View



Evaluate patient motion

- 1 – Click on “Targeting”
- 2 – Re-select the targeting image to show it in the slice viewers
- 3 – Select the “Red slice only layout” to see a maximized view of the axial slice
- 4 – Select the latest acquired image to be in the foreground
- 5 – Use the slider to fade between the targeting and the latest image to see if there was any significant patient motion





Conclusion

- 3D Slicer with ProstateNav allows planning, performing, and evaluating MRI-guided prostate intervention.
- ProstateNav relies on Slicer core features for volume, model, and fiducial visualization and applies them to fulfill application-specific needs.
- Slicer core features and extensions can be used to interactively explore, understand the data, and troubleshoot the image-guided intervention system (proved to work very well in preliminary clinical testing).



Acknowledgements



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5U54EB005149, 5R01CA109246