Non-rigid MR-CT Image Registration

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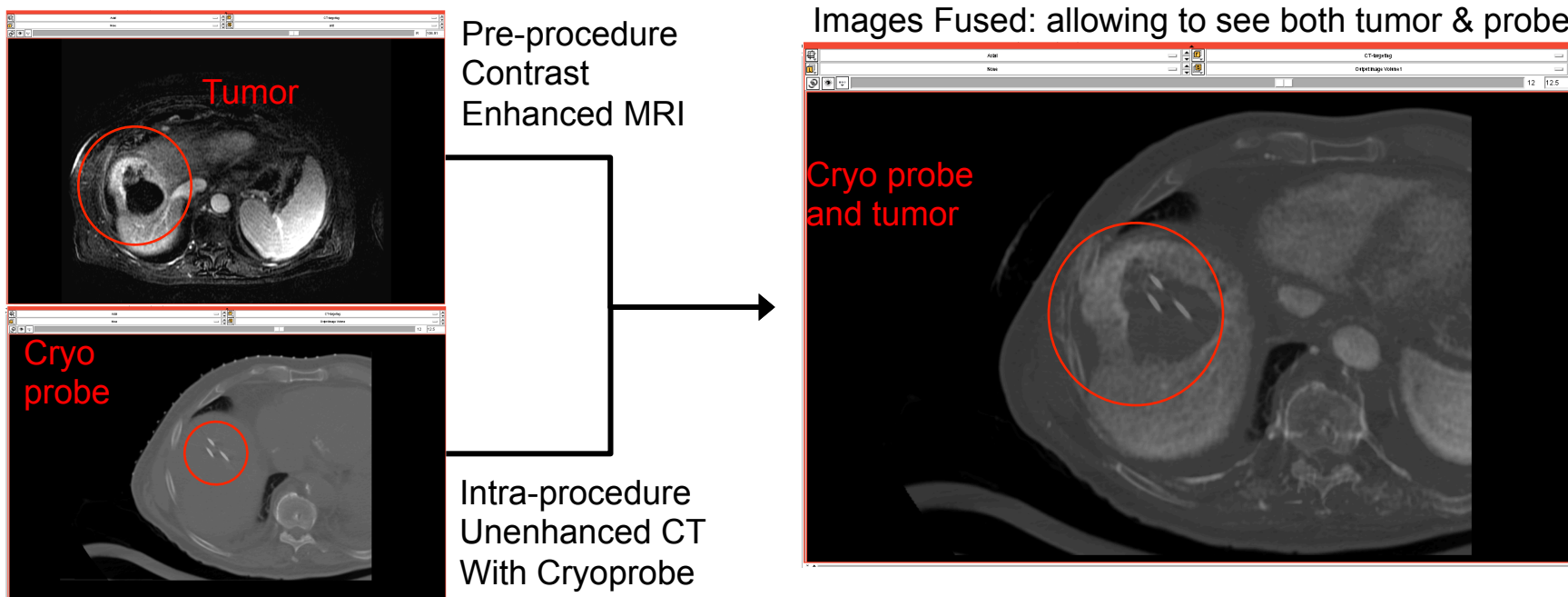Brigham and Women's Hospital

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NA-MIC Tutorial Contest: Summer 2011

Learning Objective

- This tutorial demonstrates how to co-register a pre-operative contrast enhanced MR image to an intra-procedure CT image via automated non-rigid registration.

- The case study is a CT-guided liver tumor cryoablation

Pre-procedure Contrast Enhanced MRI

Intra-procedure Unenhanced CT With Cryoprobe

Images Fused: allowing to see both tumor & probe

Tutorial Topics / Targets

Slicer Modules Used:

- N4ITKBiasField Correction

- Editor

- BRAINSFitIGT Registration

Image Processing Tasks Performed:

- Intensity non-uniformity correction

- Mask generation / segmentation

- Inter-modality non-rigid image registration

Image Data Used:

- Pre-operative abdominal MR with surface coil, showing liver

- Planning and Intra-operative CT with cryo-probe

Material

This tutorial website is at:

http://wiki.na-mic.org/Wiki/index.php/Non-rigid_MR-CT_Image_Registration

This tutorial dataset is available at:

http://www.na-mic.org/Wiki/images/4/47/Non-rigid_MR_CT_Image_RegistrationTutorialData_TutorialContestSummer2011.tar.gz

Platform

- This tutorial was developed and tested on an Intel MacBook Pro (2.3 GHz Core i7, 4GB).

- This tutorial also uses a custom-designed BRAINSfitIGT module, which requires the **compilation** of Slicer3.6 from **source f**iles.

- For the purpose of learning the steps & basic usage, you can use the regular BRAINSfit, but registration results will differ.
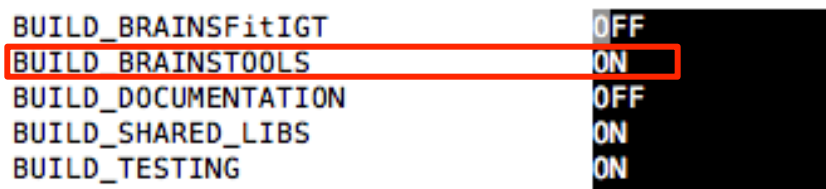
Compilation Instructions

If you choose to use the BRAINSfitIGT version:
go to the Slicer3.6 Build Instruction page

http://www.slicer.org/slicerWiki/index.php/Slicer3:Build_Instructions

1. After building Slicer3.6, command "make edit_cache" at "[install folder]/Slicer3.6-build/Modules".
2. Select "ON" of "BUILD BrainsFitIGT" on ccmake screen editor.

```
BUILD_BRAINSFitIGT        OFF
BUILD_BRAINSTOOLS         ON
BUILD_DOCUMENTATION       OFF
BUILD_SHARED_LIBS         ON
BUILD_TESTING             ON
```

3. Press "c" then press "g" to generate new CMakeLists.txt.
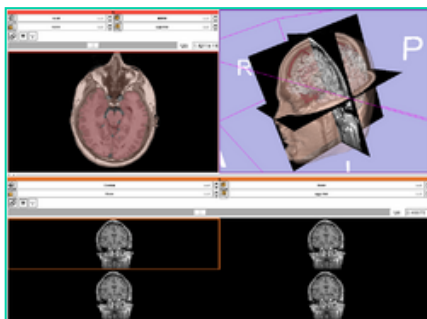4. After executing "make", you can use BrainsFitIGT module.
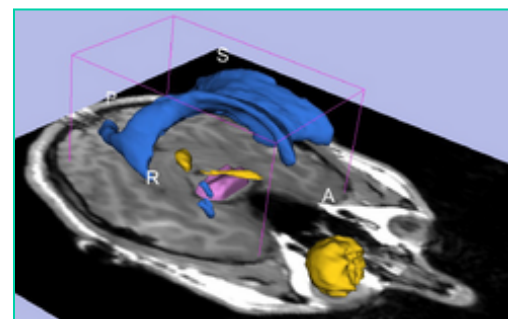
User Skill Pre-requisites

- Before running this tutorial, if new and unfamiliar with the Slicer user interface, we recommend to first complete the following tutorials, available here:

- http://www.slicer.org/slicerWiki/index.php/Slicer_3.6:Training
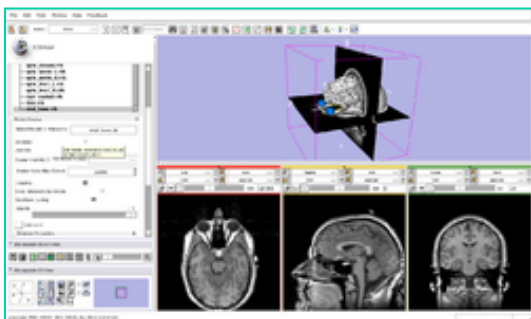
Slicer3Minute Tutorial

**Slicer3Visualization Tutorial**

Interactive Editor

Clinical Significance

CT imaging can be used to plan an interventional approach to facilitate the safe placement of **the ablation applicators** in the tumor. **However, the tumor is invisible or poorly visible on the intra-operative CT**

Pre-operative MRI

Tumor margins and surrounding structure are visible

Intra-operative CT
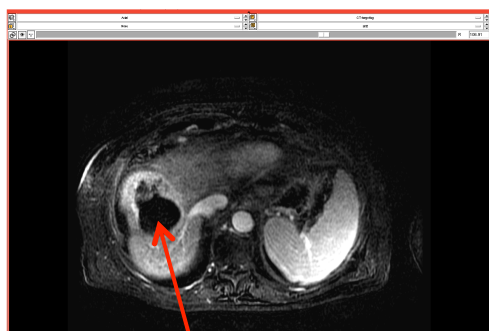
Only interventional probes are visible, not the tumor

Liver position, shape and structures may differ significantly between the two exams.

A non-rigid registration is desirable to compensate for liver deformation caused by patient positioning, respiratory motion and interventional manipulation.

CT

MRI

tumor
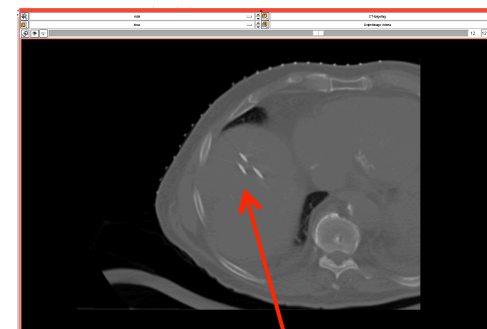
Cryoprobe

Overview

- This tutorial will go through the following steps (in order):

- Preprocessing

    1. MRI mask generation

    2. CT mask generation

    3. MRI Bias Field Intensity Correction

- Registration

    4. MRI-CT(#1) non-rigid registration

   5. CT(#1)-CT(#2) affine registration

    6. Resampling & Fusion

Image Processing Workflow Overview

In this particular CT-guided cryoablation, there are two registrations necessary: 1) a non-rigid registration between the pre-op MR and another intra-op CT (#1) without the probes, 2) an affine registration between the CT #1 and the intra-op CT with the probes (#2). This minimizes differences between image pairs and increases robustness of the registration.
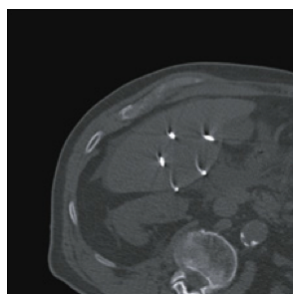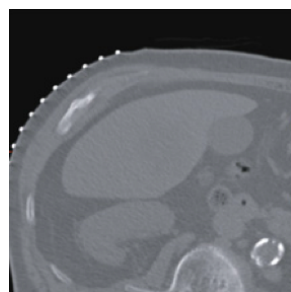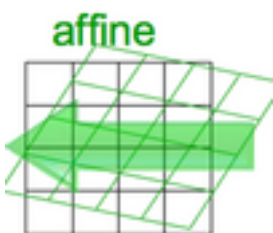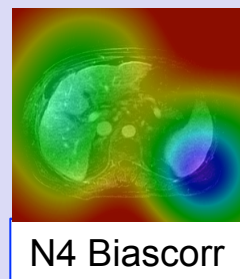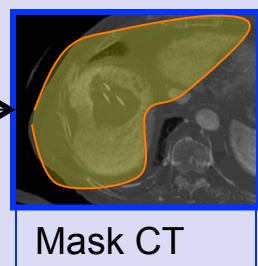

Intra-op CT #2　　　　　　　**Intra-op CT #1**　　　　　　　**Pre-procedure enhanced MRI**
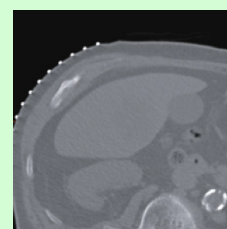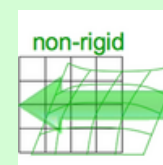
Registration Strategy/Roadmap

National Alliance for Medical Image Computing
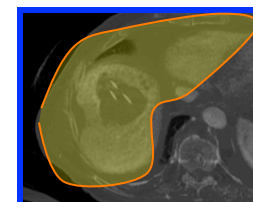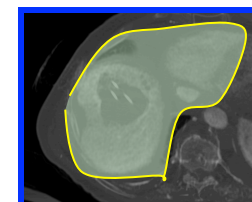http://www.na-mic.org

Preprocessing Step 1+2
Obtain ROI masks
1. for the MR image
2. For the CT image
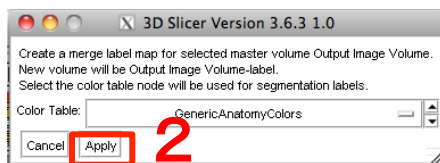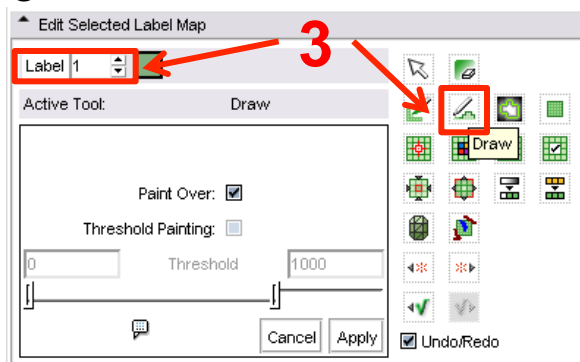# Module used: Editor

Mask CT   Mask MRI

Step 1: MR mask of liver

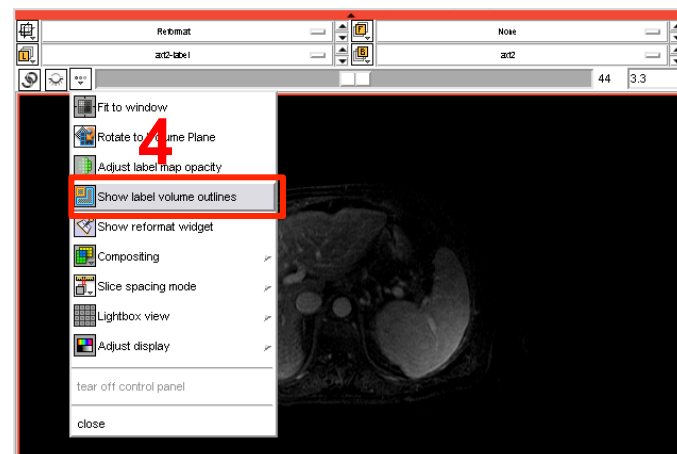**Output: t2ax-label.nrrd (made automatically when Editor works)**

1. Go to the "Editor" module

2. Click "Apply" on the small window about Color table. This will automatically generate a new label volume, called "t2ax-label".

3. Select "Draw" button of the module pane to segment liver with label 1

4. Select "Show label volume outline" to confirm the segmented area easily

Step 1: MR mask of liver

Using the draw, draw an outer border around the liver in the current axial slice. When done hit the "Return" key or double click the left mouse to close the contour. Then use the arrow key to advance to the next slice.

To undo a drawing, click on the left "undo" arrow in the editor palette.
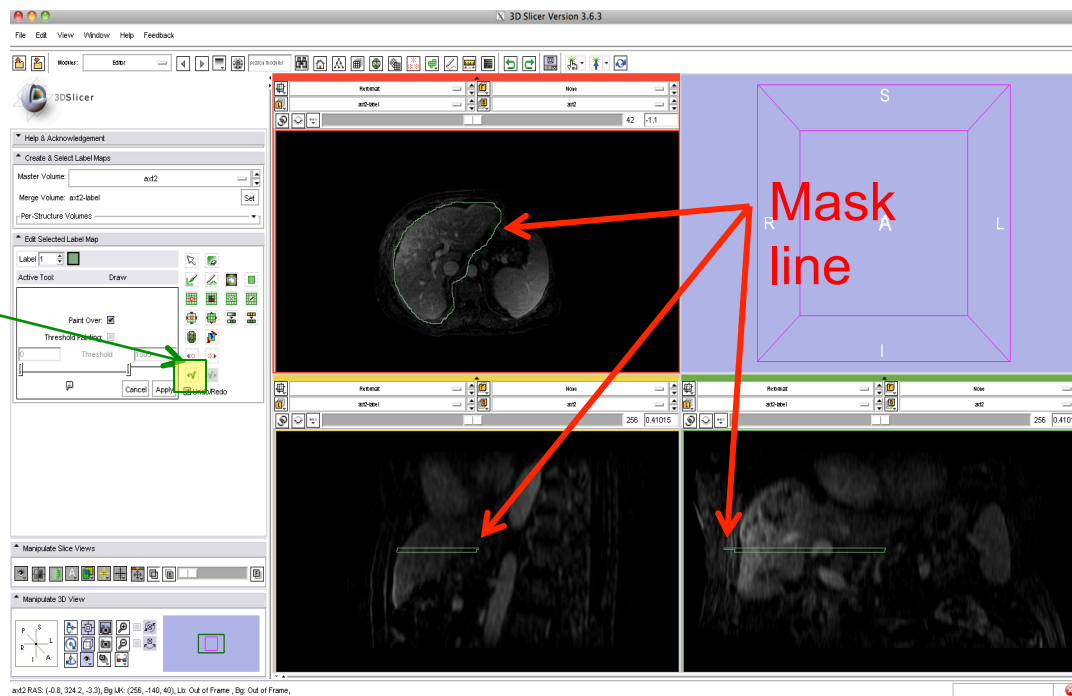
Step 2: CT mask of liver

Input: CT-plan.nrrd, Output: CT-plan-label.nrrd

1. Save your current work (via File / Save …)

2. We now repeat the same outlining process on the CT image.

3. In the Editor, select under Master Volume the "CT-plan" volume

4. As before, the editor will automatically suggest a "**CT-plan-label**" automatically.

5. Proceed as for Step 2 above to generate a CT liver mask

6. Again Save your work.

National Alliance for Medical Image Computing
*http://www.na-mic.org*
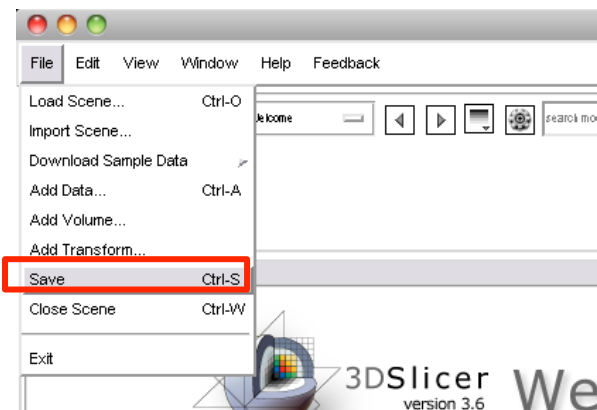
Preprocessing Step 3: MR Bias Correction

The MRI is obtained with surface coils that exhibit a strong intensity falloff, visible in the MR image as areas away from the surface being significantly darker. Because this can negatively affect registration quality, we correct it first. This process of intensity normalization is often called "Bias Correction"

Module Used: "N4ITK MR Bias Correction" (in the module menu under "Filtering")
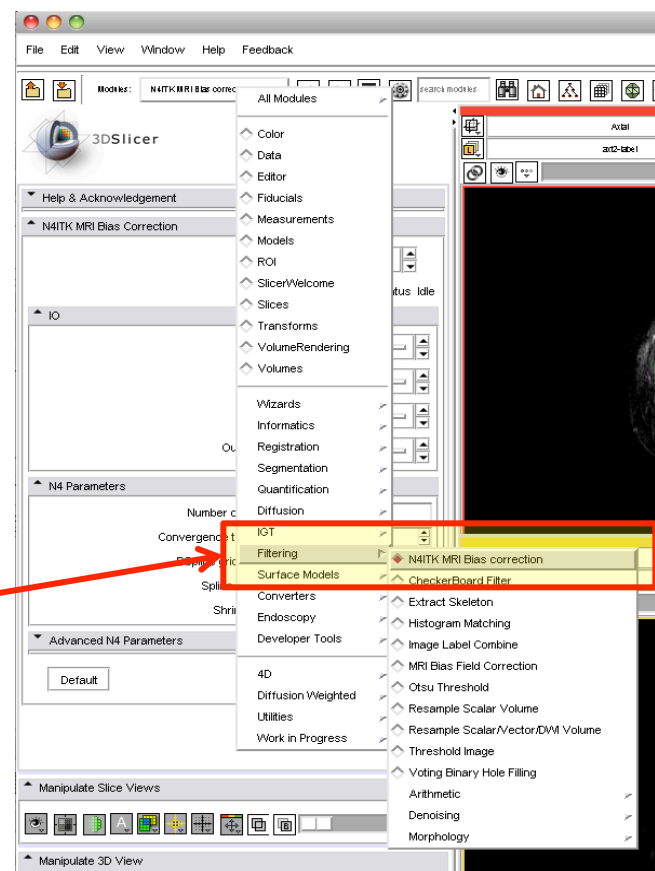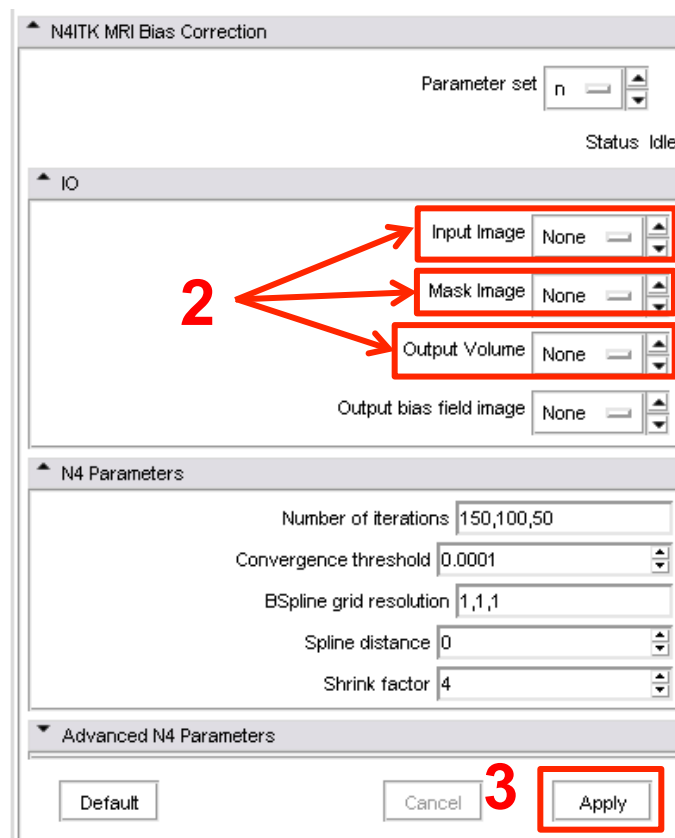
Step 3: MR Bias Correction

Input: t2ax.nrrd and t2ax-label.nrrd, Output: t2ax-N4.nrrd

2. Parameters: Input image = t2ax, Mask image = t2ax-label, Output volume = create new volume and name it "t2ax-N4"

3. Click "Apply"

4. You should see a progress bar in the lower right corner. Depending on your CPU, this process will take ca. 1-3 minutes.

5. Save your current work (via File / Save …)

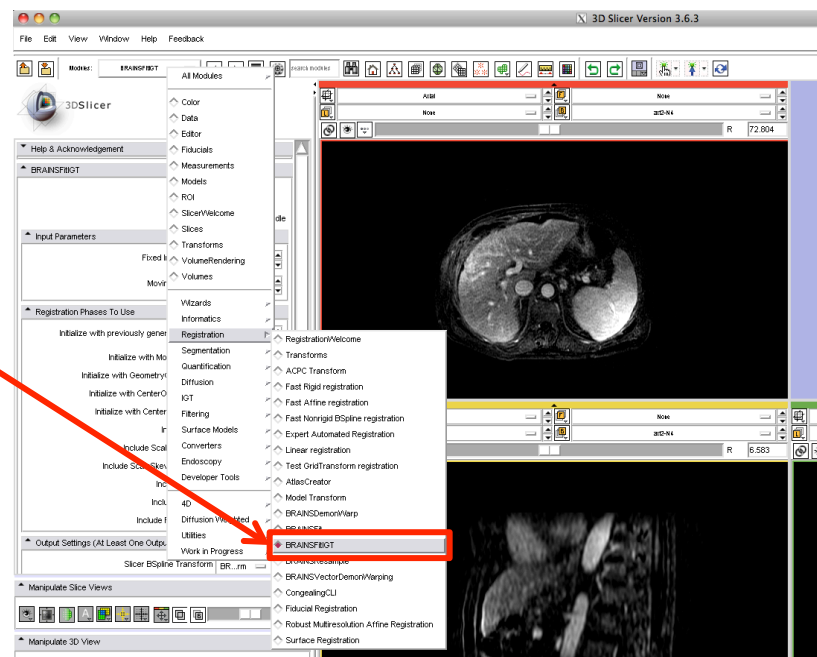# Step 4:
MRI – CT Non-rigid Registration

We've now completed all the preprocessing and are ready for the actual registration.

Step 4: MRI-CT Registration

1. Go to the "BRAINSFitIGT" module in the "Registration" category of the module menu

   (if not using a compiled Slicer version, use the regular BRAINSfit module instead)

Step 4: MRI-CT Registration

Set "BRAINSFitIGT" module parameters as follows

1. Set Fixed image volume = "CT-plan", Moving image volume = "t2ax-N4"

2. Select BSpline transform = "create a new transform" and name it "T1"

3. Select Output image volume = "create a new volume" and name it "t2ax-REG"

4. Select Input fixed mask = "CT-plan-label", Input moving mask = "t2ax-label". Check "ROI" of Mask Proceeding
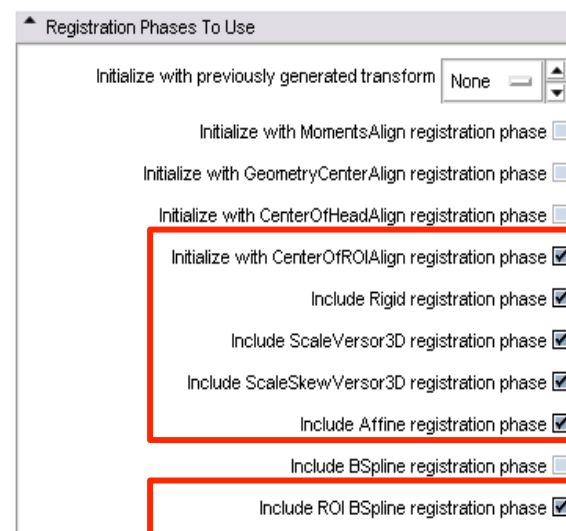
Step 4: MRI-CT Registration

Output: T1 and t2ax-REG

4. Select the Registration methods to run, check the following boxes:

- "Initialize with CenterOfROIAlign registration phase"
- "Include Rigid registration phase"
- "Include ScaleVersor3D registration phase"
- "Include ScaleSkewVersor3D registration phase"
- "Include Affine registration phase"
- "Include ROI BSpline registration phase"

> Registration Phases To Use
>
> Initialize with previously generated transform [None ▲▼]
>
> Initialize with MomentsAlign registration phase ☐
>
> Initialize with GeometryCenterAlign registration phase ☐
>
> Initialize with CenterOfHeadAlign registration phase ☐
>
> Initialize with CenterOfROIAlign registration phase ☑
>
> Include Rigid registration phase ☑
>
> Include ScaleVersor3D registration phase ☑
>
> Include ScaleSkewVersor3D registration phase ☑
>
> Include Affine registration phase ☑
>
> Include BSpline registration phase ☐
>
> Include ROI BSpline registration phase ☑

6. Click "Apply"
7. With ~ 1 minute (depending on CPU), you can see the moved and deformed t2ax-N4 image as "t2ax-REG".
8. Save your work.

Step 4: MRI-CT Registration Result

1. Select "t2ax-REG" at Background layer and "t2ax-N4" at Foreground layer. Switching between background and foreground you can now see the deformation applied.

2. Select "CT-plan" at Foreground layer. You can see that the shape of the liver on MRI was deformed and fitted the liver on CT image.
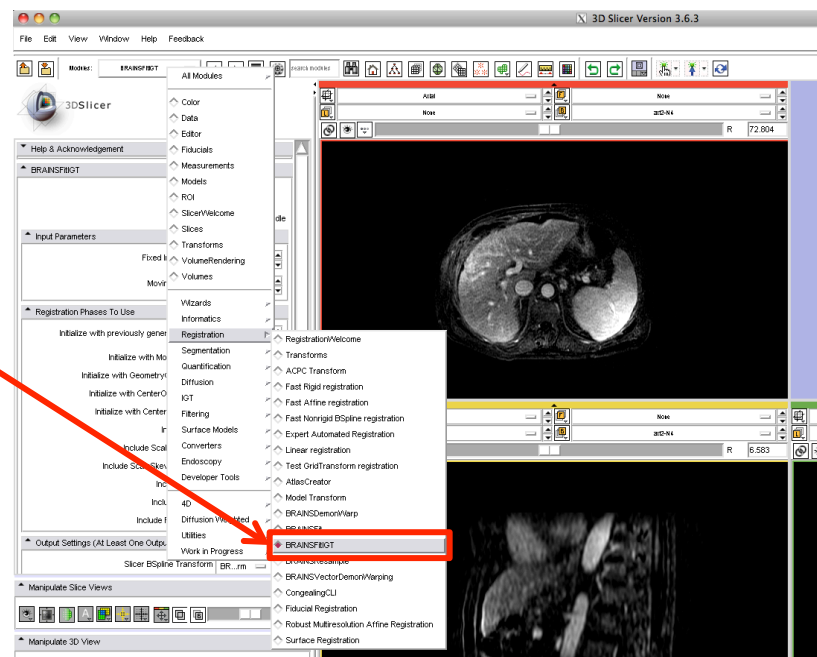

t2ax-N4 and t2ax-REG

CT-plan

t2ax-REG (deformed MRI)

CT and deformed MRI
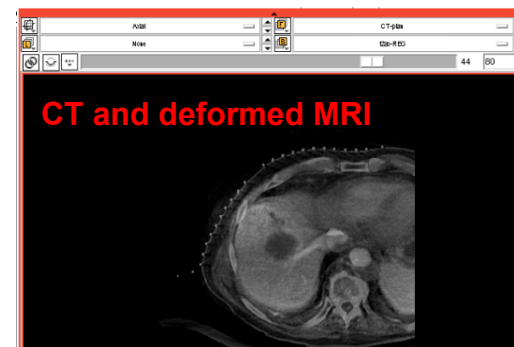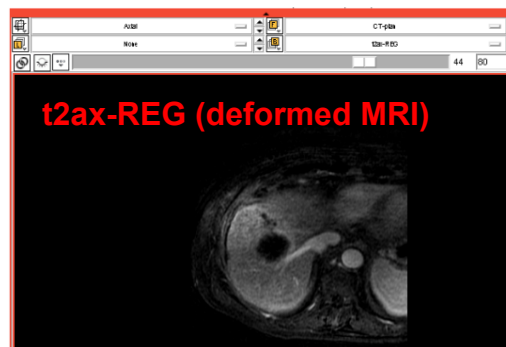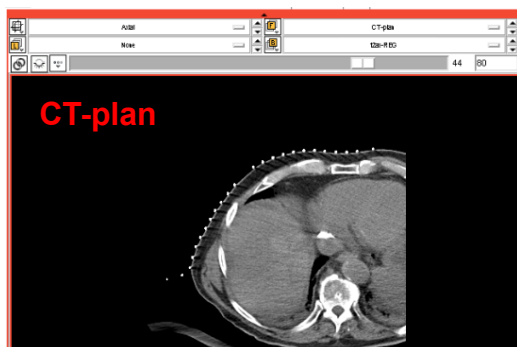
Step 5:
Pre-CT to Intra-CT Affine Registration

Step 5: Pre-CT to Intra-CT Affine Registration

1. Go to the "BRAINSFitIGT" module in the "Registration" category of the module menu

Step 5: Pre-CT to Intra-CT Affine Registration

Input: CT-intra.nrrd, CT-plan.nrrd, CT-intra-label and CT-plan-label

Set "BRAINSFitIGT" module parameters as follows

1. Set Fixed image volume = "CT-intra", Moving image volume = "CT-plan"

2. Select BSpline transform = "create a new transform" and name it "T2"

3. Select Output image volume = "create a new volume" and name it "CT-plan-REG"

4. Select Input fixed mask = "CT-intra-label", Input moving mask = "CT-plan-label". Check "ROI" of Mask Proceeding

Step 5: Pre-CT to Intra-CT Affine Registration

Output: T2.tfm and CT-plan-REG.nrrd

4. Select the Registration methods to run, check the following boxes:

- "Initialize with CenterOfROIAlign registration phase"
- "Include Rigid registration phase"
- "Include ScaleVersor3D registration phase"
- "Include ScaleSkewVersor3D registration phase"
- "Include Affine registration phase"
- "Include ROI BSpline registration phase"
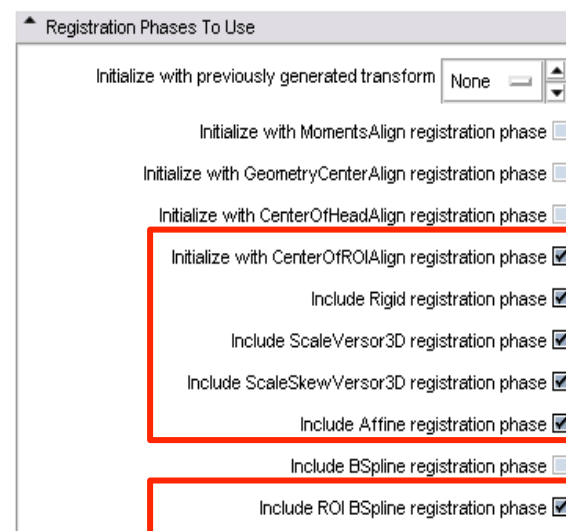

6. Click "Apply"
7. With ~ 1 minute (depending on CPU), you can see the moved and deformed CT-plan image as "CT-plan-REG".
8. Save your work.

Step 4: MRI-CT Registration Result

1. Select "CT-plan-REG" at Background layer and "CT-plan" at Foreground layer. Switching between background and foreground you can now see the deformation applied.

CT-plan and CT-plan-REG

2. Select "CT-intra" at Foreground layer. You can see that the shape of the liver on CT-plan was deformed and fitted the liver on CT-intra image.

CT-intra

CT-plan-REG (deformed CT)

CT-intra and deformed CT
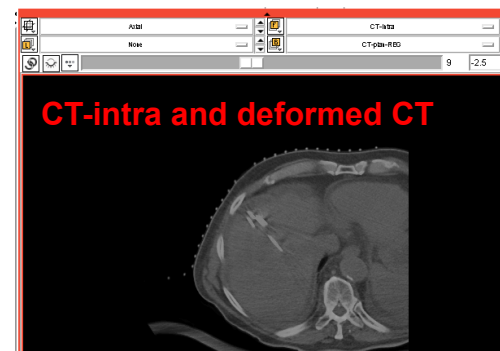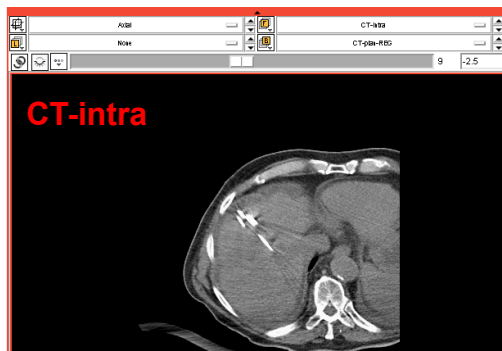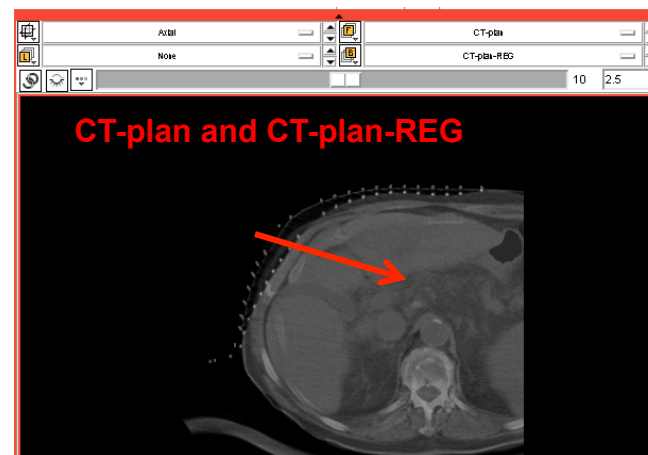
Step 6:
# Resampling of the MRI to Intra-CT Image and Fusion

We've now completed all the preprocessing and are ready for the actual registration.

Step 6: Resampling and Fusion

**Input: t2ax-REG.nrrd, CT-intra.nrrd, T2.tfm, Output: MR-CT-intra.nrrd**

1. Go to BRAINSResample module

2. Set Image To Warp = "t2ax-REG", Reference Image = "CT-intra", Output Image = create a new volume and name it "MR-CT-intra", Warp By Transform = "T2.tfm".

3. Check Interpolation mode "BSpline" of Warping Parameters

4. Click "Apply"

5. After about 6 sec (depending on CPU), you can see the moved and deformed t2ax-REG image as "MR-CT-intra".
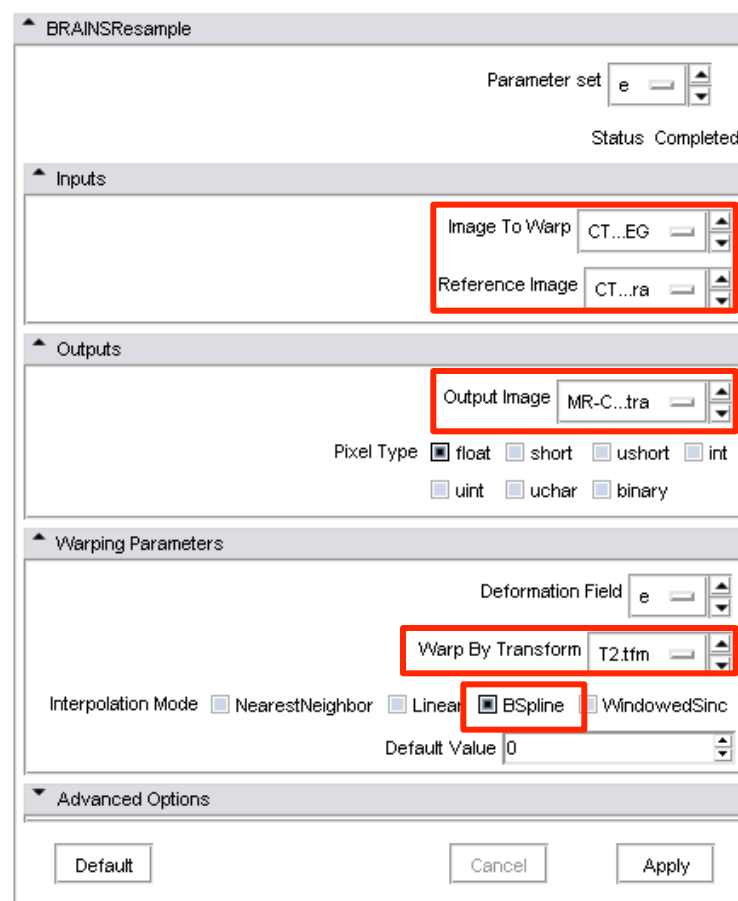
Step 6: Resampling and Fusion

1. Select "MR-CT-intra" at Background layer and "t2ax-REG" at Foreground layer. Switching between background and foreground you can now see the deformation applied.

2. Select "CT-intra" at Foreground layer. You can see that the shape of the liver on MR-CT-intra was deformed and fitted the liver on CT-intra image.

MR-CT-intra and t2ax-REG

CT-intra

MR-CT-intra (deformed MRI)

CT-intra and deformed MRI
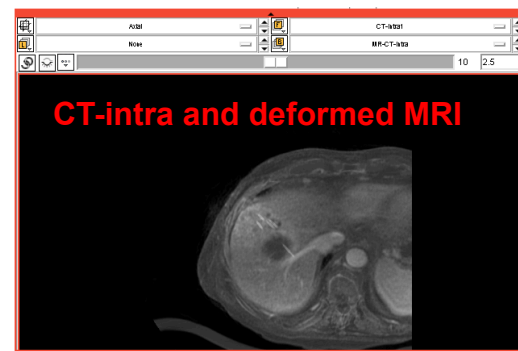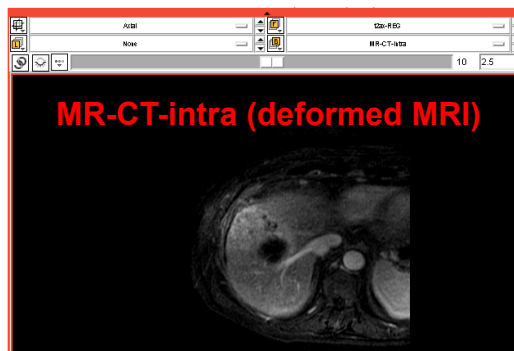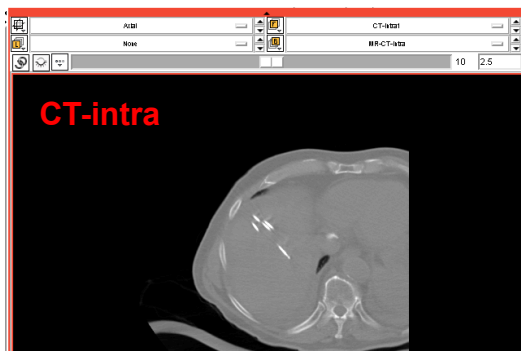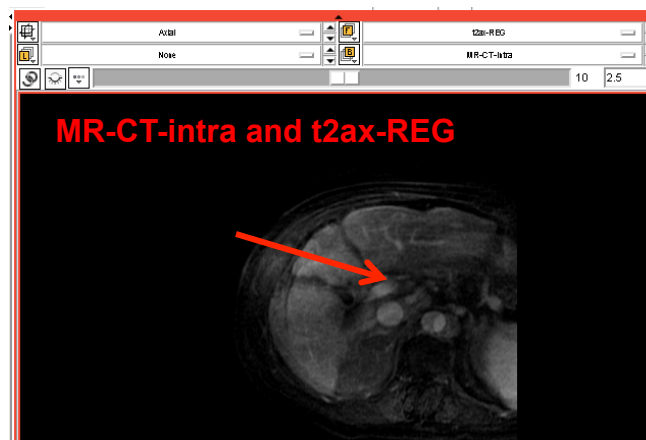
Conclusion

- 3D Slicer with BRAINSFitIGT module successfully performs non-rigid image registration of MR and CT liver data.

- For this particular type of image data, masking of the region of interest is usually necessary to obtain a good result.

- In the fused image pair, the distance between the cryoprobe on CT and the tumor on MR can now be assessed.

Acknowledgments

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