Non-rigid Registration of MR and CT images for CT-guided liver ablation

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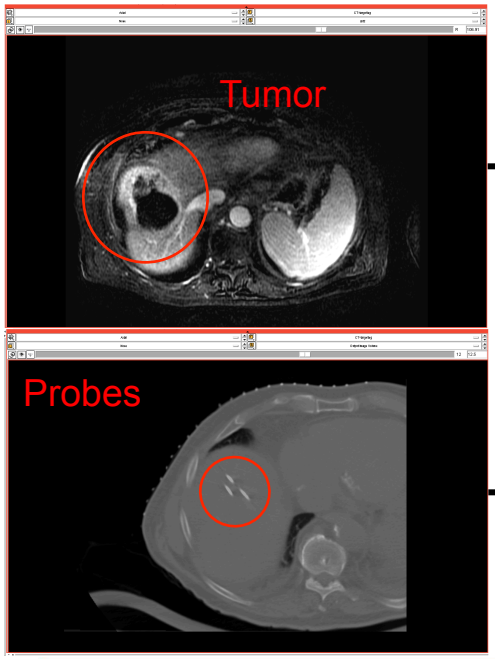
Learning Objective

- This tutorial demonstrates how to co-register the pre-operative contrast enhanced MR image to the intra-procedure CT image via automated non-rigid registration.
- A workflow of image-guided ablation can be understood.



Pre-procedure
Contrast
Enhanced MRI

Registration

Intra-procedure
Unenhanced CT
With probes

Images Fused: allowing to see both tumor & probes

Tutorial Topics / Targets

Slicer Modules Used:

- N4ITK MRI Bias Correction
- Editor
- General Registration (BRAINS)

Image Processing Tasks Performed:

- Intensity non-uniformity correction
- Mask generation / segmentation
- Inter-modality non-rigid/affine image registration

Image Data Used:

- Pre-operative abdominal MR with surface coil, showing liver
- Planning CT and Guidance CT with probes

Prerequisites

- This tutorial was developed and tested on
- Windows 7, OS X 10.10.2, Ubuntu Linux 14.04
- Slicer 4.4.0-2015-01-26

This tutorial website is at:

http://www.slicer.org/slicerWiki/index.php/Documentation/4.4/Training

Anonymized image dataset for this tutorial is available at:

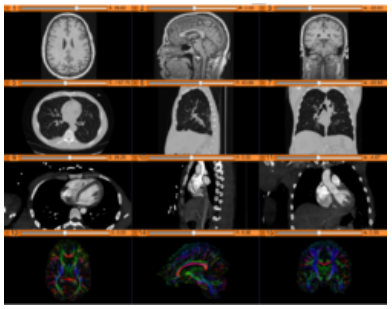
http://www.slicer.org/slicerWiki/images/0/04/NRR-CTgLiverAblation.zip

Disclaimer

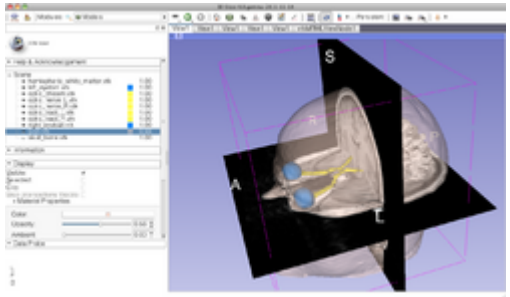
Slicer is not FDA approved or CE marked and is for clinical research only.

User Skill Pre-requisites

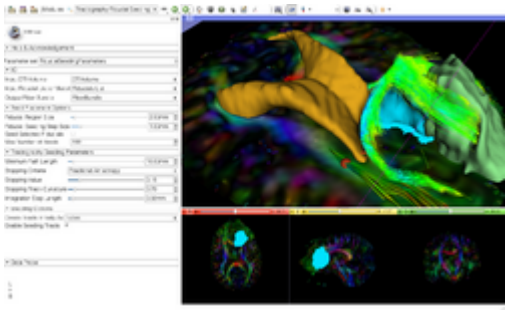
- Before running this tutorial, if new and unfamiliar with the Slicer user interface, we recommend to first complete the following tutorials, available here:
- http://www.slicer.org/slicerWiki/index.php/Documentation/UserTraining



SlicerWelcome tutorial



Slicer4Minute tutorial



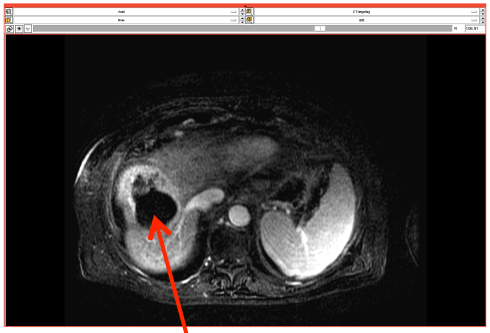
Neurosurgical Planning tutorial

Clinical Significance

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

Pre-operative MRI

Tumor margins and surrounding structure are visible



MRI

Tumor

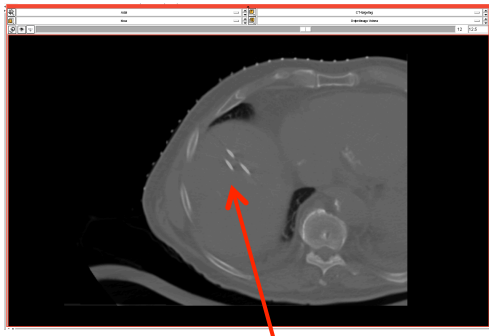
Liver position, shape and structures may differ significantly between the two exams.

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

Intra-operative CT

Only interventional probes are visible, not the tumor

CT



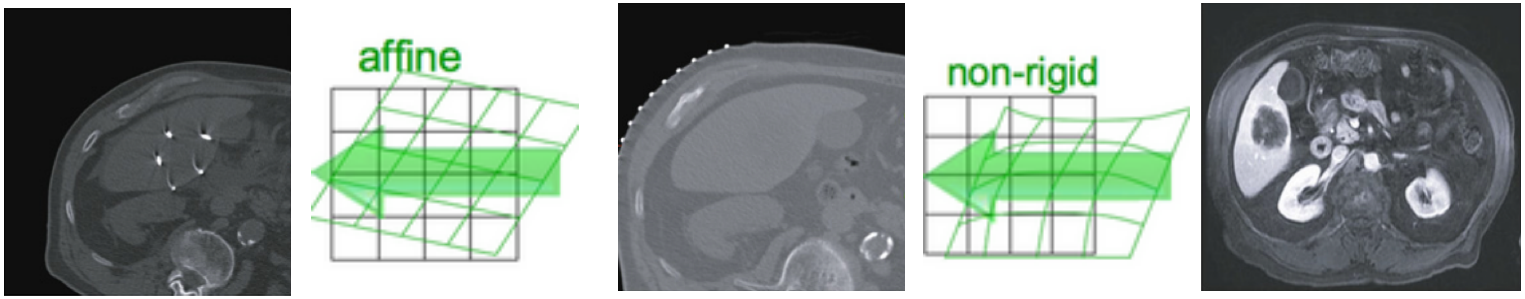
Probes

Overview of Registration Workflow

In this particular CT-guided ablation, there are two registrations necessary:

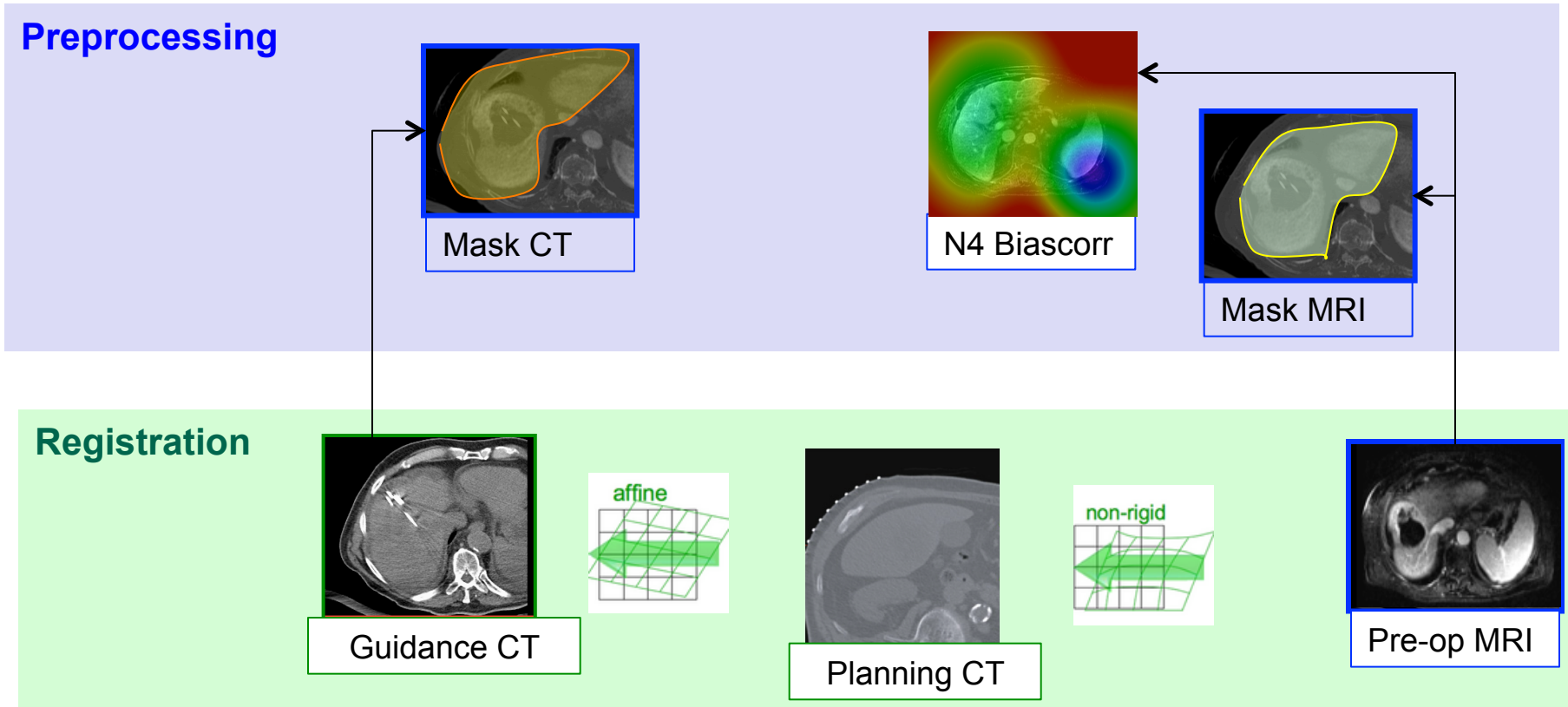
1) Non-rigid registration between the pre-op MR and Planning CT
2) Affine registration between the Planning CT and Guidance CT

This minimizes differences between image pairs and increases robustness of the registration.



Guidance CT **Planning CT** **Pre-procedure enhanced MRI**

Registration Strategy/Roadmap



Clinical Scenario

One month before the ablation procedure

A patient with a **possible liver tumor** is enrolled in the study. CT-guided percutaneous cryoablation is scheduled.

One week before the ablation procedure

Pre-operative contrast-enhanced MRI is acquired (**"MR"**)

During the procedure

0 min: The patient is moved into the room

5 min: Preparation

20 min: Acquisition of planning CT that covers the entire liver **("Planning CT")**

25 min: Image review for planning

40 min: Placement of probes under CT fluoroscopy guidance

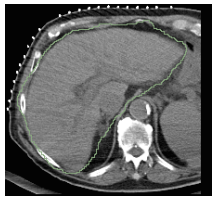
45 min: Confirmation of probe placement **("Guidance CT")**

60 min: Cryoablation under CT guidance

Overview of Registration Workflow

- **1.** Before operation
  - **A.** Mask the liver on MR
  - **B.** Apply MRI Bias Field Intensity Correction

- **2.** During operation (before insertion)
  - **A.** Mask the liver on Planning CT
  - **B.** Apply MRI-CT non-rigid registration



- **3.** During operation (after insertion)
  - **A.** Mask the liver on Guidance CT
  - **B.** Apply CT-CT affine registration
  - **C.** Apply Resampling & Fusion

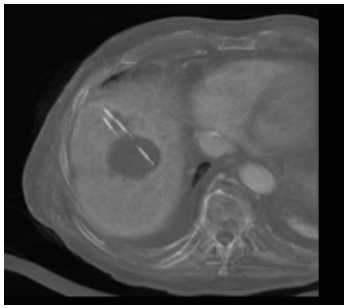


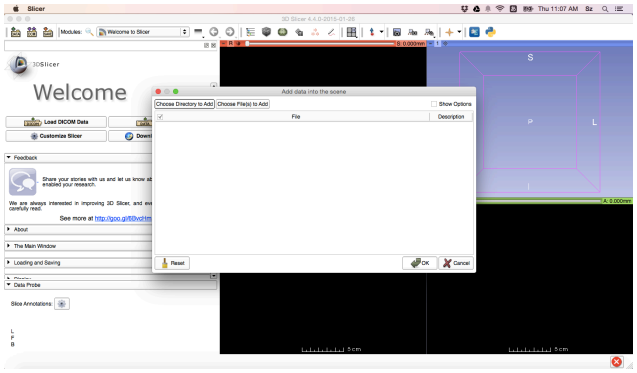
Image loading

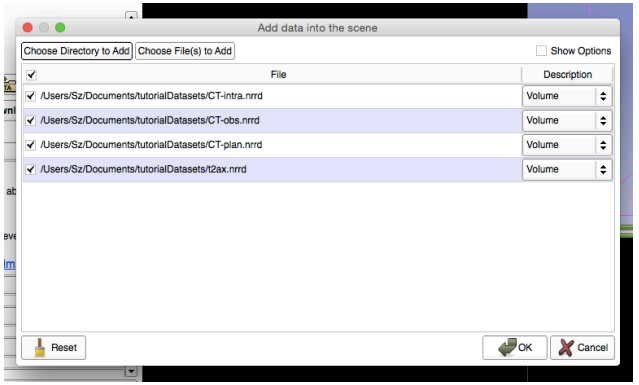
1. Click “Load Data” on Welcome column (or “DATA” icon on toolbar)

2. “Choose Directory to Add” and select the downloaded data named “tutorial Datasets.

3. Push “OK” after confirming that all four check boxes are checked.

4. Now all image sets are downloaded to be processed.





In real clinical cases, image importing is required in each time new images are scanned.
In this tutorial all images are downloaded at a time to avoid complexity.

1. Processing before operation

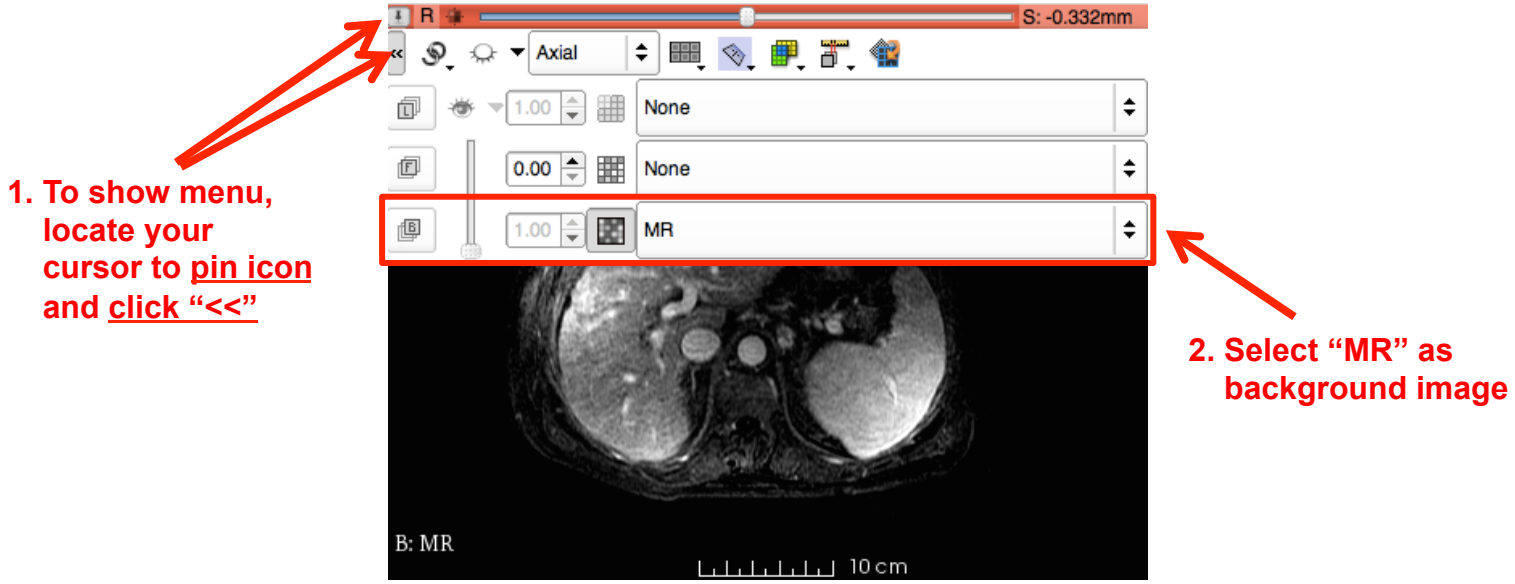
This process is done using MR images which are taken before operation.

1-A. MR mask of liver

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

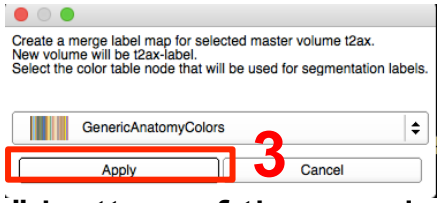
1. Show menu and confirm image data set

   First, confirm that the current background image set is “MR” which is the contrast-enhanced MR taken before operation.

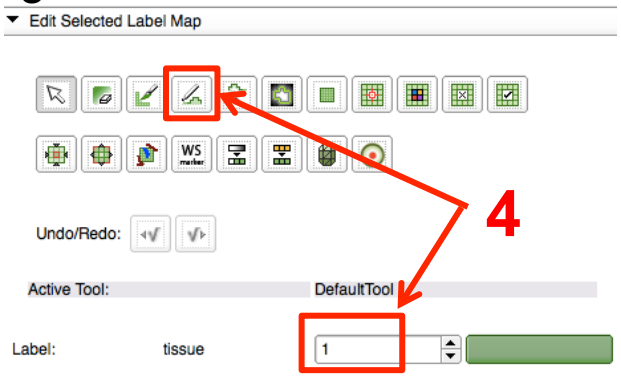


1-A. MR mask of liver

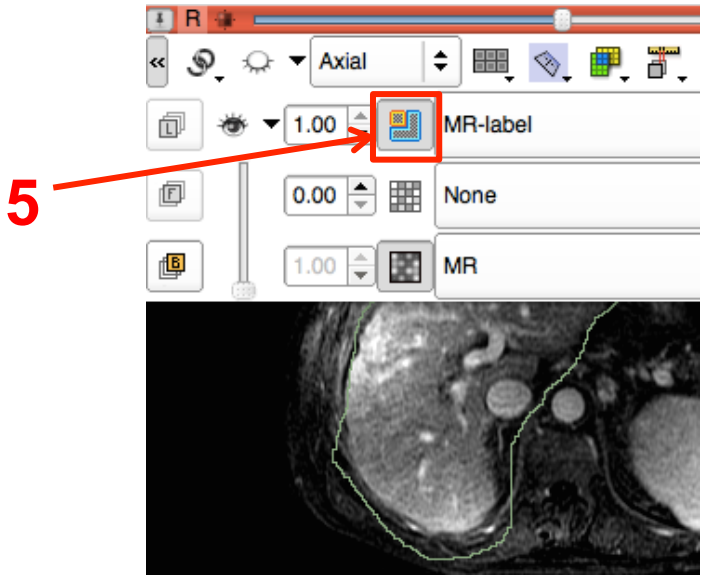
2. Go to the “Editor” module
3. Click “Apply” on the small window about Color table. This will automatically generate a new label volume, called “t2ax-label”.



4. Select “Draw” button of the module pane to segment liver with label 1

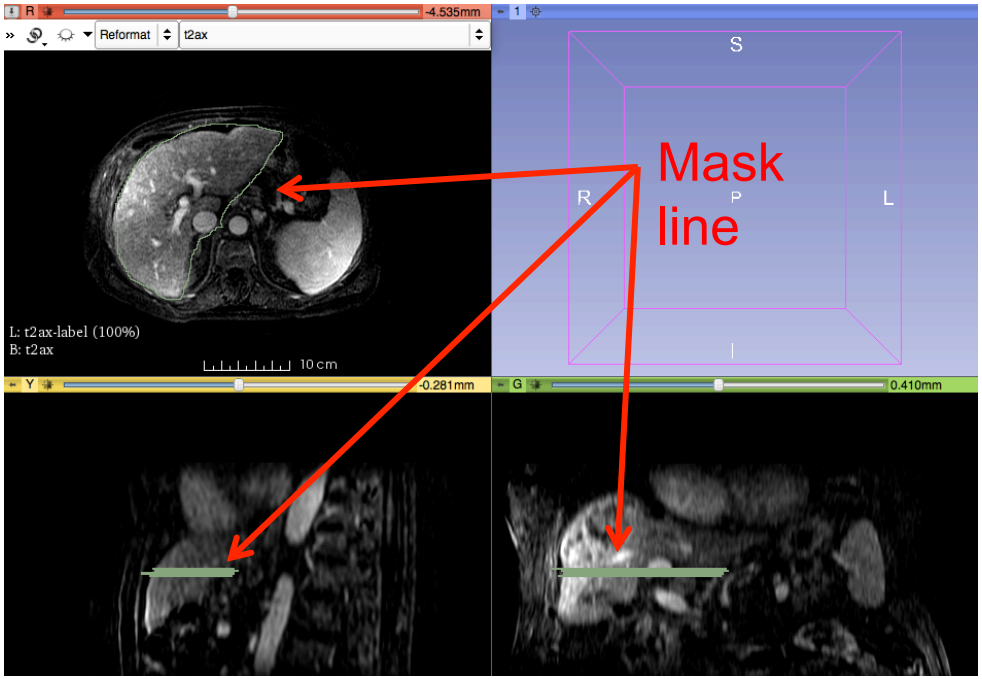


5. Choose the outlined icon below to confirm the segmented area easily



1-A. MR mask of liver

6. Draw an outer border around the liver on the axial slice. When done hit the “Return” key or “Apply” button to close the contour. Then hit arrow keys to move to the next slice.

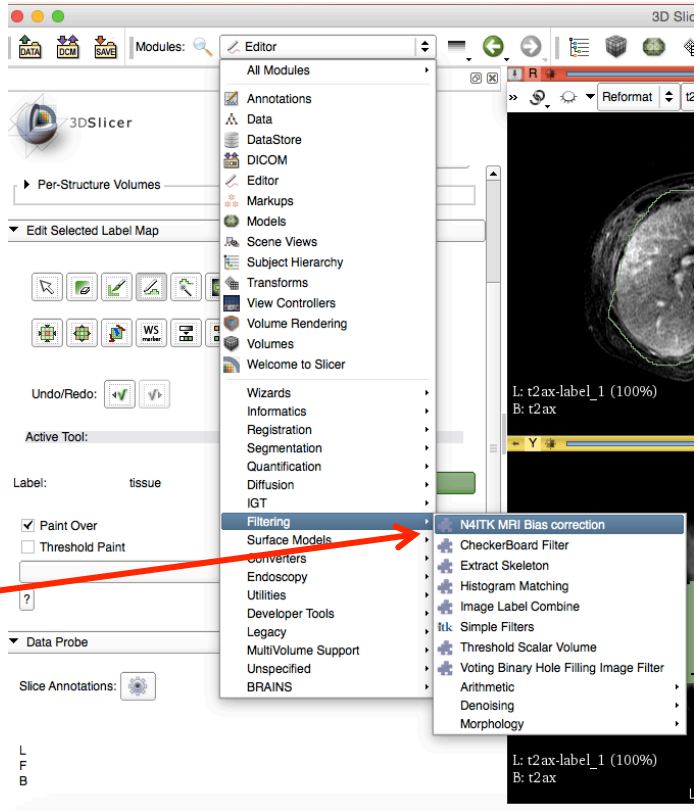


1-B. MR Bias Correction

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

This “MR” images are 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”)



1-B. MR Bias Correction

1. Set Parameters:

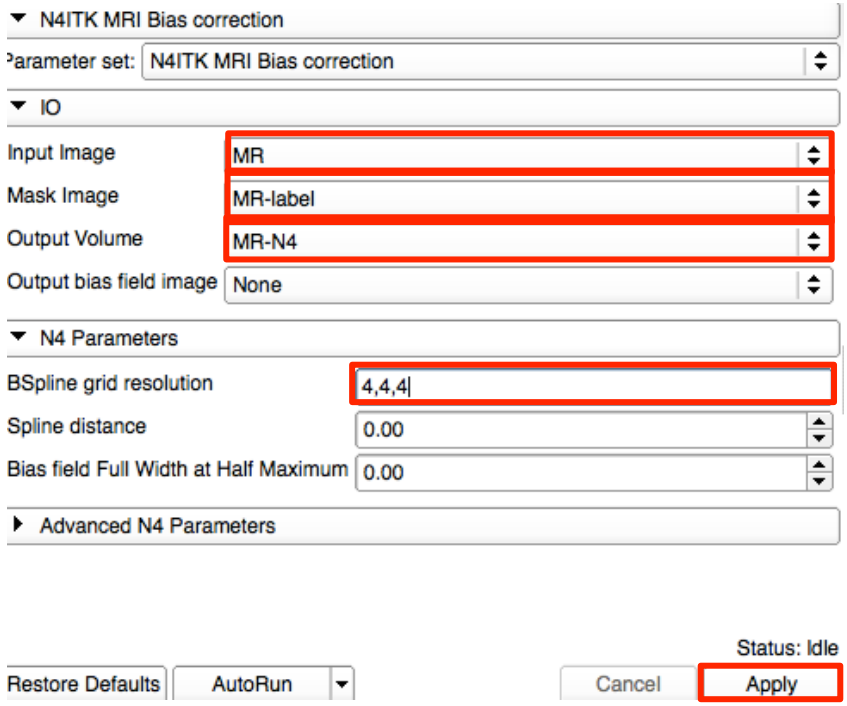
   Input image = **MR**

   Mask image = **MR-label**

   Output volume = choose “Create and rename new Volume” and name it “**MR-N4**”

   BSpline grid resolution = **4,4,4**

2. Click “Apply”*
3. Save your current work

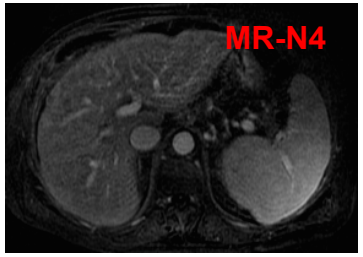


*This process will take 1-3 minutes.

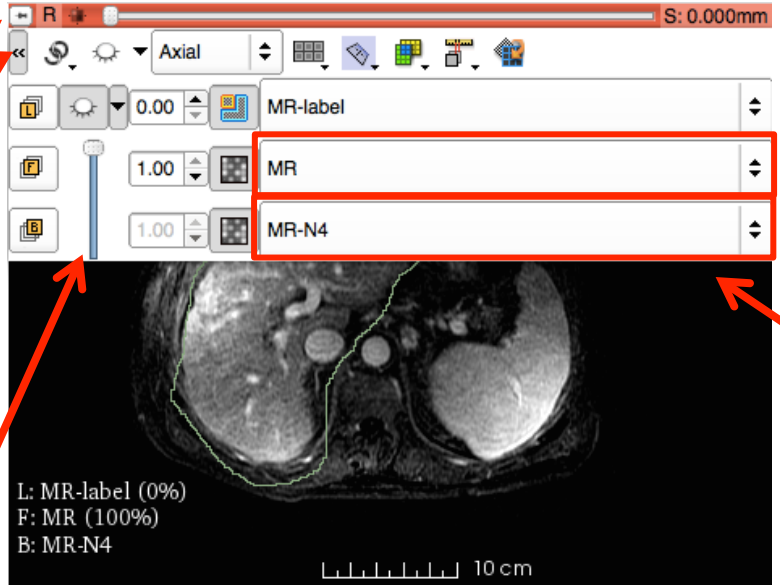
1-B. MR Bias Correction Result

Select “MR-N4” at Background layer and “MR” at Foreground layer.

Switching between background and foreground you can see the Bias Correction applied.



1. To show menu, locate your cursor to pin icon and click “<<”



2. Set images as follows:
   Foreground = MR
   Background = MR-N4

3. Use the slider to fade between the background and foreground viewers

2. Processing during operation (before insertion)

Now imagine that the patient is prepared for operation in a CT room.
CT scan for planning is taken before needle insertion and imported to Slicer.

2-A. Liver masking on Planning CT

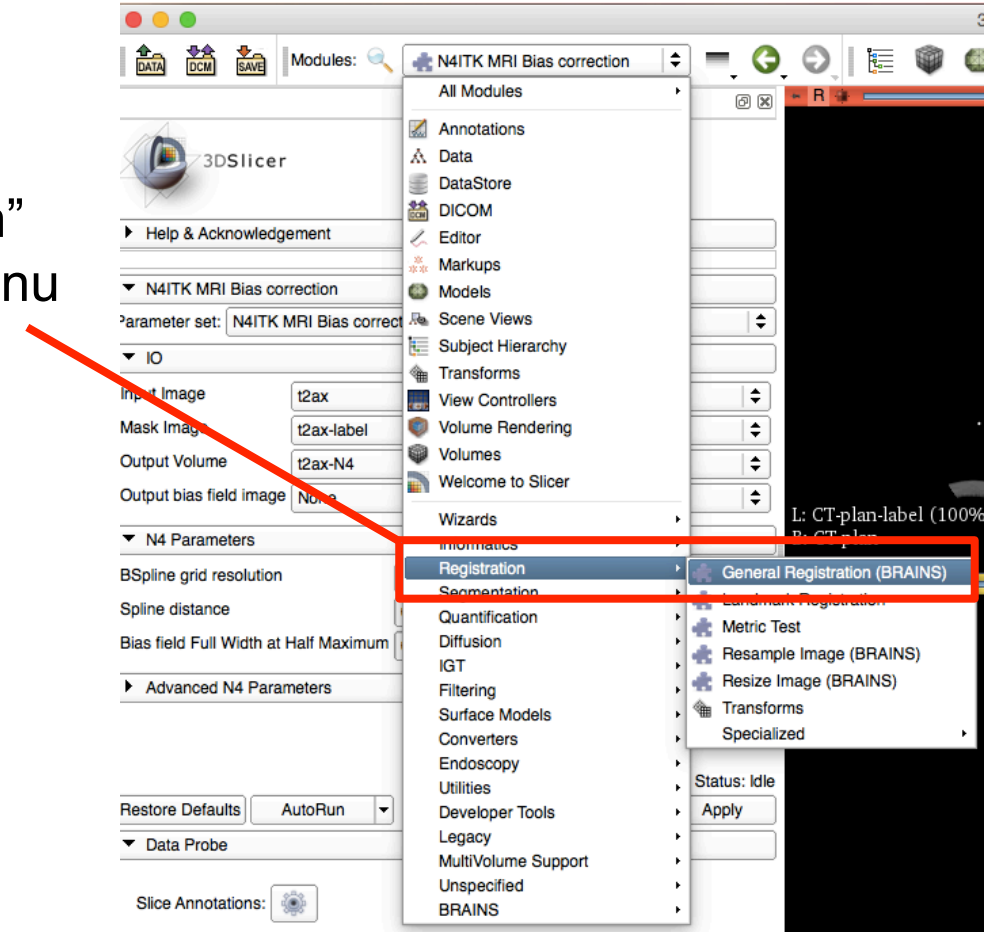
Input: CTp.nrrd, Output: CTp-label.nrrd

1. Save your current work (Please confirm the directory).
2. We now repeat the same outlining process on the CT image.
3. In the Editor, select under Master Volume the “CTp”.
4. As before, the editor will suggest a “CTp-label” automatically.
5. Proceed as for “1-A. MR mask of liver” above to generate a CT liver mask.
6. Again Save your work.

2-B. MRI-CT Registration

Input: CTp.nrrd, MR-N4.nrrd, CTp-label and MR-label

Go to the “General Registration (BRAINS)” module in the “Registration” category of the module menu

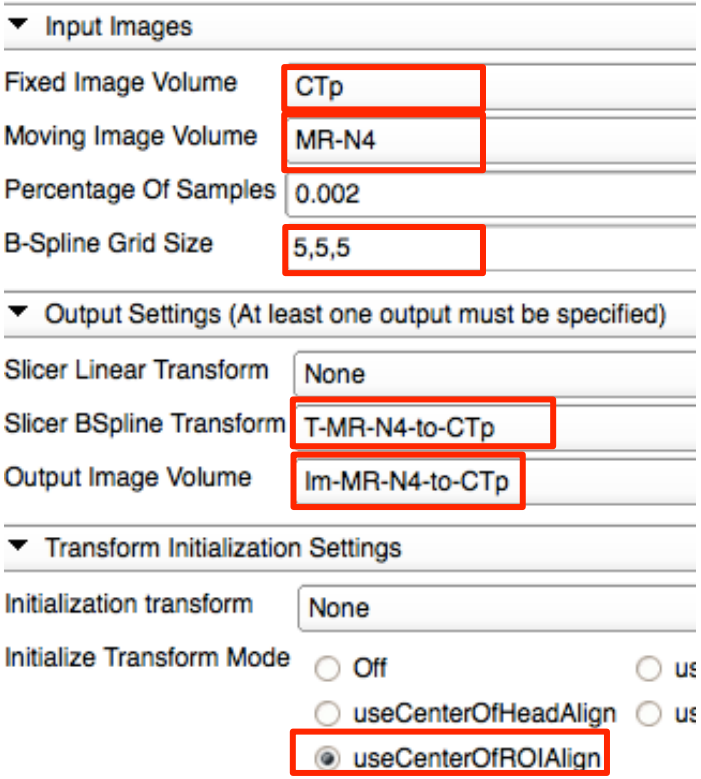


2-B. MRI-CT Registration

Output: T-MR-N4-to-CTp and Im-MR-N4-to-CTp

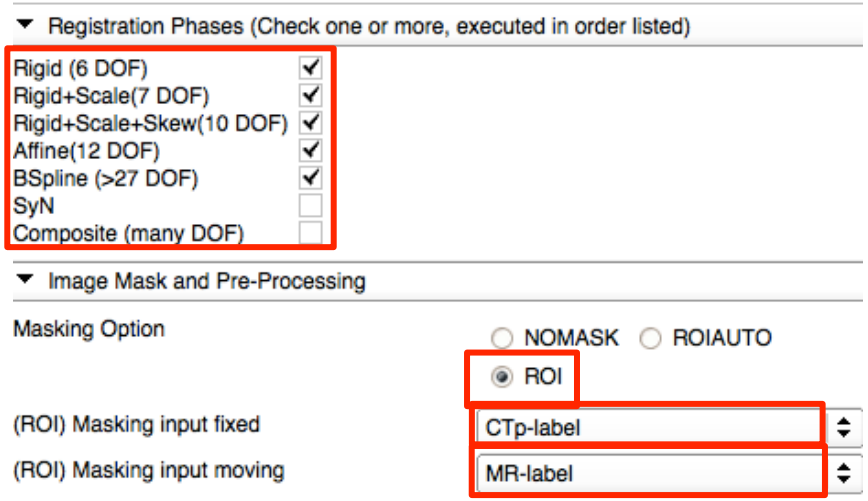
Set “General Registration (BRAINS)” module parameters as follows

- Fixed image volume = “**CTp**”
- Moving image volume = “**MR-N4**”
- Bspline Grid Size = “**5,5,5**”
- Slicer BSpline transform = “Create and rename a new transform” and name it “**T-MR-N4-to-CTp**”
- Output image volume = “Create and rename a new Volume” and name it “**Im-MR-N4-to-CTp**”
- Check “**useCenterOfROIAlign**”



2-B. MRI-CT Registration

- Select the Registration methods to run, check the following boxes:
  - "Rigid (6DOF)"
  - "Rigid+Scale(7DOF)"
  - "Rigid+Scale+Skew(10DOF)"
  - "Affine(12DOF)"
  - "BSpline (>27DOF)"

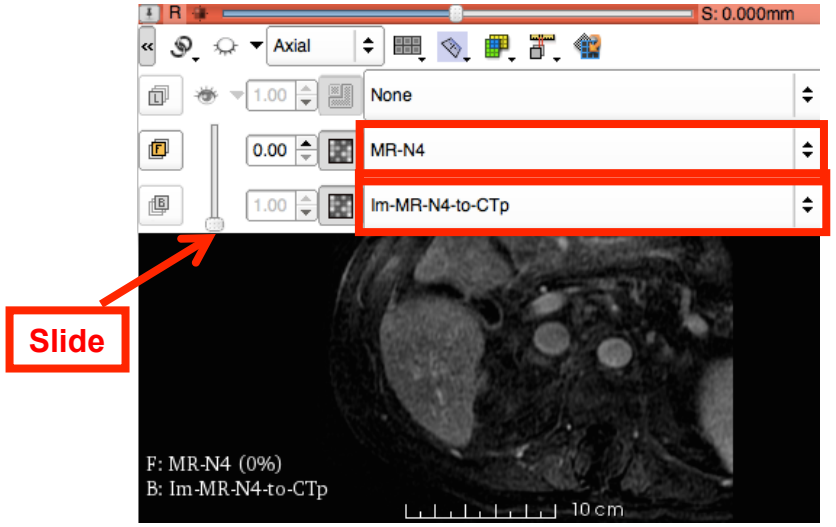


- Check "**ROI**" of Mask Proceeding
- Input fixed mask = "**CTp-label**"
- Input moving mask = "**MR-label**".

Click "Apply" and wait for 1-3 minutes.

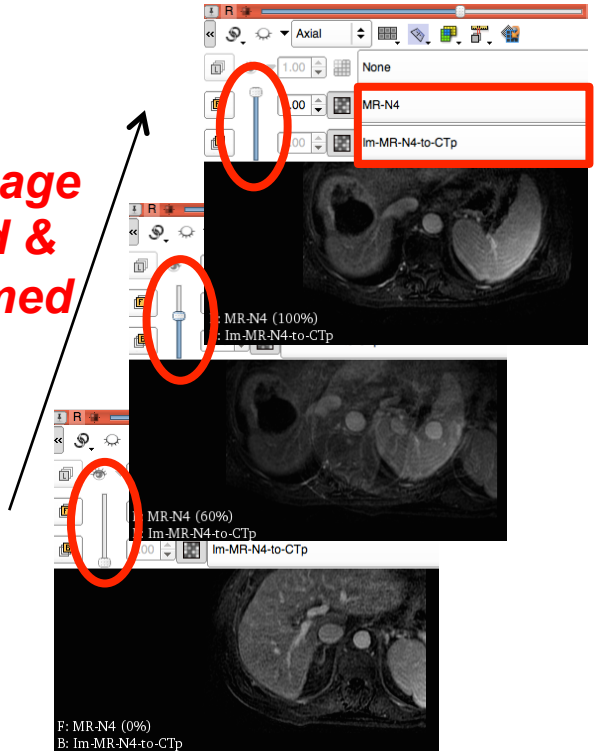
2-B. MRI-CT Registration Result – Comparison 1

Select "**Im-MR-N4-to-CTp**" at Background layer and "**MR-N4**" at Foreground layer. Switching between background and foreground you can now see the deformation applied.



Foreground: **MR-N4**
Background: Im-MR-N4-to-CTp

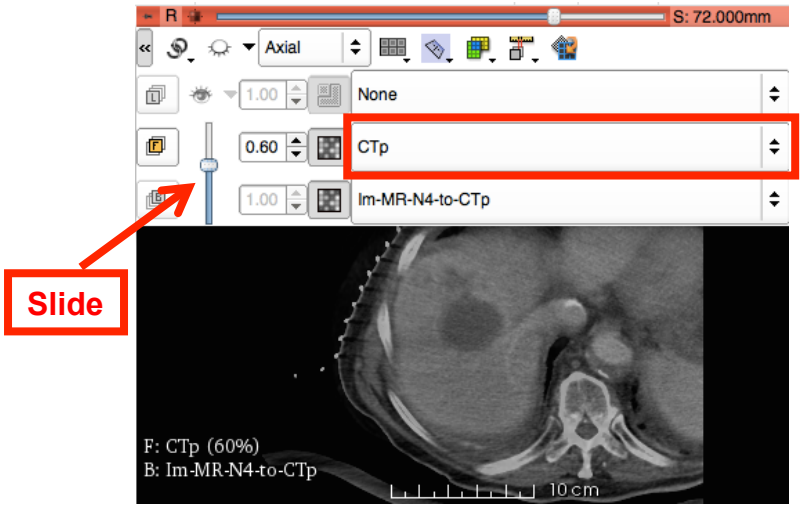
MR image moved & deformed



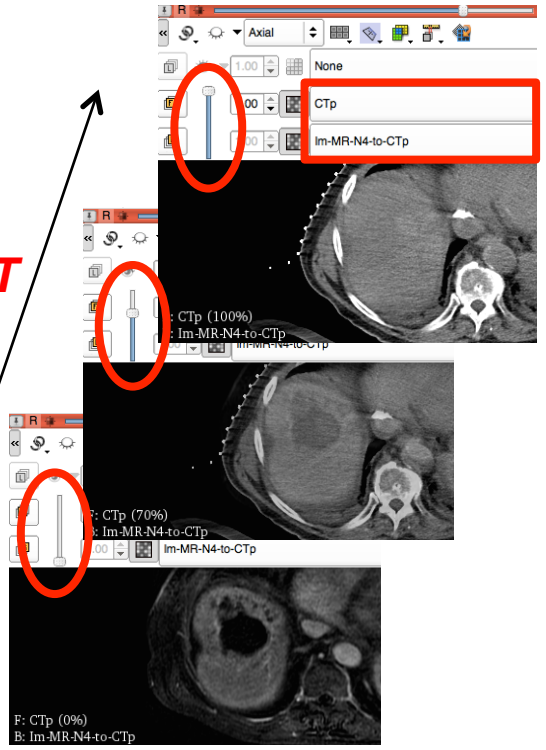
2-B. MRI-CT Registration Result – Comparison 2

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

Foreground: **CTp**
Background: Im-MR-N4-to-CTp



MR image fitted Planning CT



3. Processing during operation (after insertion)

The liver tumor is targeted and needles are inserted by the physician.
CT image for guidance is taken to confirm location of needles.

3-A. Liver masking on Guidance CT

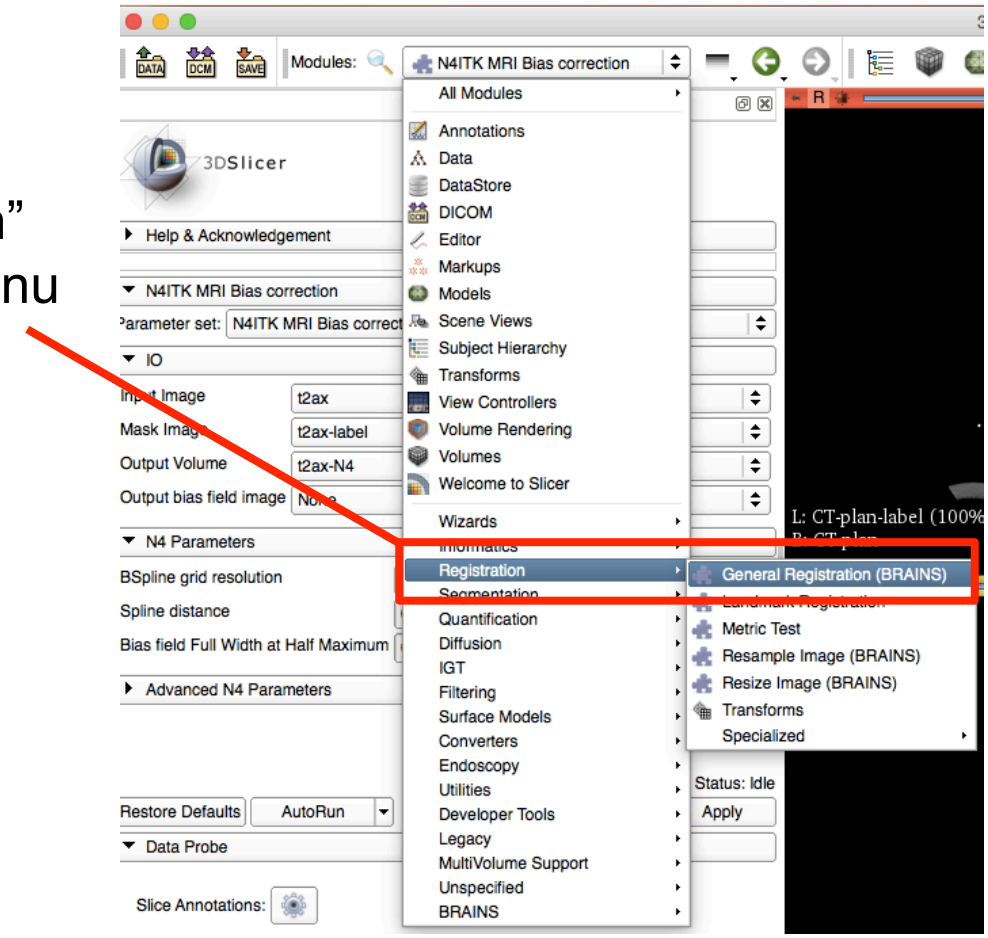
Input: CTg.nrrd Output: CTg-label

1. Save your current work.
2. We now repeat the same outlining process on the CT image.
3. In the Editor, select under Master Volume the "**CTg**".
4. As before, the editor will automatically suggest a "**CTg-label**" automatically.
5. Proceed as for "1-A. MR mask of liver" above to generate a CT liver mask
6. Again Save your work.

3-B. Planning CT to Guidance CT Affine Registration

Input: CTg.nrrd, CTp.nrrd, CTg-label and CTp-label

Go to the “General Registration (BRAINS)” module in the “Registration” category of the module menu



3-B. Planning CT to Guidance CT Affine Registration

We apply affine registration here.

Deference between “Planning CT” and “Guidance CT” is supposed to be small because these two image sets are taken in the same operation in the same modality while the patient is kept lying down.

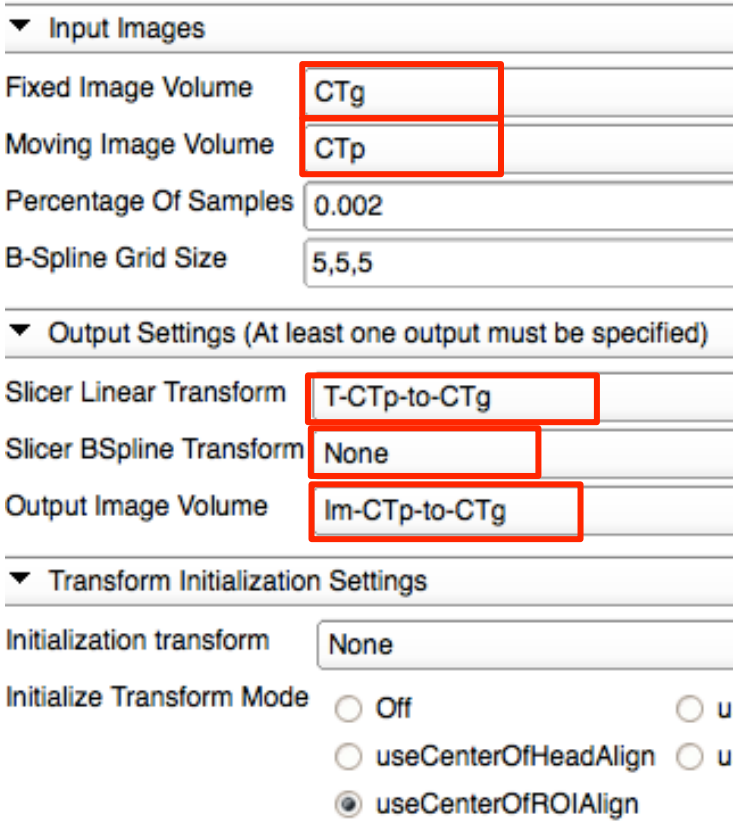
The obtained transform data here is to be applied at 3-C.

3-B. Planning CT to Guidance CT Affine Registration

Output: T-CTp-to-CTg, Im-CTp-to-CTg

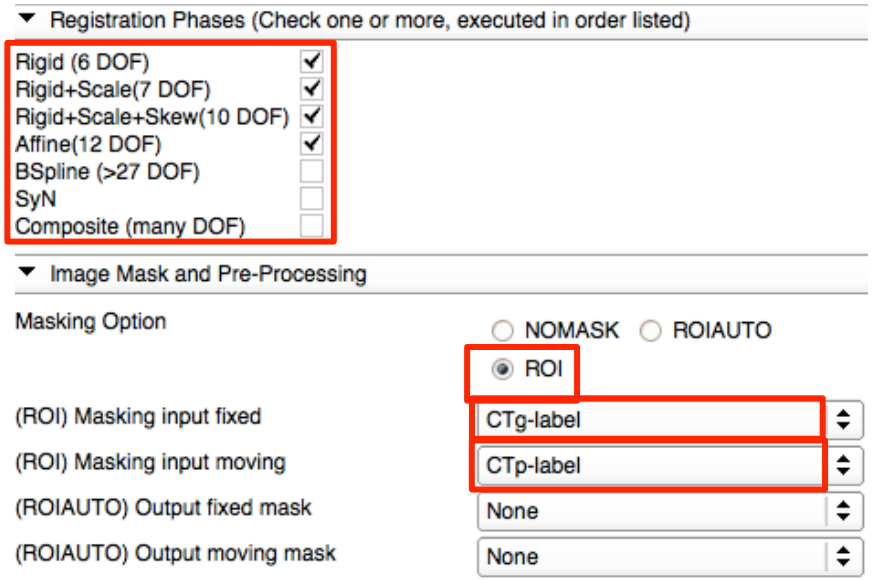
Set “General Registration (BRAINS)” module parameters as follows.

- Fixed image volume = “**CTg**”
- Moving image volume = “**CTp**”
- Slicer Linear transform = “Create and rename a new transform” and name it “**T-CTp-to-CTg**”
- Slicer BSpline transform = “**None**”
- Output image volume = “Create and rename a new Volume” and name it “**Im-CTp-to-CTg**”



3-B. Planning CT to Guidance CT Affine Registration

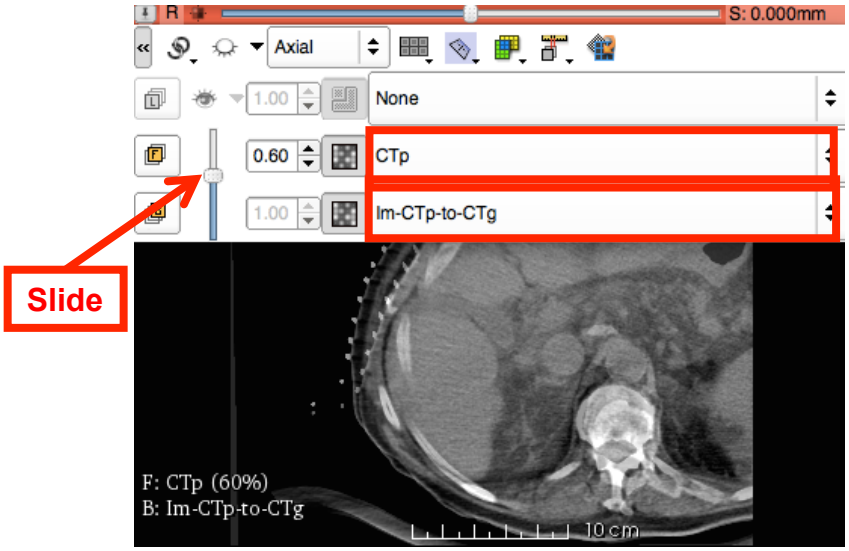
- Uncheck "BSpline (>27DOF)" box
- Input fixed mask = "**CTg-label**"
- Input moving mask = "**CTp-label**"



Click "Apply" and you can see deformed CTp image as "**Im-CTp-to-CTg**". Please save your work.

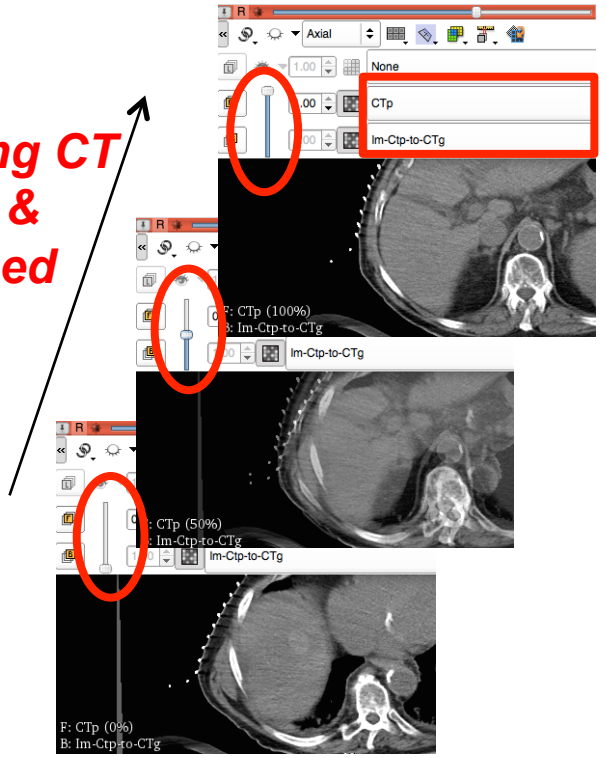
3-B. CT-CT Registration Result – Comparison 1

Select "**Im-CTp-to-CTg**" at Background layer and "**CTp**" at Foreground layer. Switching between background and foreground you can now see the deformation applied.



Foreground: **CTp**
Background: Im-CTp-to-CTg

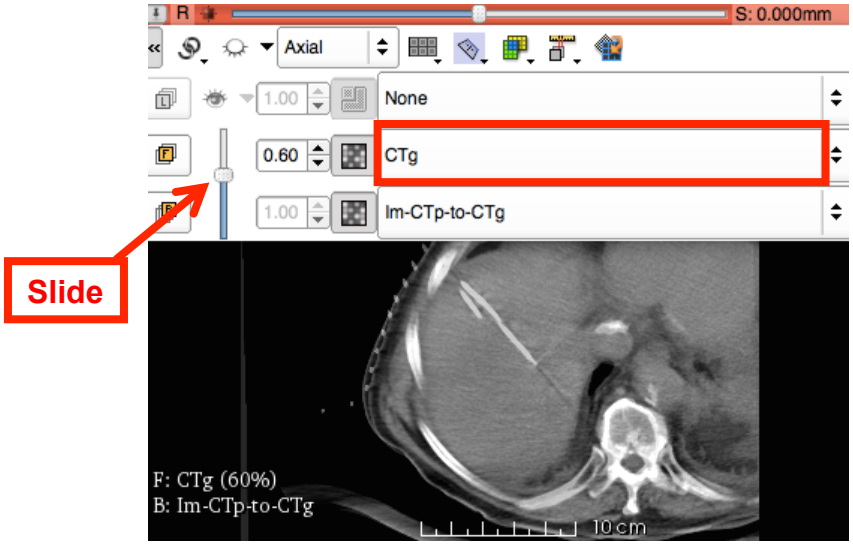
Planning CT moved & deformed



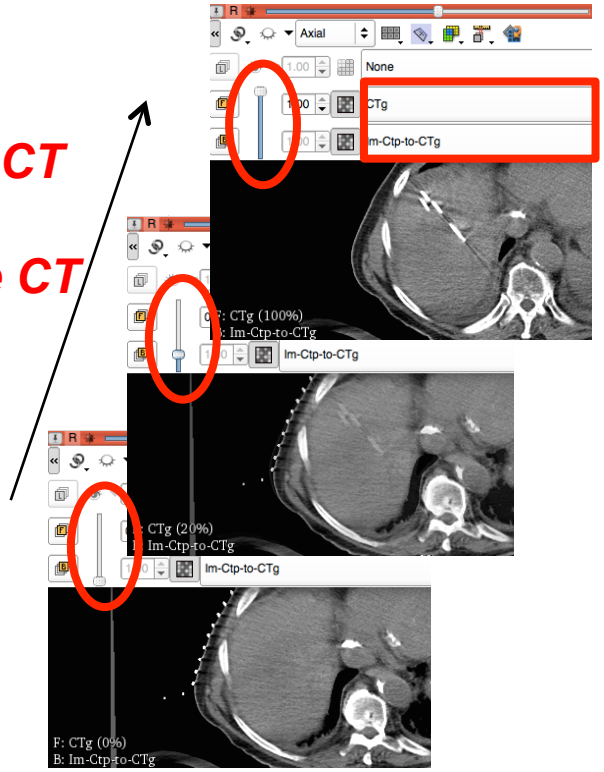
3-B. CT-CT Registration Result – Comparison 2

Select "**CTg**" at Foreground layer. You can see that the shape of the liver on CTp was deformed and fitted the liver on CTg image.

Foreground: **CTg**
Background: Im-CTp-to-CTg



Planning CT fitted Guidance CT



3-C. Resampling and Fusion

Input: Im-MR-N4-to-CTp.nrrd, CTg, T-CTp-to-CTg Output: Im-MR-N4-to-CTp-to-CTg

Transform the deformed MR again following the CT-CT registration data

1. Go to Resample Image (Brains) module
2. Set parameters as follows:

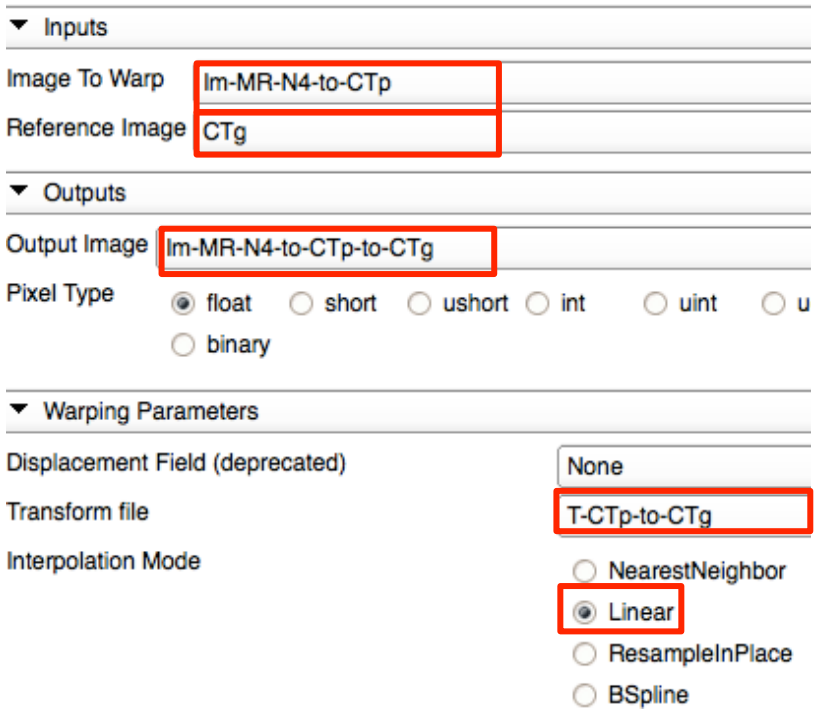
   Image To Warp = "**Im-MR-N4-to-CTp**"

   Reference Image = "**CTg**"

   Output Image = create and rename new Volume as "**Im-MR-N4-to-CTp-to-CTg**"

   Transform file= "**T-CTp-to-CTg**"

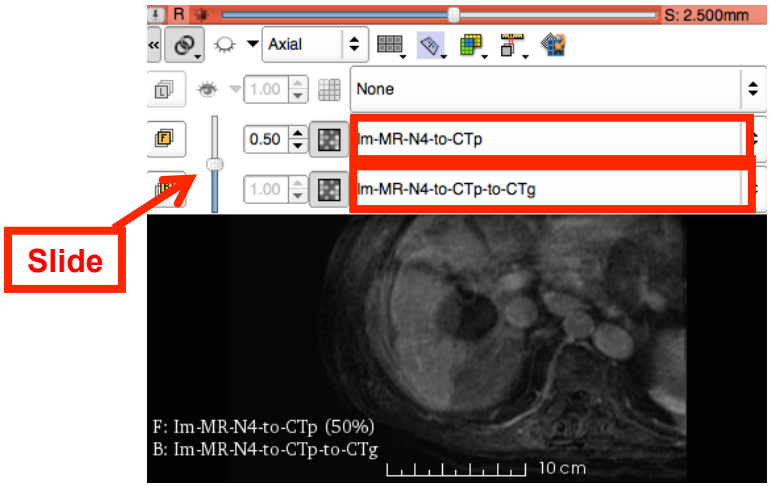
   Check Interpolation mode "**Linear**"
3. Click "Apply" and you can see the moved and deformed Im-MR-to-CTp image as "**Im-MR-N4-to-CTp-to-CTg**".



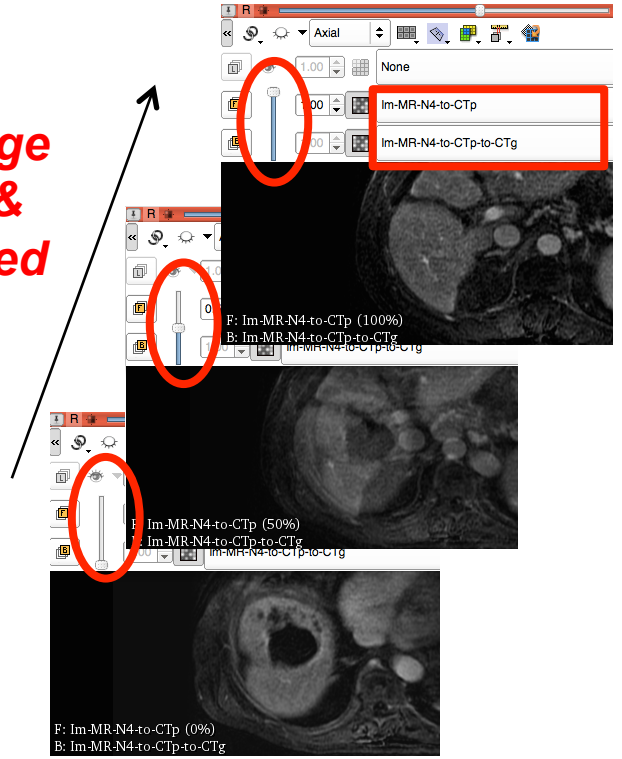
3-C. MRI-CT Resampling Result – Comparison 1

Select "**Im-MR-N4-to-CTp-to-CTg**" at Background layer and "**Im-MR-N4-to-CTp**" at Foreground layer. Switching between background and foreground you can now see the deformation applied.

Foreground: **Im-MR-N4-to-CTp**
Background: Im-MR-N4-to-CTp-to-CTg



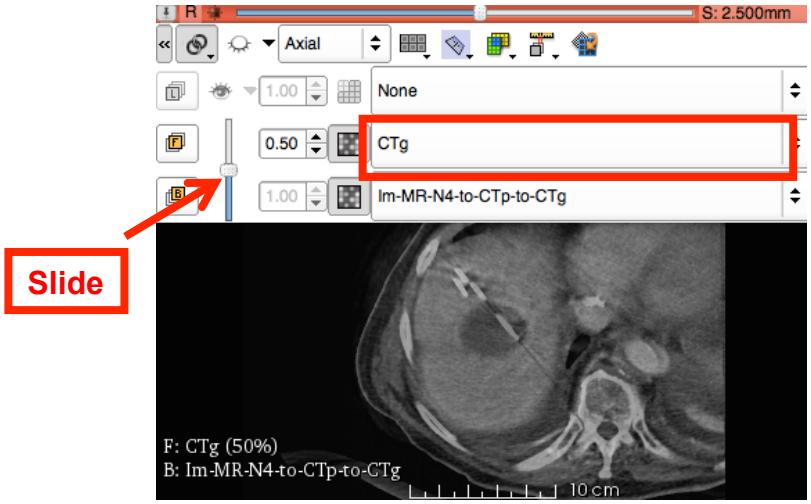
MR image Moved & Deformed again



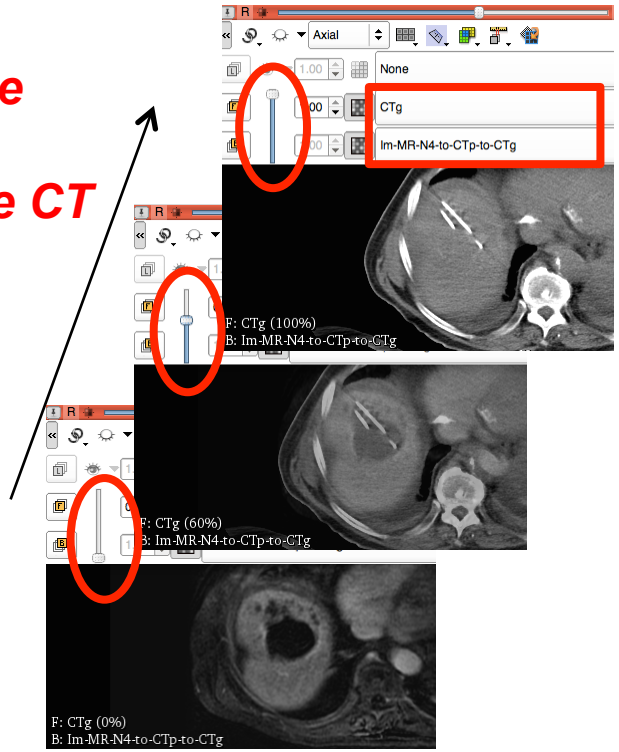
3-C. MRI-CT Resampling Result – Comparison 2

Select "**CTg**" at Foreground layer. You can see that the shape of the liver on **Im-MR-N4-to-CTp-to-CTg** is fitted the liver on CTg image.

Foreground: **CTg**
Background: Im-MR-N4-to-CTp-to-CTg



MR image fitted Guidance CT



Ablation and confirmation of margins

Now ablation is performed and CT images are taken to confirm the ablated area.
If ablated area covers the tumor with sufficient margins, the operation ends.

Conclusion

- Deformable registration and rigid registration are done on 3D slicer 4 following the process of a CT guided ablation case.
- For this particular type of image data, masking of the region of interest is usually necessary to obtain a good result.
- This registration technique can be applied to other scenario of clinical research in surgical navigation.

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