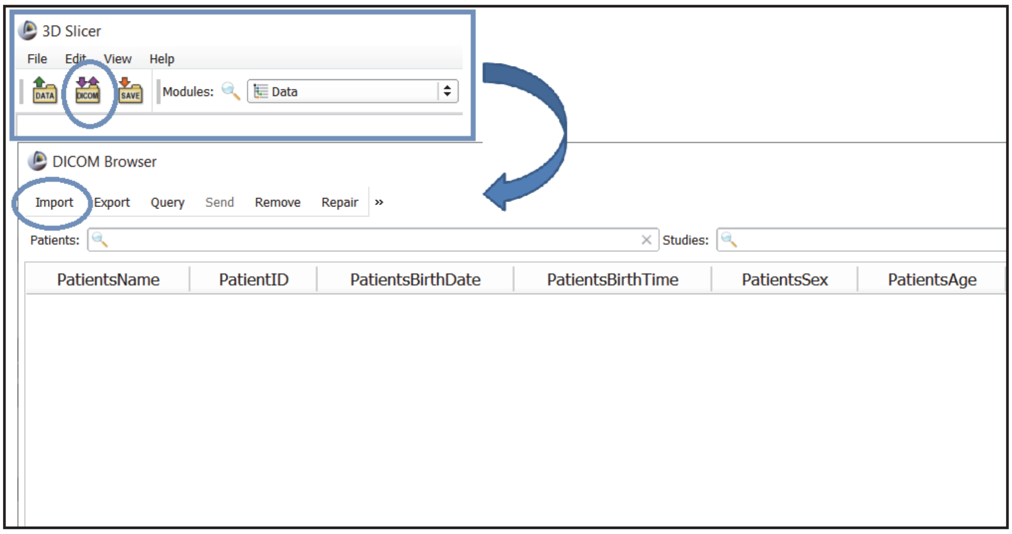
Supplementary File

Instructions for performing an EAM-CT merge in 3D Slicer

This supplement describes our EAM-CT merge method in more detail. You will need 3D Slicer software, which is freely available (www.slicer.org).

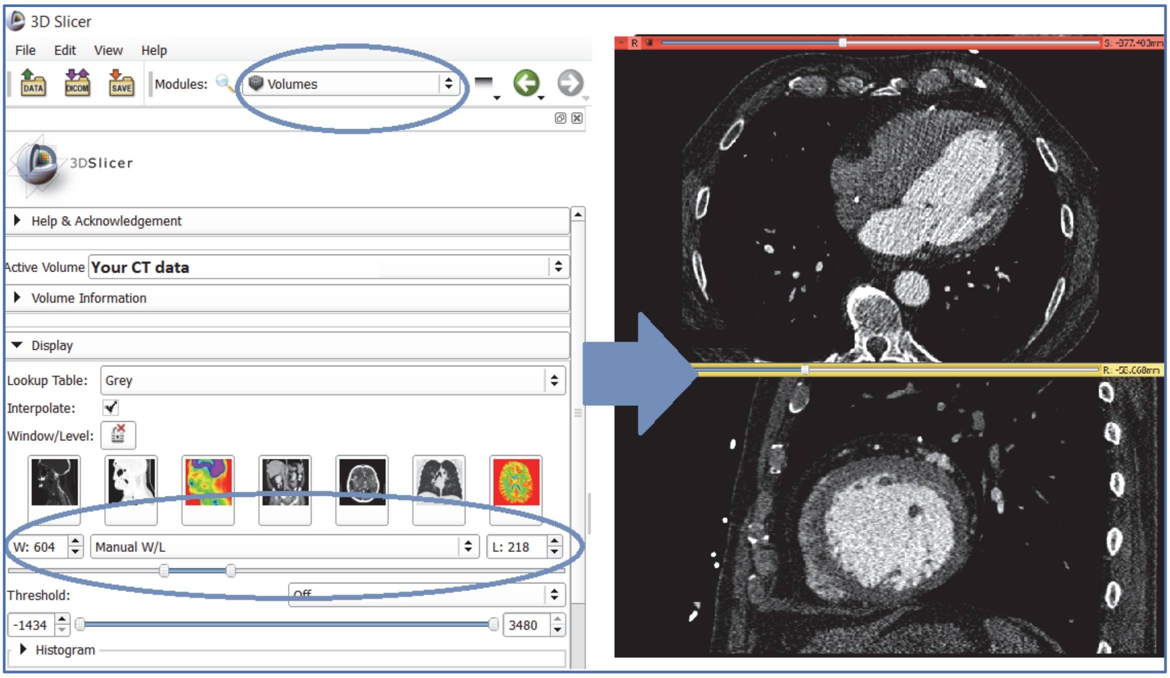
1) Uploading contrast-enhanced CT image series to 3D Slicer software

a. Use "DICOM browser" to **Import** and **Load** the relevant CT series.



b. When the CT is uploaded, adjust contrast with the left mouse button or use the **Volumes** module where several Window/Level presets are available.

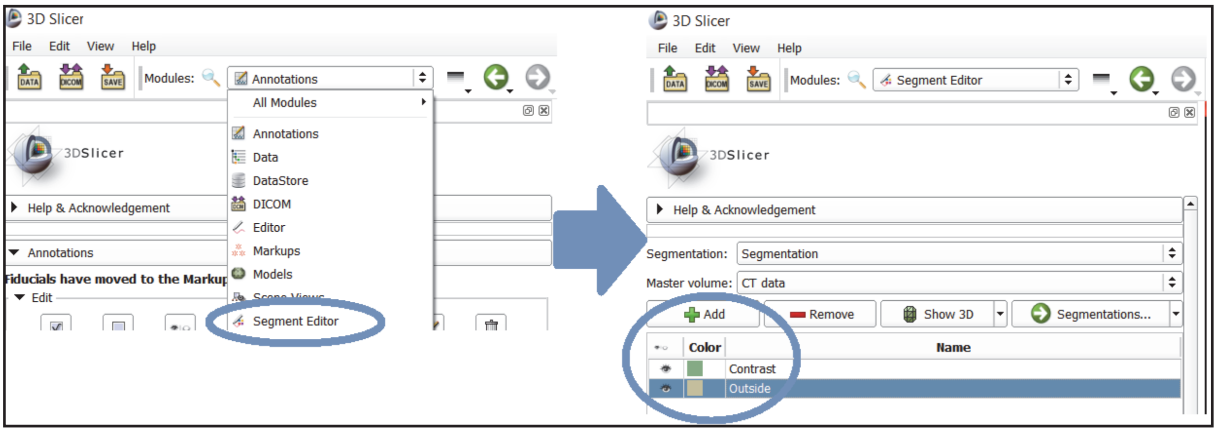
c. For contrast-enhanced CT, we usually start with W600-1000/L200-400 and perform manual adjustments with the left mouse button to increase the difference between the left ventricle (LV) with contrast agent and surrounding tissue.



2) Segmentation of LV from CT (CT LV)

a. Choose **Segment Editor** from the drop-down menu. Select your CT as **Master volume** if not selected automatically.

b. Use the **+ADD** button to make two new segments. We renamed the defaults as **Contrast** (for the LV) and **Outside**.



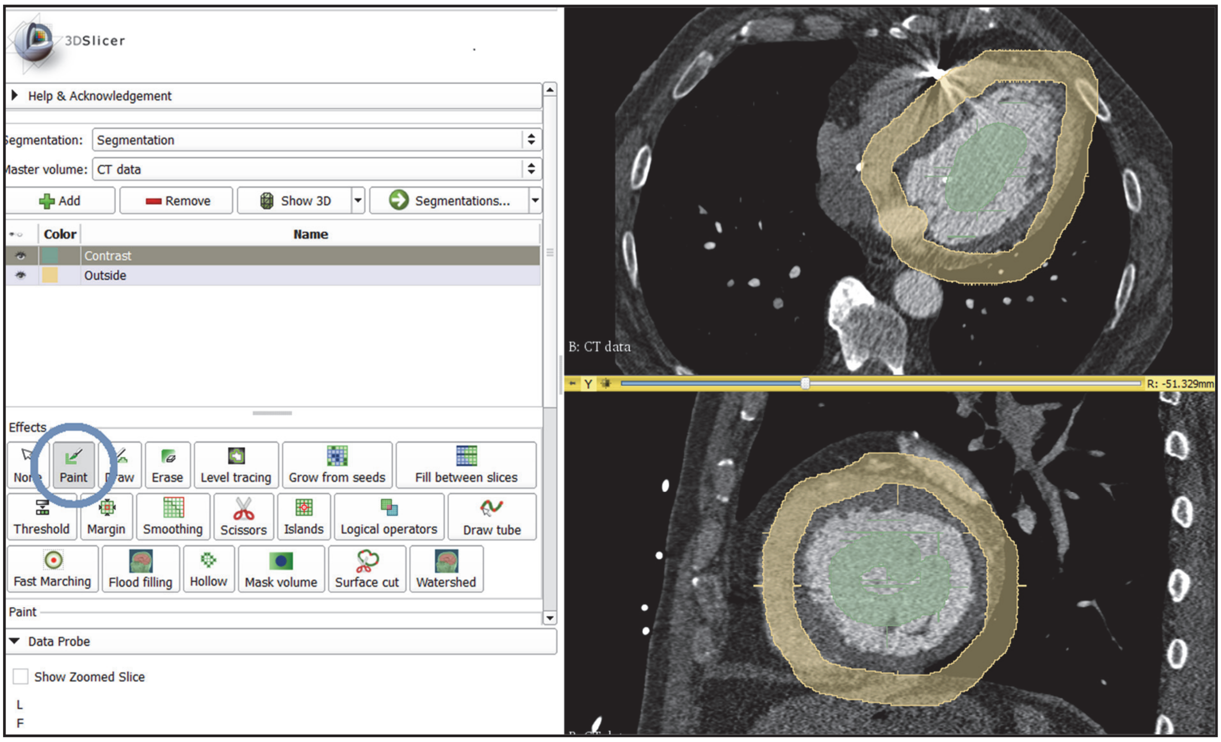
c. For **Contrast** segment, mark several points inside the left ventricle using the **Paint** effect.

d. Mark some points within LV in all planes (transversal, coronal, sagittal).

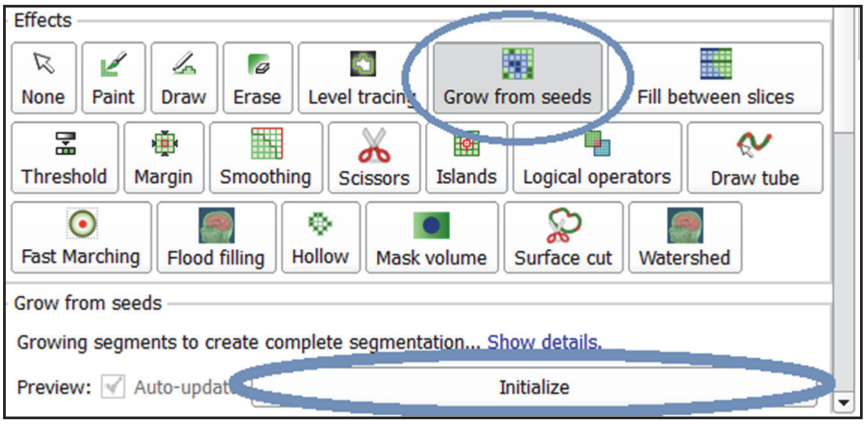
e. For **Outside** segment, mark several points that will clearly indicate what is outside the LV.

f. All of these marked areas will serve as "SEEDS" for the "**grow from seeds**" algorithm.

Tips: mark border between atrium and ventricle; border between aorta and LV; carefully check areas with artifacts and electrodes.



g. Select **Grow from seeds** in the Segmentation Module and Initialize. This process takes a few seconds or minutes (based on your PC performance).

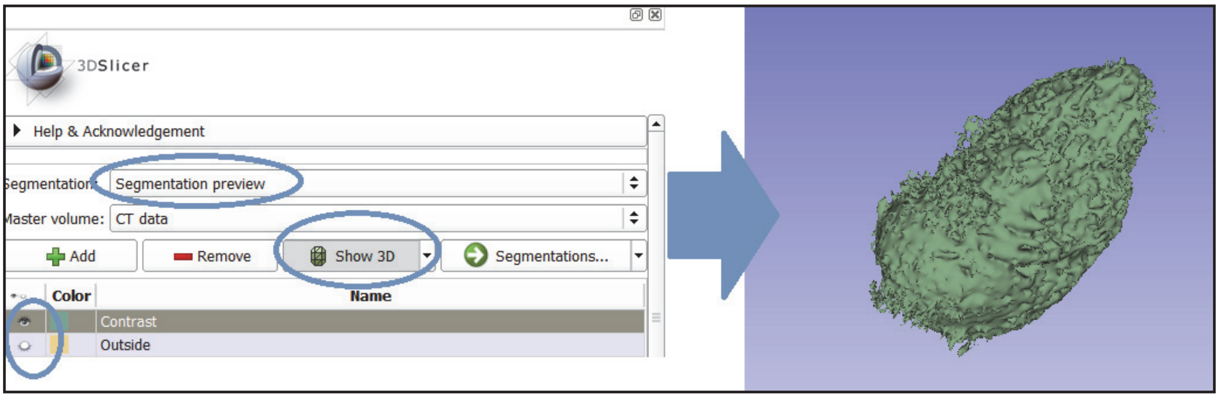


h. Select **Segmentation** as **Segmentation preview**.

i. Choose **Master Volume** as your CT data.

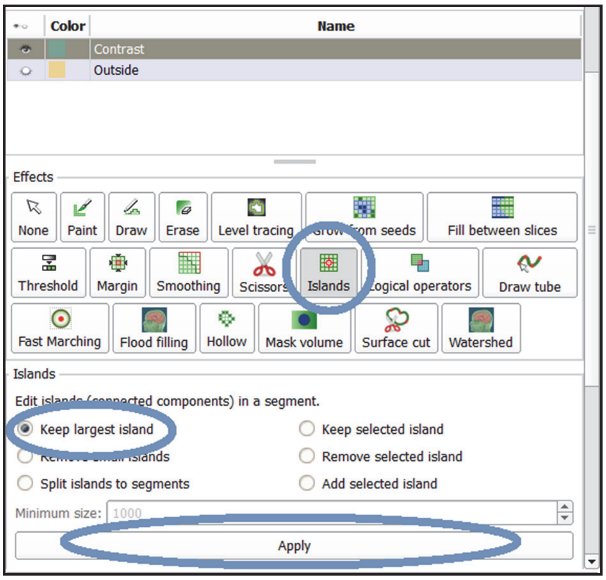
j. Select "Show 3D" and UNcheck "Outside" segment (the eye symbol) – now you can see your segmented LV in all planes and 3D.

*Note: In this step, it is useful to check segmentation in all slices and, if needed, perform manual fine adjustments with the **Paint** or **Erase** tools under the **Effects** tab.*



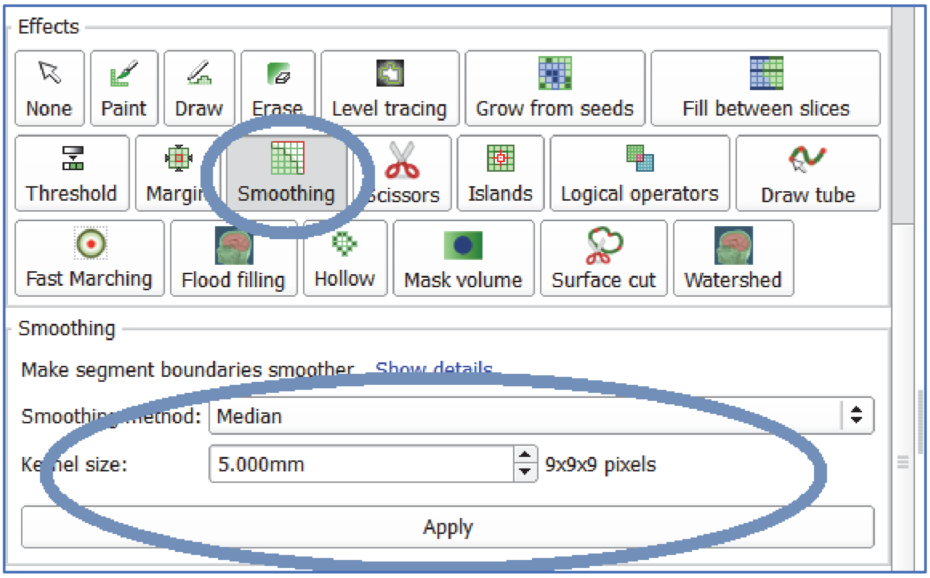
3) Smoothing of the segmented LV with median filter

a. Still in **Segmentation Preview**, select the **Islands** effect, and under the **Islands** tab choose **Keep the largest island** and select **Apply** (this step removes small connected components created during the "Grow from seeds" step).



b. Select the **Smoothing** effect.

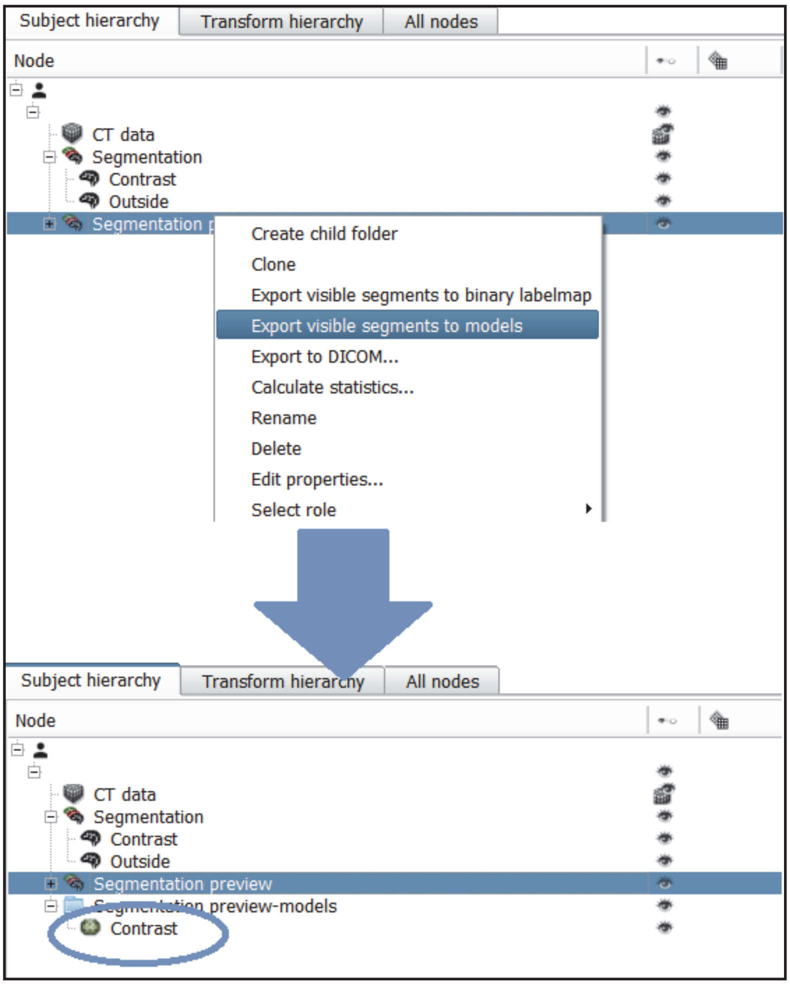
c. **Smoothing method**: Median; **Kernel Size**: 5 mm (more details about the filter are at the end of this Supplement).



Now, you have completed segmentation of the LV.

d. Choose the **Data** module from the drop-down menu.

e. Select **Segmentation preview**, press the right mouse button, and select **Export visible segments to models**. The segmented LV will change to a model.



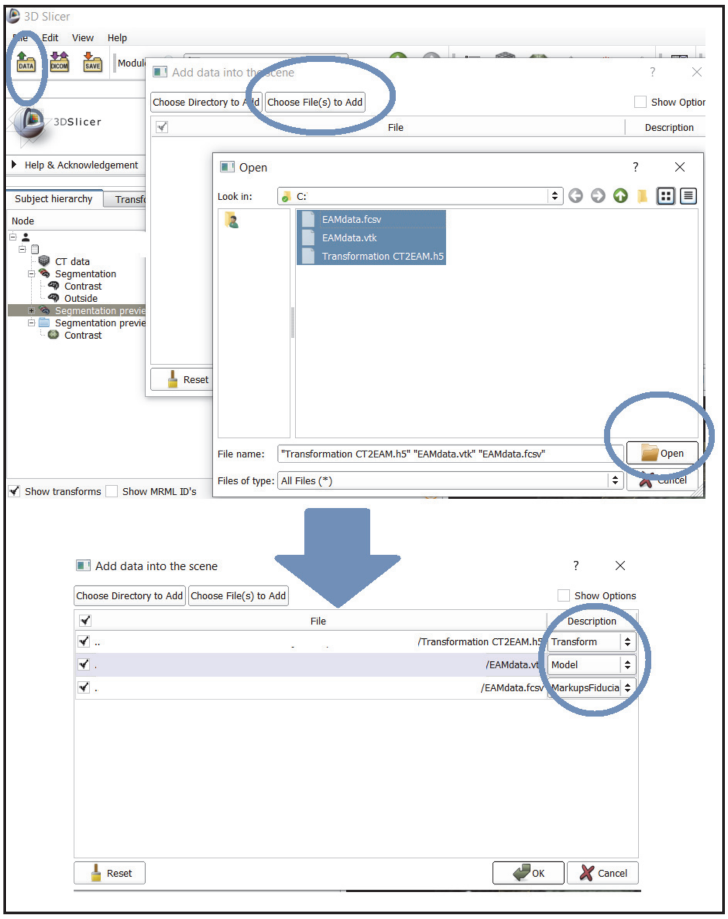
4) **Uploading EAM data (left ventricle = EAM LV, points with specific tag for GTV delineation)**

a. For next steps, it is necessary to load additional data:

- File with transformation for correction of coordinate systems (this file, *CT2EAM_transformation*, is part of this Supplement)
- EAM data – map of the LV and specific points indicating the target area (***EAMmodel, EAMpoints*** in these instructions)

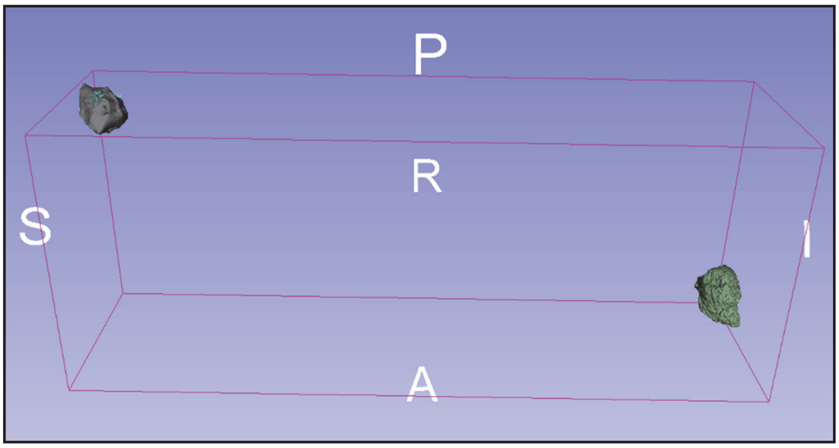
Note: EAM data in this work were exported from CARTO software (CARTO® 3 system (Biosense Webster, Diamond Bar, CA, US) and converted to a format compatible with 3D Slicer software (open source,) using an in-house program written in C# (we can share this code upon request).

b. For data import, select **Data** in the top left corner of the screen, select **Choose File(s) to Add**, and choose your folder with data, or simply drag and drop these files from the specific folder to 3D Slicer. Another window will appear with a description of files being loaded – Transform, Model, MarkupsFiducial (3D Slicer usually recognizes the correct type).



5) Applying transformation for correction of coordinate systems between EAM data and CT

After loading of EAM data into 3D Slicer, you can see in the 3D view the different positions and orientations of the segmented LV and EAM data (model and points). The correction transformation will unify different orientations (90° rotation in SI direction and 180° rotation in AP direction).



5.1.) 3D Slicer version > 4.10

a. Select EAMmodel in the **Data** module, press the right mouse button, and choose the relevant **Transformation**. A symbol of applied transformation (grid) will appear on the right in the **Data** module.

b. Again, press the right mouse button and choose **Harden Transform** to permanently fix transformation.

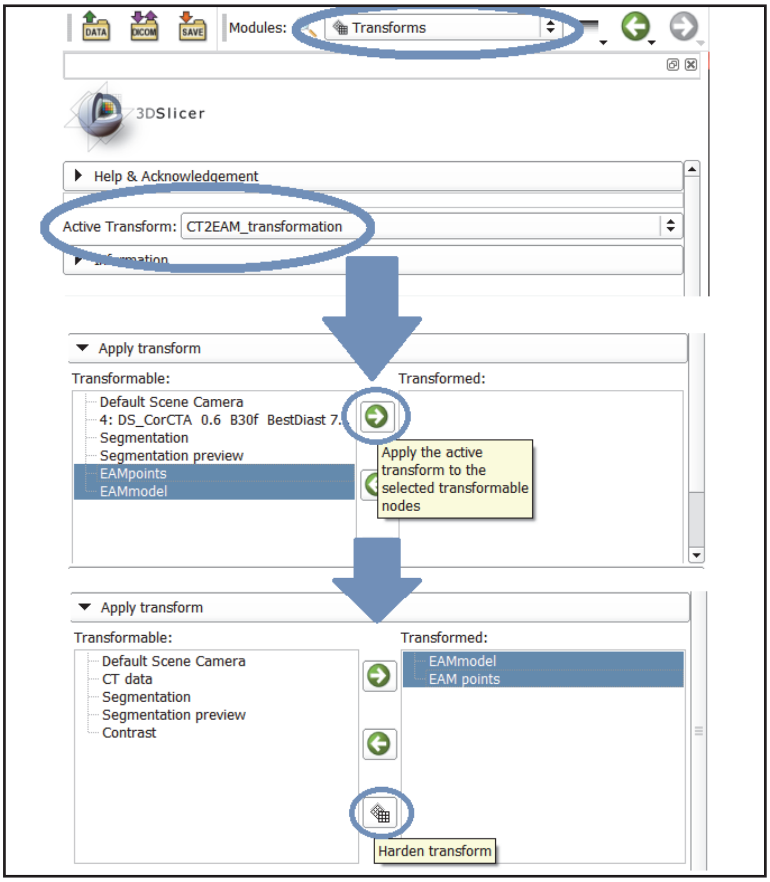
c. Repeat the same steps for EAMpoints.

5.2.) 3D Slicer version < 4.10

a. Choose the **Transforms** module from the drop-down menu and select the relevant transformation as **Active Transform**.

b. At the bottom of this module, select EAMmodel and EAMpoints and apply the active transform to the selected transformable node by clicking on the **arrow icon**.

c. With EAMmodel selected in the **Transformed** window, harden the transform by clicking on the **transform icon** (EAMmodel and EAM points will be back in the Transformable window with the new orientation).

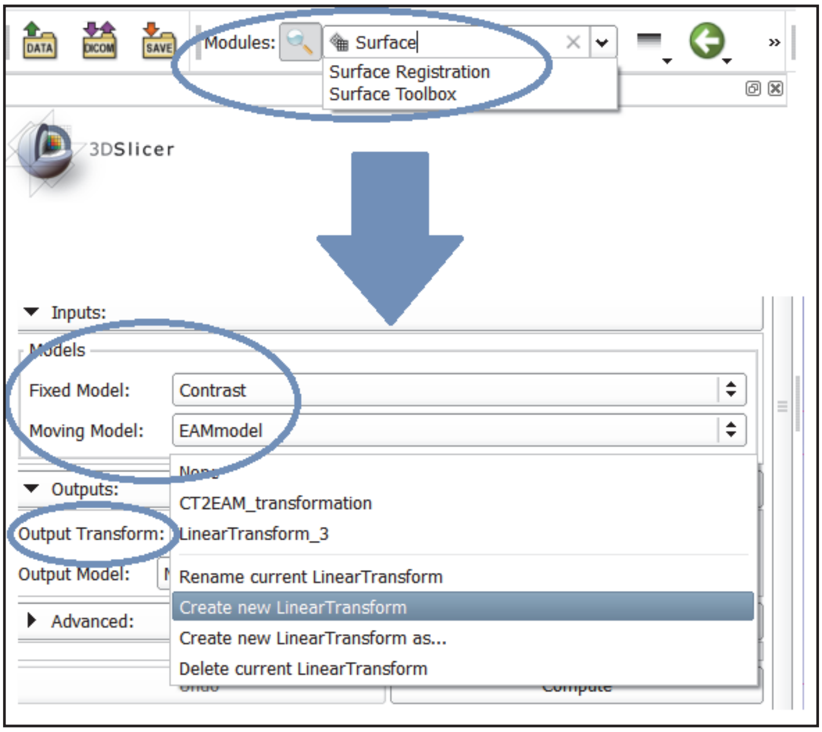


6) Automatic surface registration of EAM LV and CT LV

a. Choose the **Surface Registration** module from the drop-down menu (or search "module" with the magnifying glass symbol).

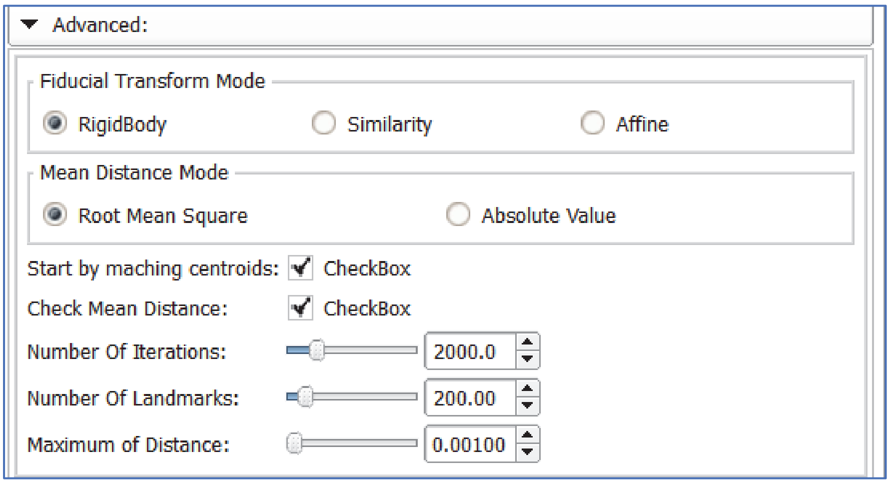
b. **Inputs tab**: select the model of segmented LV as the **Fixed Model** and EAMmodel as the **Moving Model**.

c. **Outputs tab**: select **Create new linear transform** as the **Output Transform** (you can rename the new transform).

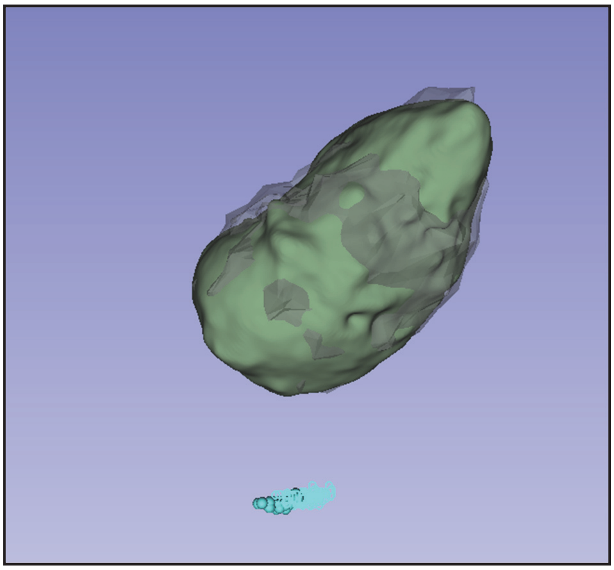


d. Advanced tab:

- **Fiducial Transform Mode:** Rigid Body
- **Mean Distance Mode**: Root Mean Square
- Check the **Start by matching centroids** checkbox.
- Check the **Check Mean Distance** checkbox.
- Select **Compute**.



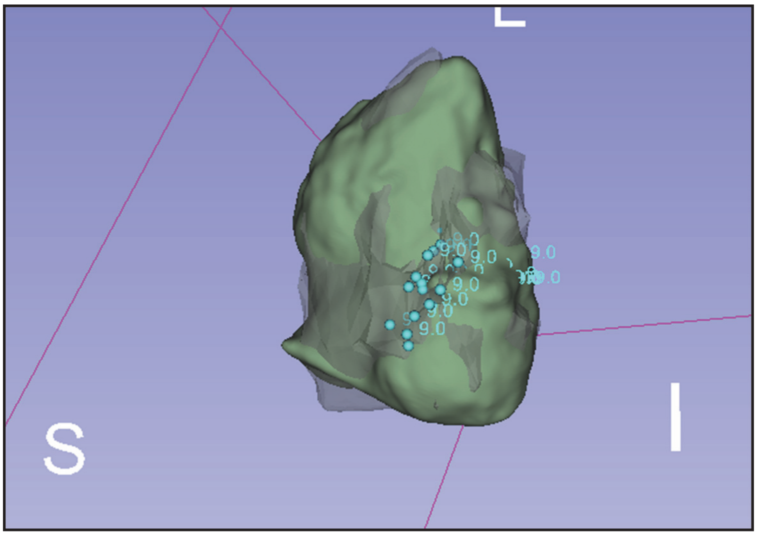
After successful computation, you will see the EAMmodel and LV model overlapping each other (EAMpoints are not affected and will be still away).



7) Applying transformation from the previous step on EAM points representing GTV

It is necessary to harden the new transform applied on the EAMmodel and also apply and harden this transform on EAMpoints.

a. Based on the 3D Slicer version, follow the same steps as mentioned in Step 5 with the transformation created in Step 6c.
b. After this step, EAMpoints, EAMmodel, and the segmented model of LV will be merged.



8) Creation of solid structure (GTV) from EAM points with specific tags

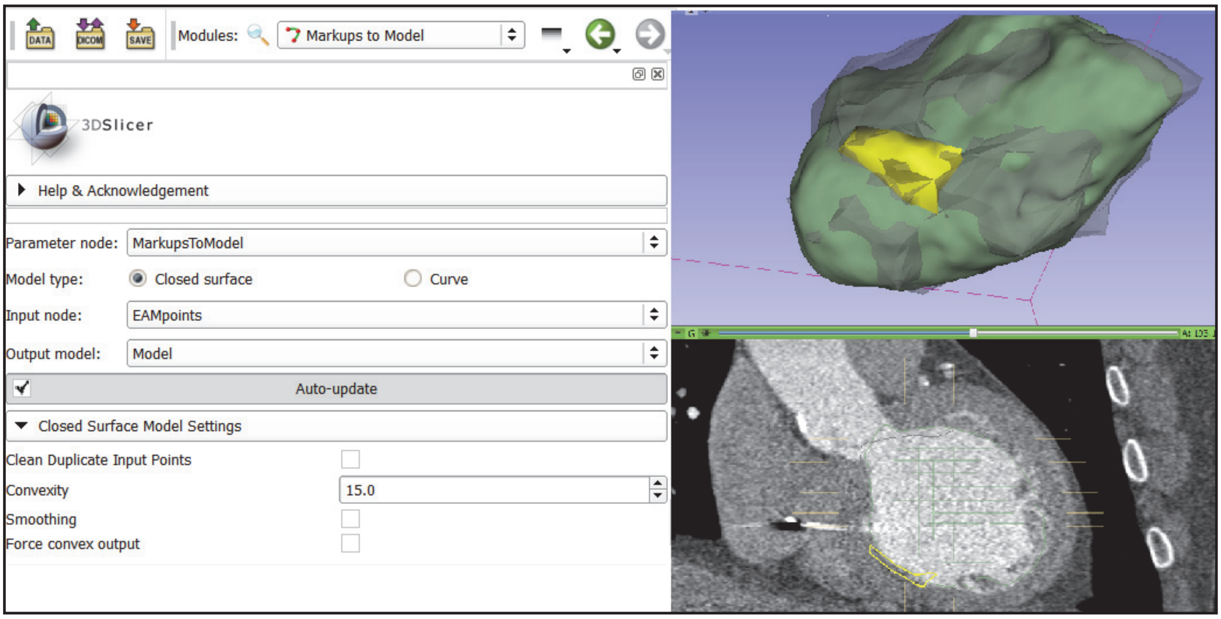
a. Choose **Markups to Model** module from the drop-down menu (or search "module" with the magnifying glass symbol).
b. **Model type**: Closed Surface.

c. Select EAMpoints as **Input node**.

d. Output model: choose **Create new model**.

e. Closed Surface Model tab: Uncheck **Clean Duplicate Input Points**, **Smoothing**, and **Force convex output**.

f. Set **Convexity** to 5–20. If the value is 0, then a convex shape is created. The larger the value, the more convex the generated surface is. Our experience shows that the chosen value depends on the spacing and number of points forming the model. Choose a value that makes the resulting model match your idea.

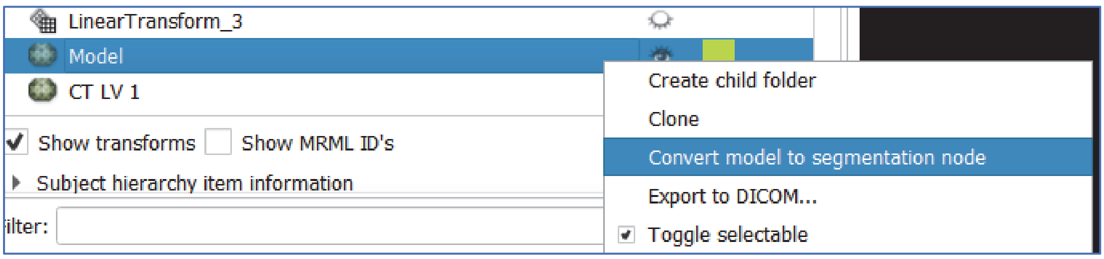


9) Masking the created model onto the CT image series as high-density pixels

The model created in Step 8 is must be converted to segmentation before masking.

9.1.) 3D Slicer version > 4.10

Select the model from step 8 in **Data** module, press the right mouse button, and choose **Convert model to segmentation node.**



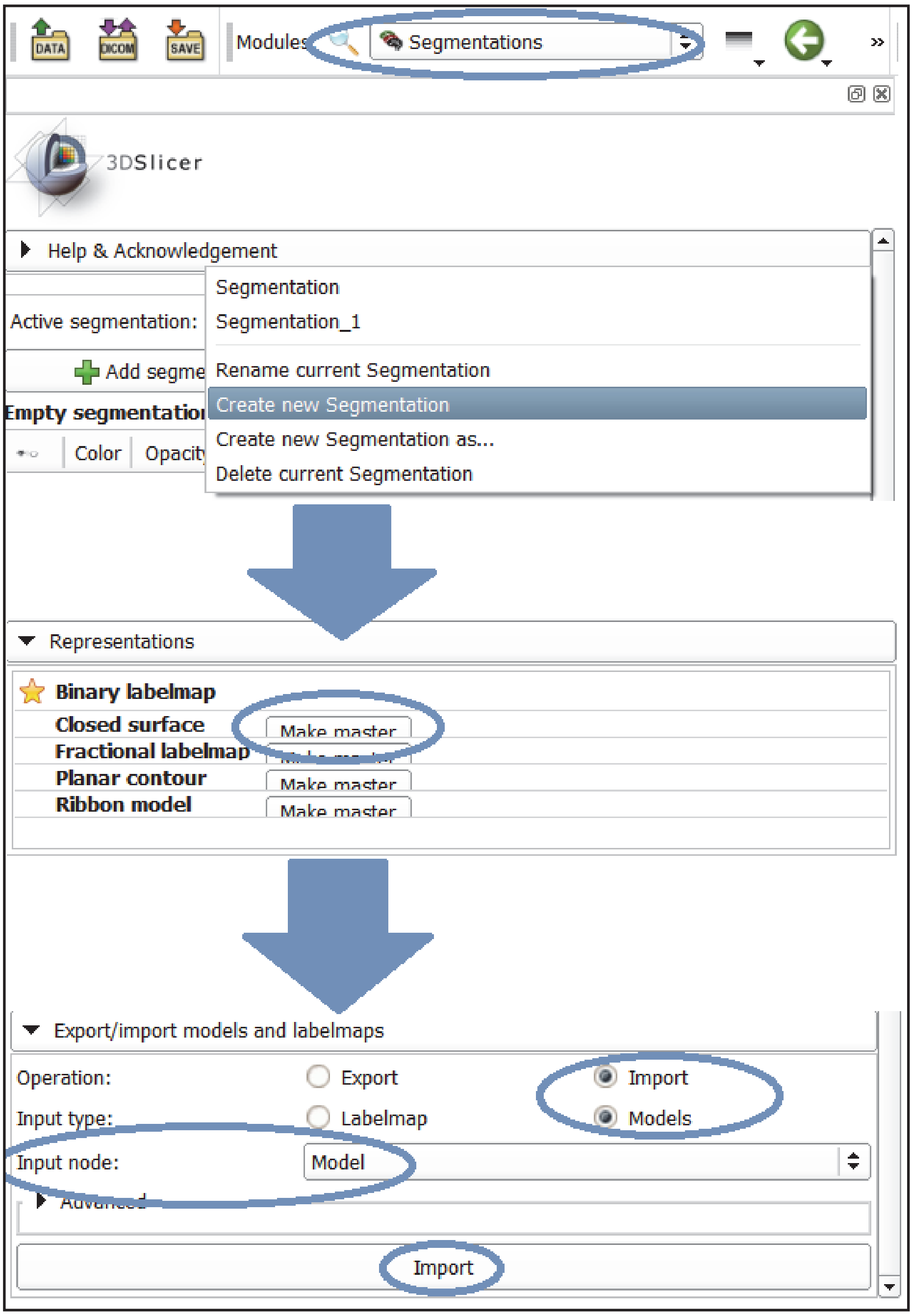
9.2.) 3D Slicer version < 4.10

a. Select the **Segmentations** module from the drop-down menu and **Create new Segmentation** under Active segmentation.

b. **Representations** tab: set **Make Master** for **Closed Surface**.

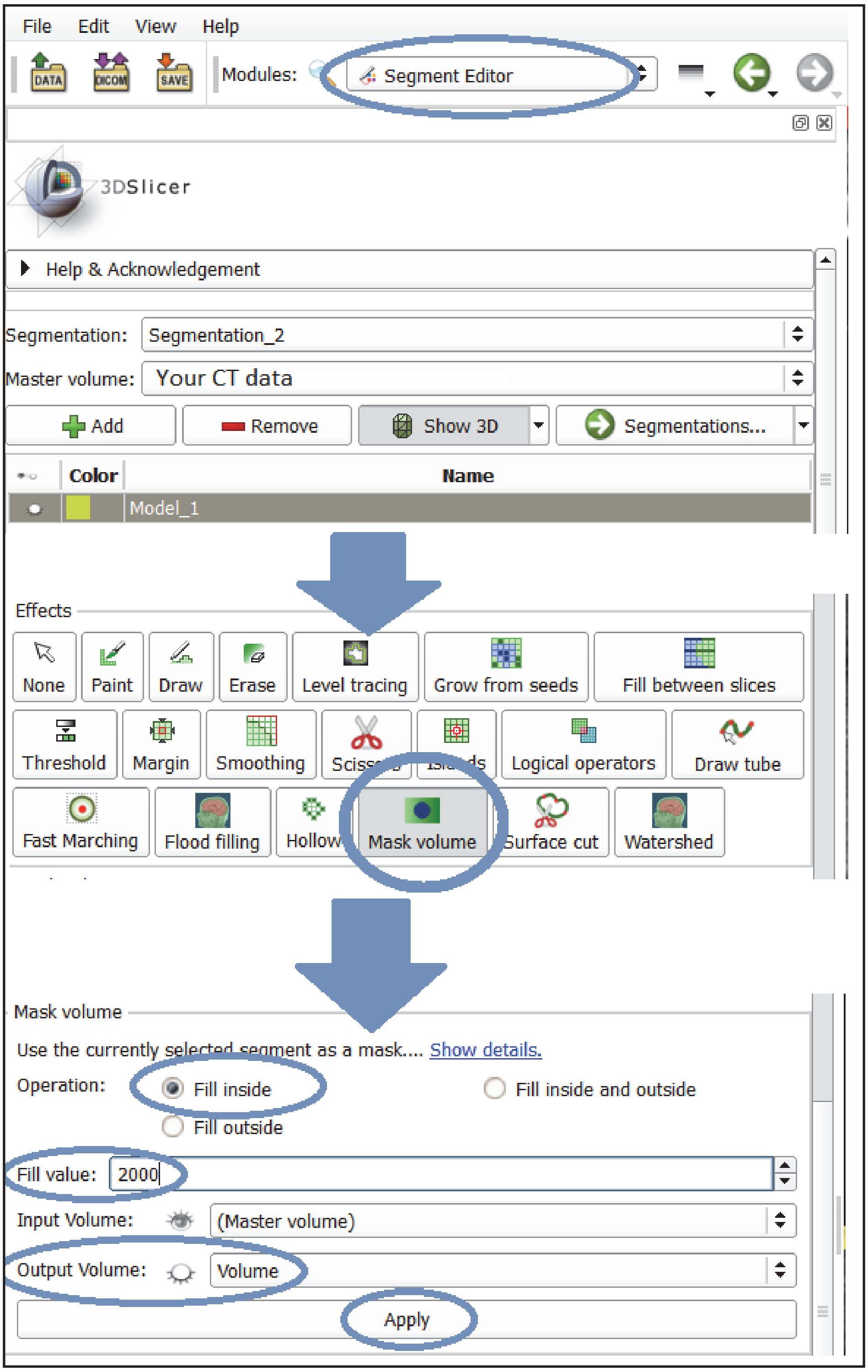
c. **Export/Import models and labelmaps** tab: Operation - **Import**, Input type - **Models**.

d. Choose the model created in step 8 as **Input node** and do **Import**.



e. After converting the final model of the target, select **Segment editor** from the drop-down menu.

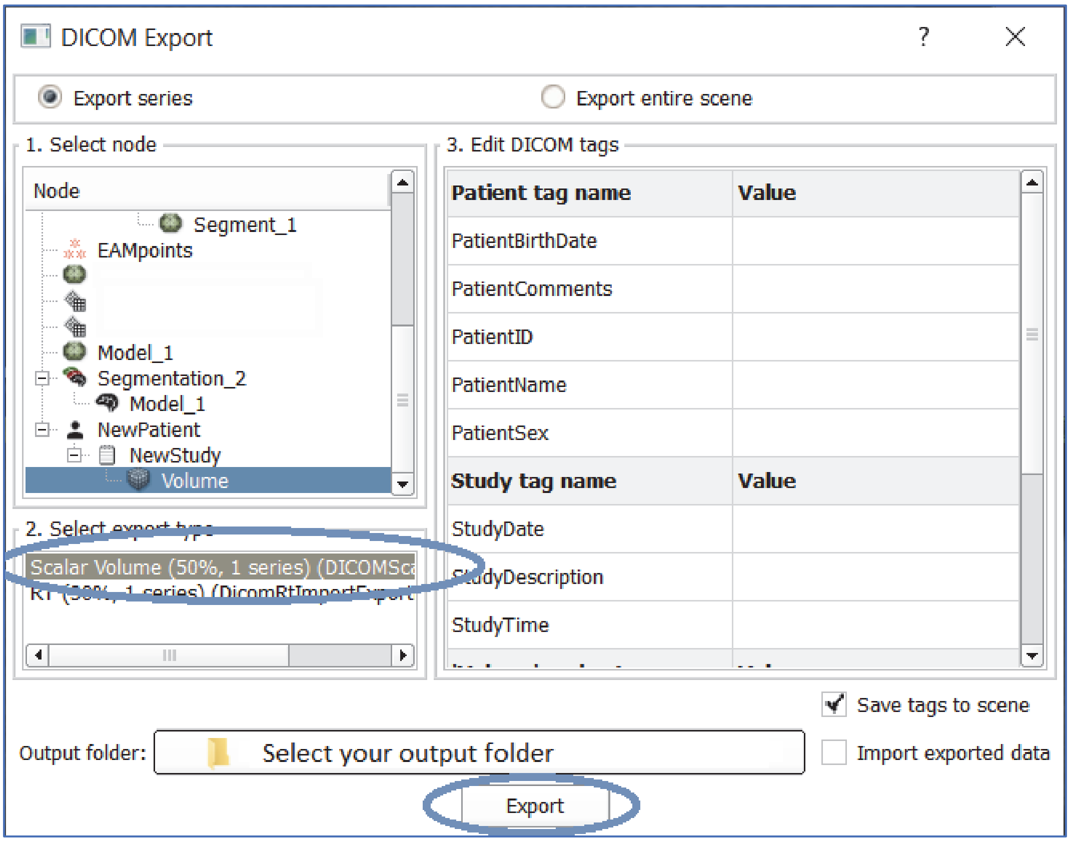
f. As **Segmentation**, choose Segmentation, which contains the target segment.
g. Select your CT data as **Master volume**.
h. **Effects** tab: choose **Mask Volume** (confirm change of representation to binary labelmap).
i. **Mask Volume** tab:
   - **Operation**: Fill inside
   - **Fill value**: 2000 (number defines the pixel intensity; we prefer high intensity propagating in high HU in CT image).
   - **Output Volume:** create new Volume
j. **Apply**.



10) Exporting CT from 3D Slicer software and uploading to the planning system

a. Select the **Data** module in the drop-down menu. Your volume with masked structure should be at the bottom.

b. Click the right mouse button and choose **Export to DICOM**.



Note: Import to planning system is based on the software you use. We noted that some systems encounter a problem with "Unknown" Scanner Manufacturer and Scanner Model (this is how 3D Slicer exports). In this case, you need to modify specific DICOM tags before importing (tag 00080070 and 00081090).

Additional information for the smoothing method from step 3:

In 3D modeling, median, opening, and closing filters are types of filters that can be used to smooth or modify the surface of a 3D model.

A median filter in 3D modeling can be used to smooth the surface of a 3D model by replacing the value of each vertex with the median value of the vertices in a surrounding window. This step can be useful for removing noise or small details that are not important for the final model.

An opening filter in 3D modeling can be used to remove small features or separate connected components in a 3D model. This step is achieved by eroding the edges of the objects in the model and then dilating the model to restore the original size of the objects. Opening filters are often used as a preprocessing step before applying other image processing techniques, such as thresholding or edge detection.

A closing filter in 3D modeling is the opposite of an opening filter. It works by dilating the edges of the objects in the model and then eroding the model to restore the original size of the objects. Closing filters are often used to fill in small holes or gaps in a model, or to smooth out rough edges.

In summary, a median filter is used to smooth the surface of a 3D model, an opening filter is used to remove small features or separate connected components, and a closing filter is used to fill in small holes or smooth out rough edges.

We tested different filters and combinations of parameters in 3D Slicer to maximize the robustness of the proposed method and reproducibility (minimalize intra/interobserver variability), which resulted in use of median 5-mm filter.

Demonstration of the effect of different filtering on the segmentation: