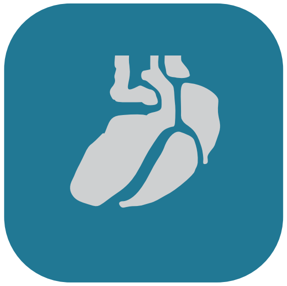
LEFT VENTRICLE
SEGMENTATION AND MEASUREMENT

Using Analyze



AnalyzeDirect

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Introduction

Some of the most important values associated with cardiac function can be obtained by measuring left ventricular volume at end-systole and end-diastole. Gated contrast-enhanced micro CT can be used to obtain high-contrast images of the cardiac blood pool at these times points in small animals. The left ventricular blood pool can be segmented at each time point and the volume measured.

The most common measurements and calculated values derived from this method are as follows:

- End-diastolic volume (EDV) is measured directly from the segmentation.
- End-systolic volume (ESV) is measured directly from the segmentation.
- Stoke volume (SV) is the volume of blood ejected from the left ventricle in each beat of the heart and is related to cardiac output.

$$SV = EDV - ESV$$

- Ejection fraction (EF) is a measure of contractile function of the left ventricle.

$$EF(\%) = \frac{SV}{EDV} * 100$$

- Cardiac output (CO) is a measure of the volumetric rate of circulation of blood throughout the body and requires the heart rate (HR) to be measured.

$$CO = HR * SV$$

Two recent studies have used Analyze to segment and measure the left ventricle in animal models.

Hermann *et al.*[1] segmented the left ventricle of pigs in order to calculate EF, SV, and LV mass from electron beam CT images to determine the effects of a proteasome inhibitor on cardiac structure and function.

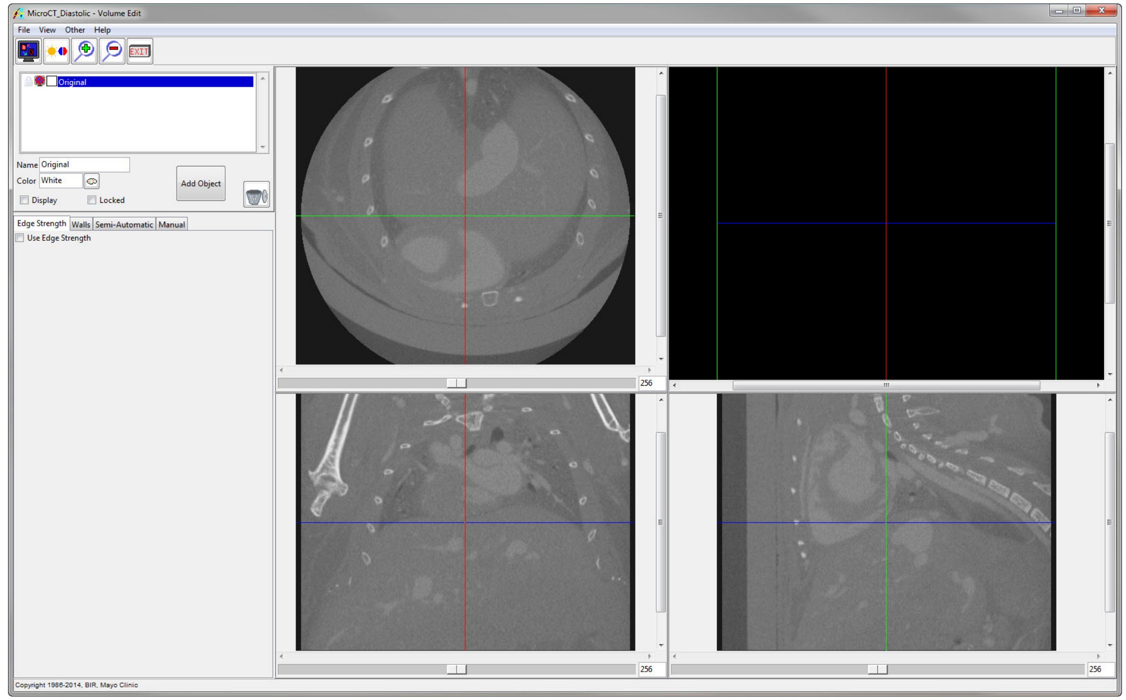
Richards *et al.*[2] segmented the left ventricle of mice in order to measure ESV, EDV, and LV volume and to calculate LV mass, SV, EF, and CO to determine the effect of different heart failure conditions on exercise intolerance.

Segmentation Instructions

Acquire a contrast-enhanced cardiac gated micro CT scan.

Load the end-systole and end-diastole time points into Analyze.

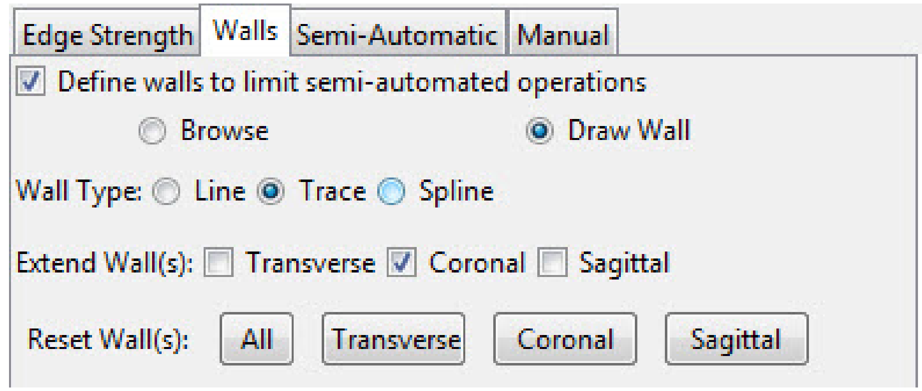
With the end-diastole dataset selected in the Analyze workspace, open the Volume Edit module (**Segment > Volume Edit**).

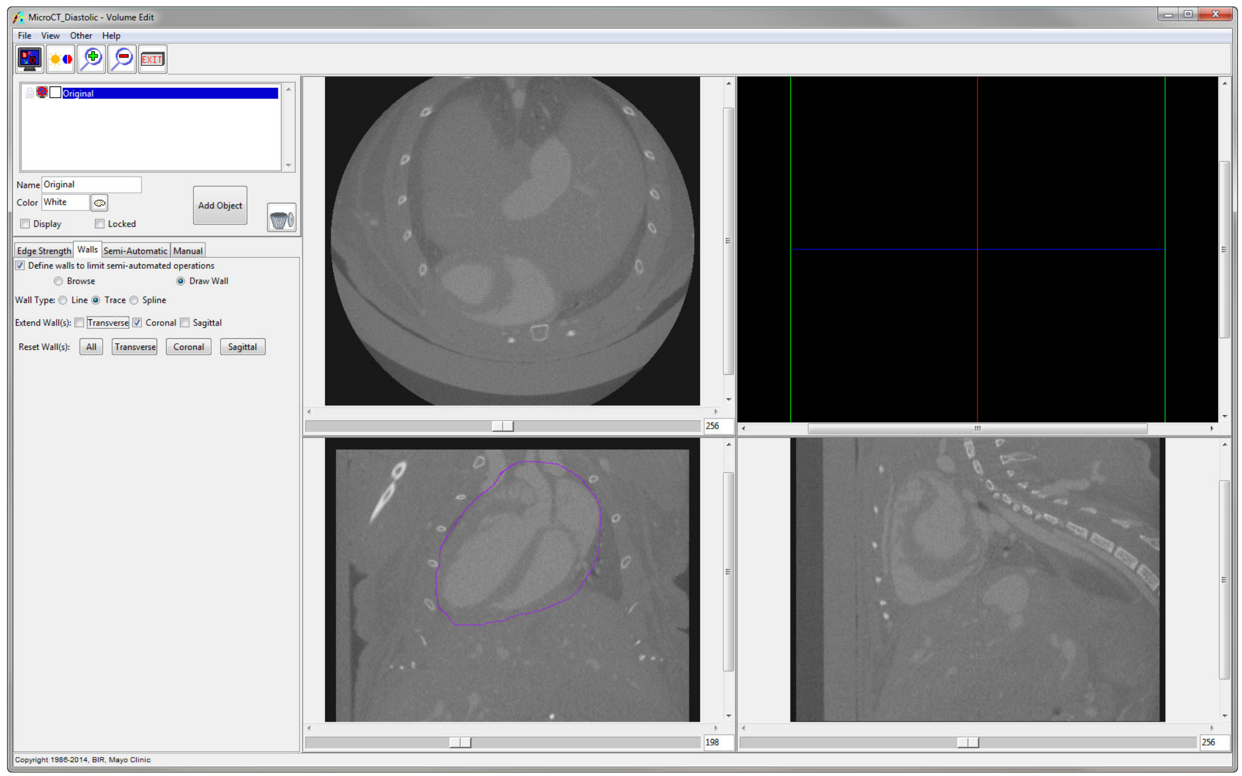


Select the **Walls** tab and check Define walls to limit semi-automated operations.

Select the **Draw Wall** radio button, and deselect the Transverse and Sagittal checkboxes so that only the Coronal checkbox is checked.

Navigate to a coronal slice showing the entire heart. Trace a wall around the heart.

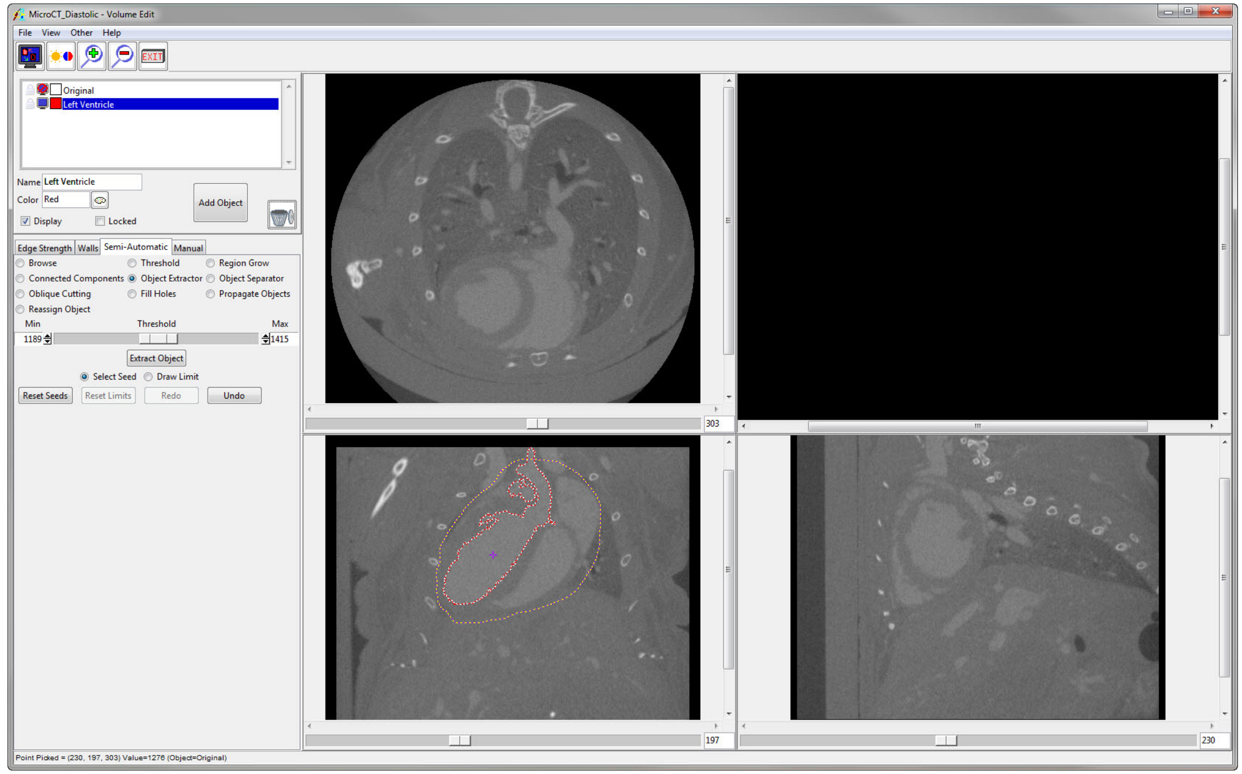




Click the **Add Object** button, and then name the new object Left Ventricle. Under the Semi-Automatic tab, select the **Object Extractor** radio button. Set a seed point by clicking in the left ventricle.

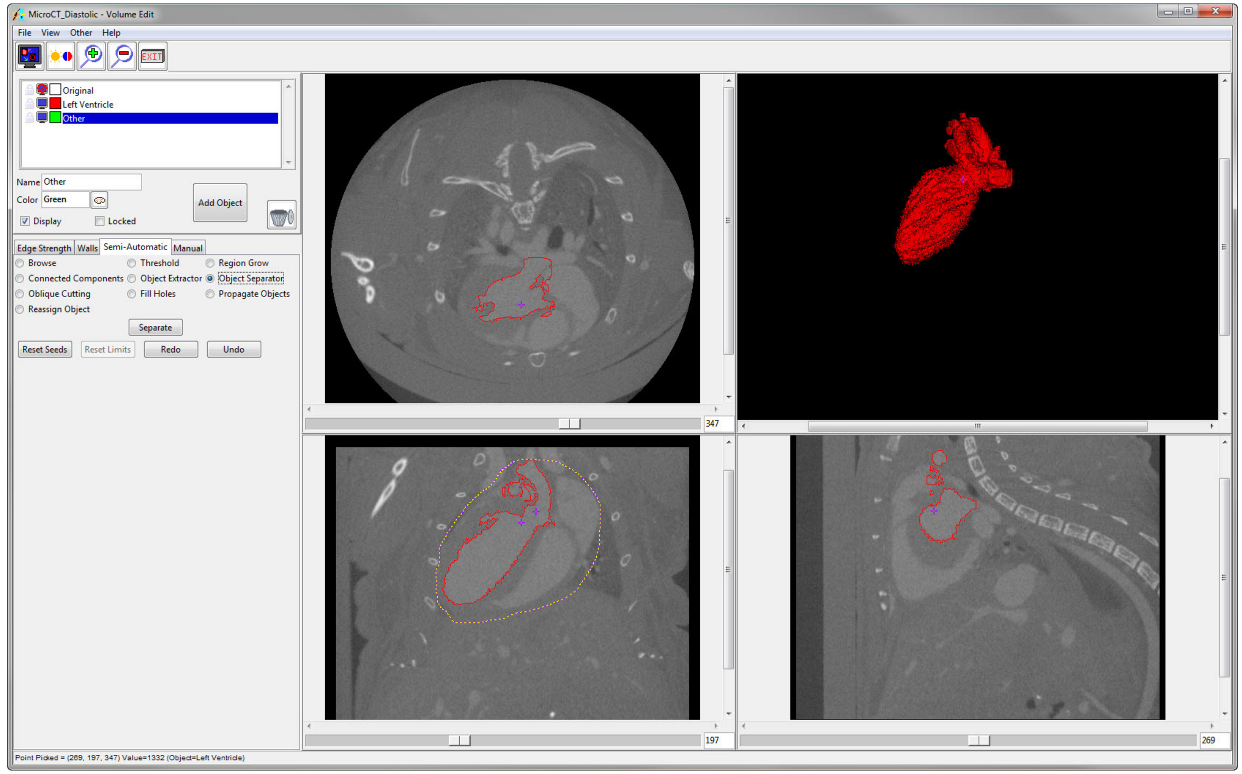
Note: In the dataset shown, the animal is lying prone, so the left ventricle is on the opposite side from where it would appear in a normal human CT scan.

Choose an appropriate threshold range that defines the left ventricle, and then click Extract Object.



Other regions were extracted along with the left ventricle. We are only interested in segmenting the left ventricle, so we will define a separate object to isolate these extra regions.

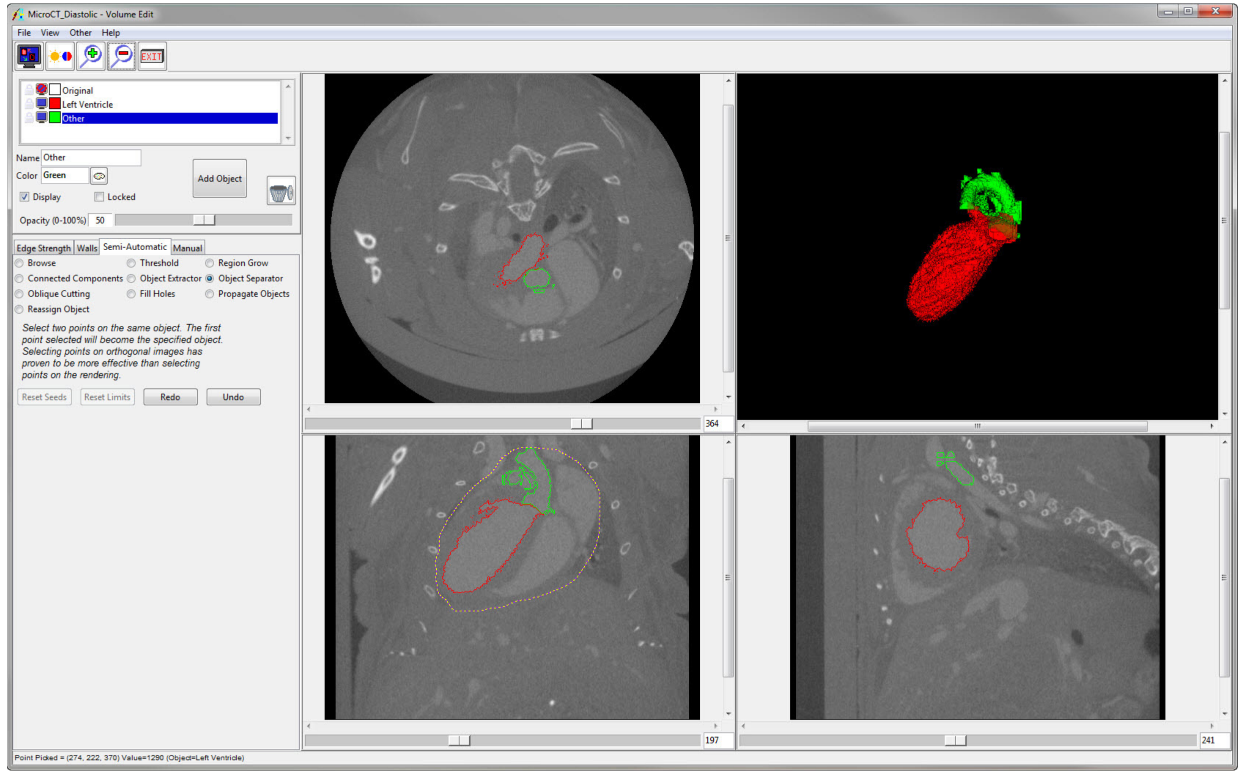
Click **Add Object** and name the new object Other.



With the Other object selected, choose the **Object Separator** option, then click first in the aorta (or another space in the Left Ventricle object not belonging to the left ventricle) and second in the left ventricle.

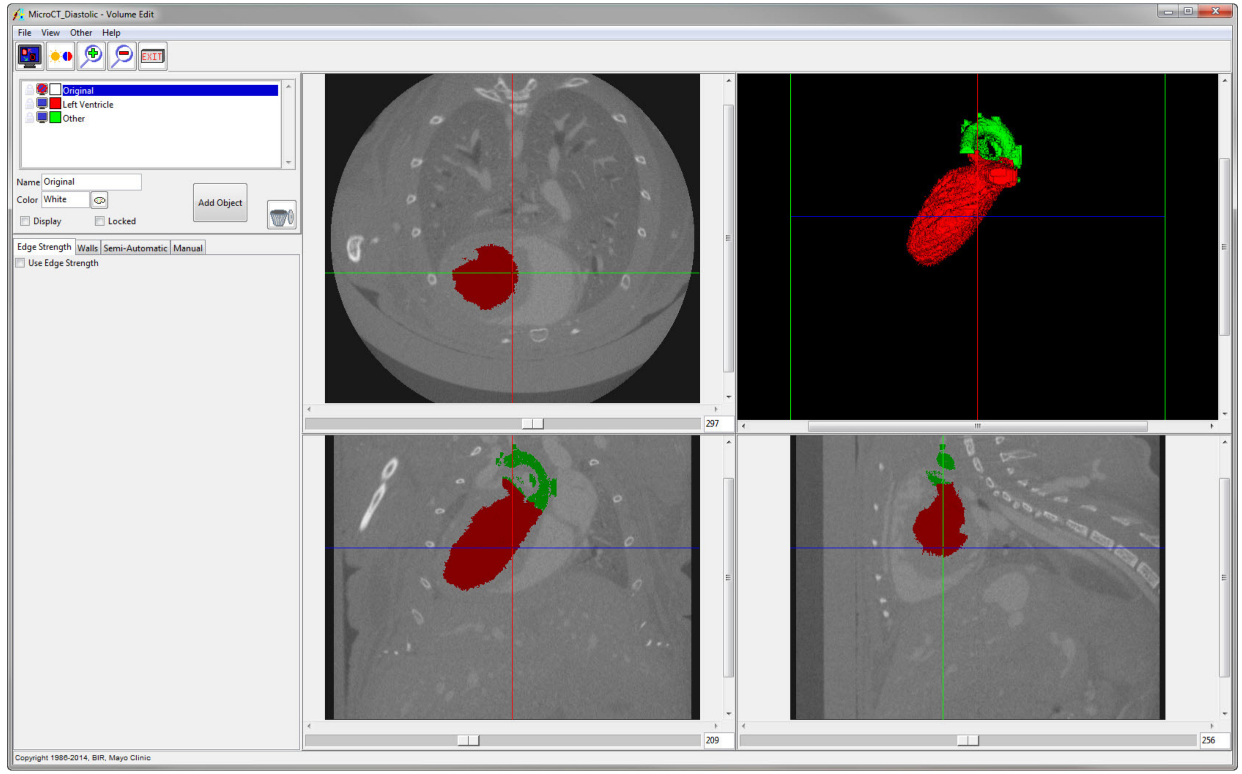
Click **Separate**. If the separation did not work correctly, click Undo and try selecting different seed points.

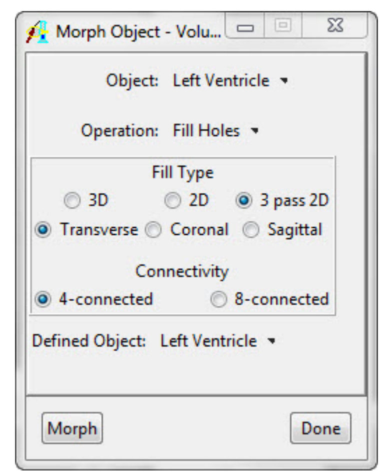
Alternatively, use Object Separator iteratively until the two regions are correctly defined, or use manual tools to edit the objects.



To improve the segmentation result, we will perform the Fill Holes operation. Navigate to **View > Objects**.

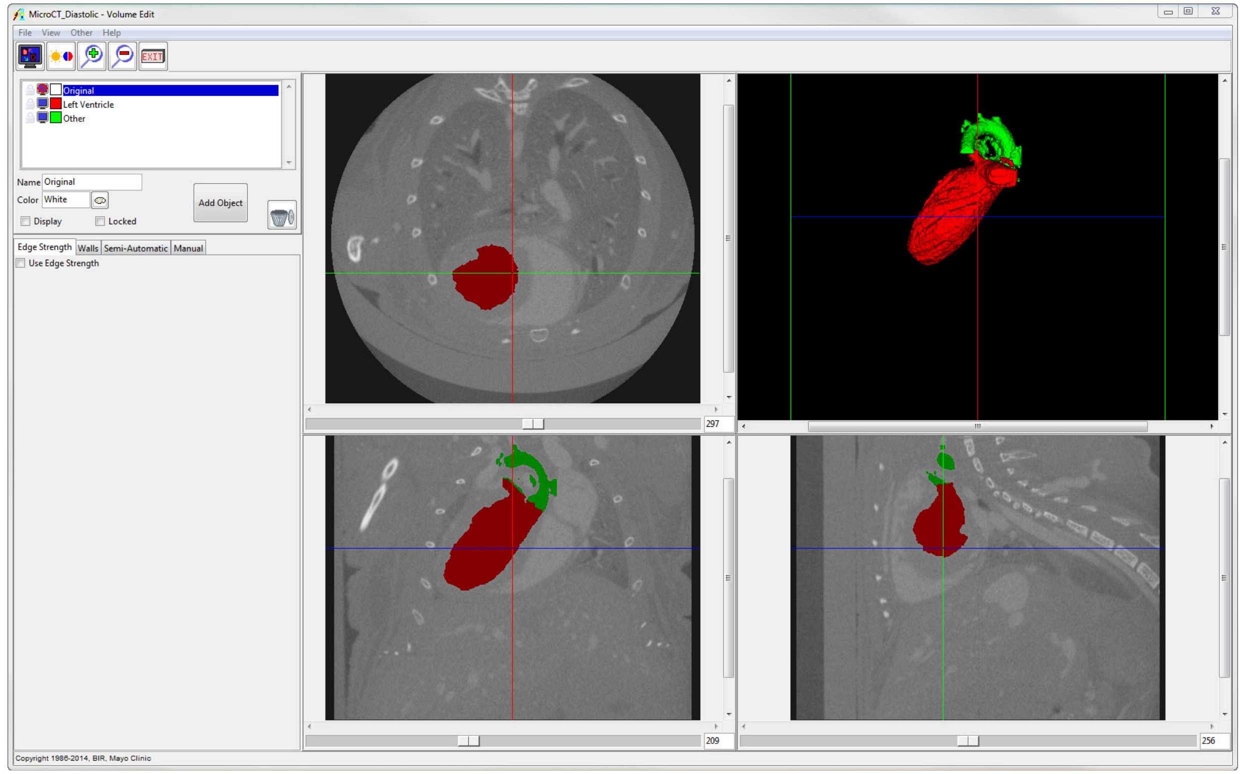
- In the Object window, click the **Morph Object** button in the bottom right
- Set Object to **Left Ventricle**, Operation to **Fill Holes**
- Fill Type to **3 pass 2D** and **Transverse**
- Connectivity to **4-connected**
- Defined Object to **Left Ventricle**
- Click the **Morph** button to perform the operation
- When prompted, click **Fill Holes**





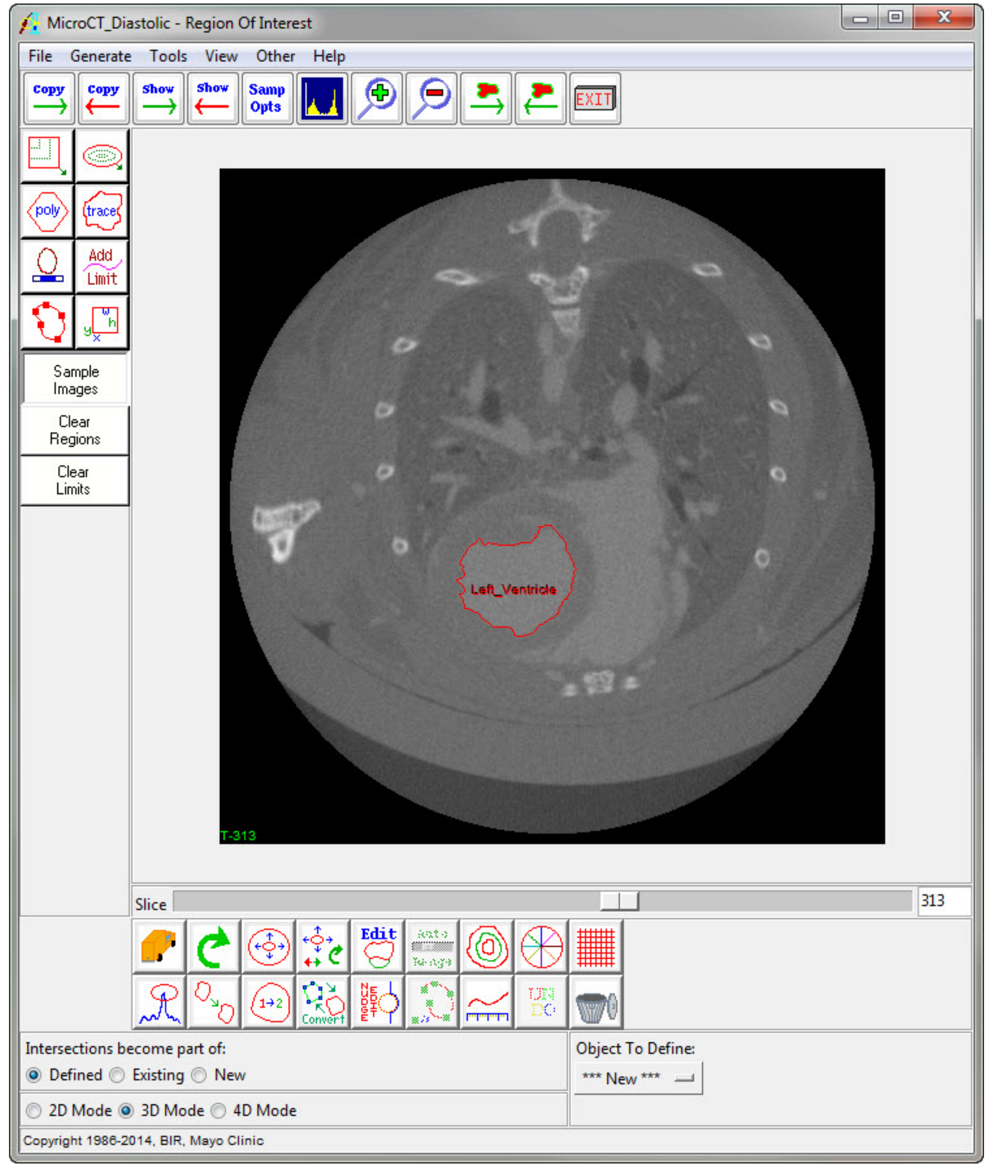
In this data set, the boundaries of the Left Ventricle object are somewhat noisy. We will filter the objects in order to improve the segmentation result even further.

- In the Objects window (**View > Objects**), click the **Filter Objects** button in the bottom right
- Leave Operation as **Median** and **Filter Size** as **3 x 3 x 3**
- Click **Filter**
- Save the object map by going to **File > Save Object Map** and choosing a directory
- Repeat segmentation steps for the end-systolic data and save the end-systolic object map



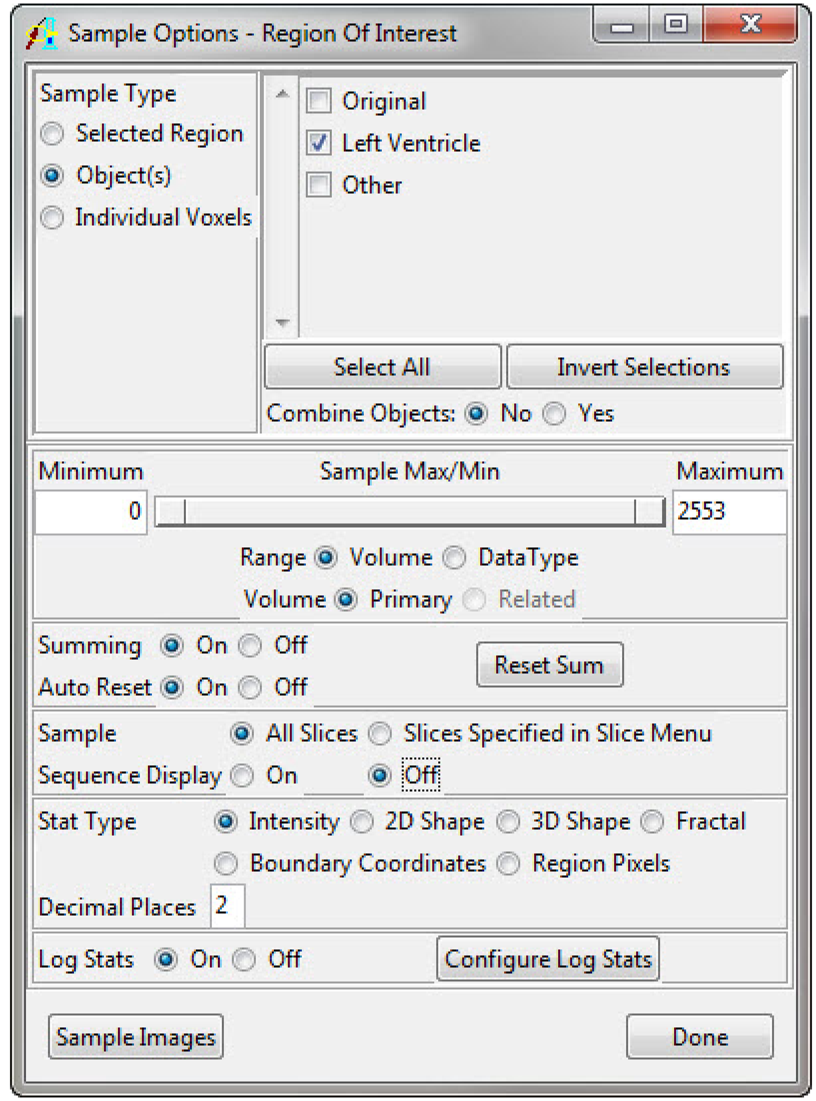
Measurement Instructions

Select the end-diastolic data in the Analyze workspace and open the ROI module (**Measure > Region of Interest**). Load the object map by navigating to **File > Load Object Map**.

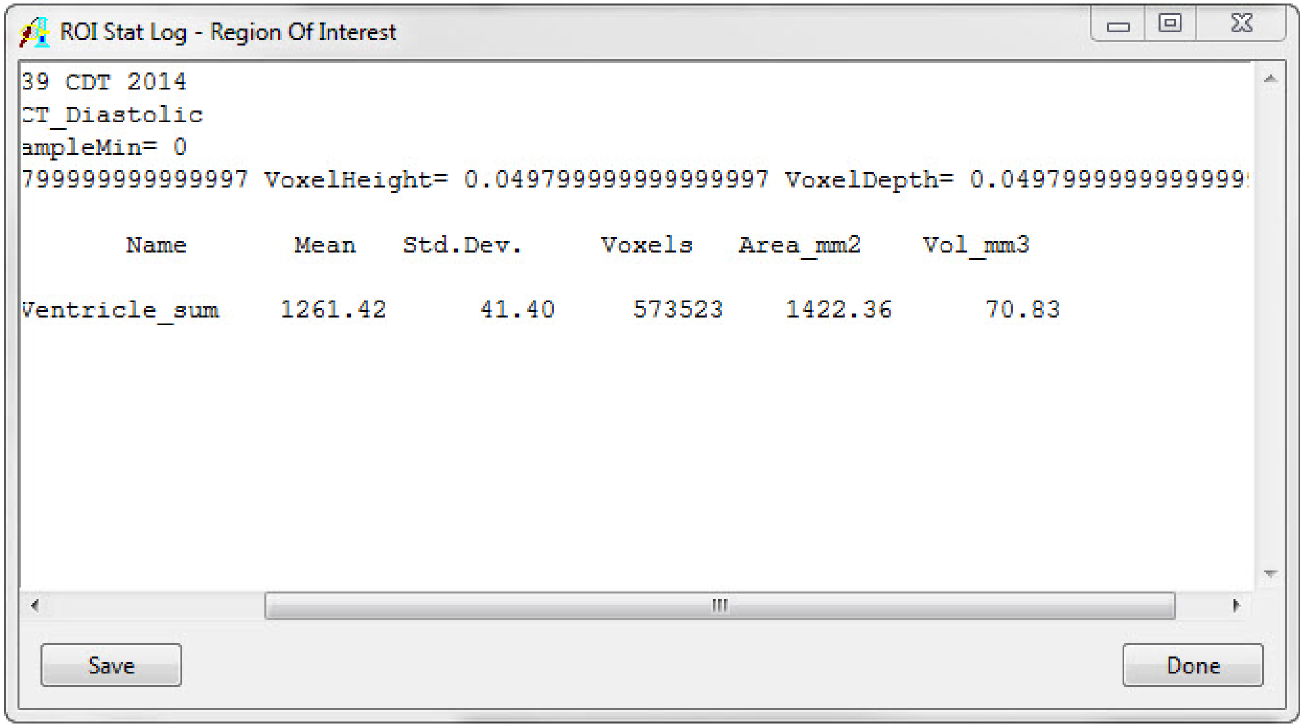


Open the Sample Options window (**Generate > Sample Options**). In the Sample Options window, set the following parameters:

- **Sample Type** to **Object(s)**
- Select **only** the left Ventricle Object
- Set **Summing** to **On**
- **Auto Reset** to **On**
- **Sample** to **All Slices**
- **Sequence Display** to **Off**
- **Stat type** to **Intensity**
- **Set Log Stats** to **On**



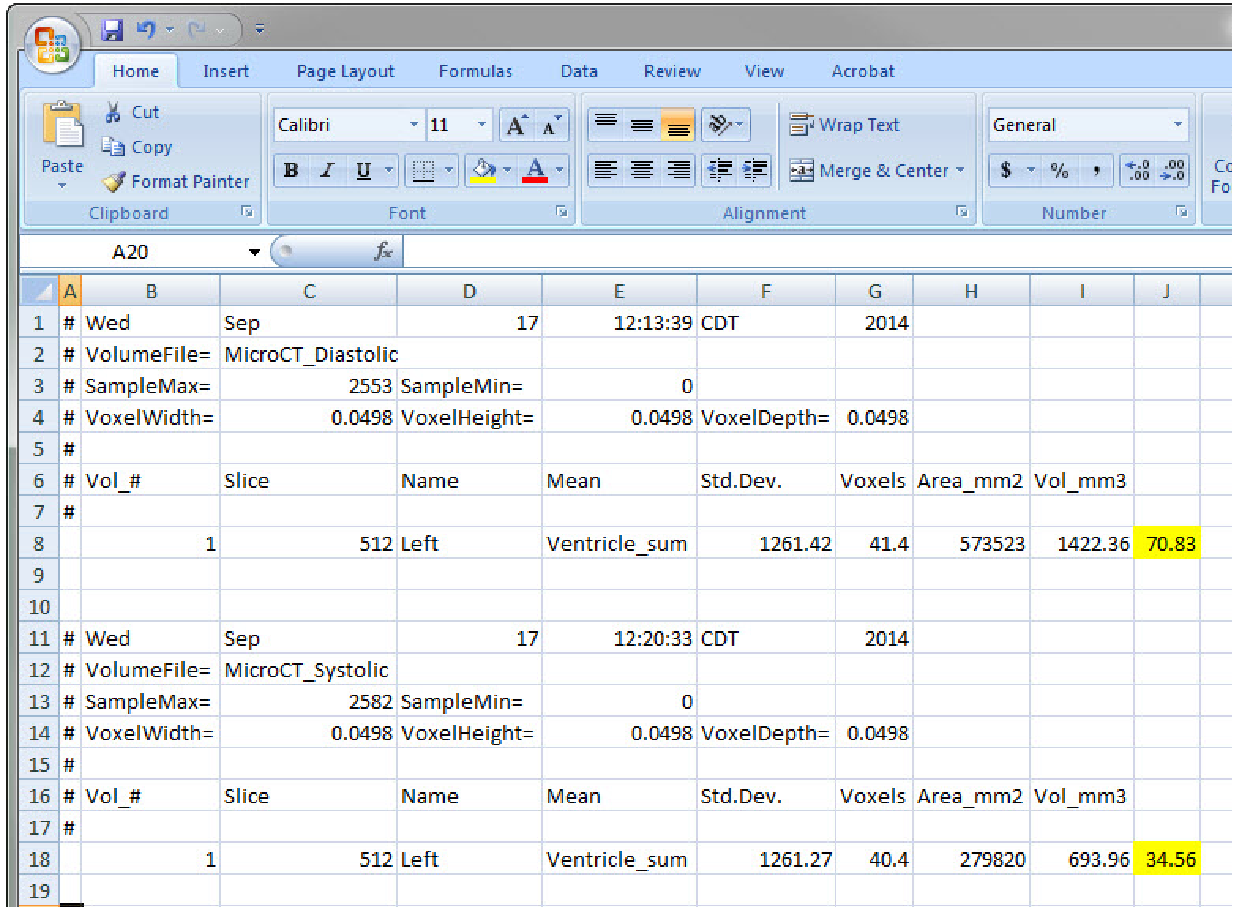
Click Sample Images, then save the generated statistics from the ROI Stat Log window. Repeat the measurement steps for the end-systolic data and save the end-systolic .stats file.



Calculation Instructions

Import the .stats files into Excel or another spreadsheet application as space-delimited files.

Use the equations from the Introduction to calculate stroke volume, ejection fraction, and cardiac output.



	A	B	C	D	E	F	G	H	I	J
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2	#	VolumeFile=	MicroCT_Diastolic							
3	#	SampleMax=	2553	SampleMin=	0					
4	#	VoxelWidth=	0.0498	VoxelHeight=	0.0498	VoxelDepth=	0.0498			
5	#									
6	#	Vol_#	Slice	Name	Mean	Std.Dev.	Voxels	Area_mm2	Vol_mm3	
7	#									
8		1	512	Left	Ventricle_sum	1261.42	41.4	573523	1422.36	70.83
9										
10										
11	#	Wed	Sep	17	12:20:33	CDT	2014			
12	#	VolumeFile=	MicroCT_Systolic							
13	#	SampleMax=	2582	SampleMin=	0					
14	#	VoxelWidth=	0.0498	VoxelHeight=	0.0498	VoxelDepth=	0.0498			
15	#									
16	#	Vol_#	Slice	Name	Mean	Std.Dev.	Voxels	Area_mm2	Vol_mm3	
17	#									
18		1	512	Left	Ventricle_sum	1261.27	40.4	279820	693.96	34.56
19										

EDV	ESV	SV	EF	HR*	CO
mm^3	mm^3	mm^3	%	1/min	cm^3/min
70.83	34.56	36.27	51.21	400	15

*Heart rate estimated here but would be a measured range.

References

1. Herrmann, J. *et al*. Primary proteasome inhibition results in cardiac dysfunction. *Eur. J. Heart Fail.* **15**, 614–23 (2013).

2. Richards, D. a *et al*. Examining the relationship between exercise tolerance and isoproterenol-based cardiac reserve in murine models of heart failure. *J. Appl. Physiol.* **114**, 1202–10 (2013).