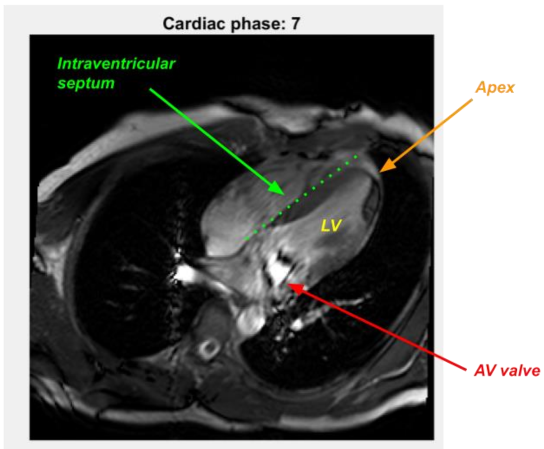
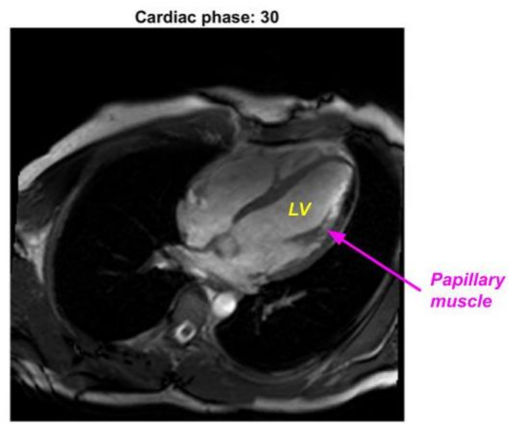
Quantitative and Functional Imaging
BME 4420/7450

Project #2: Cardiac Ejection Fraction

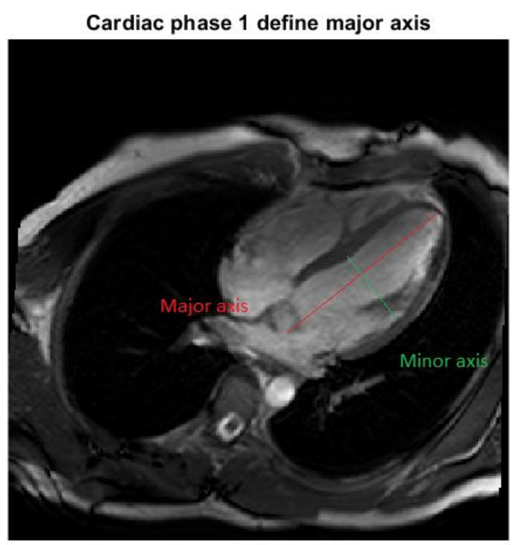
Coding Deliverables:

1. Create movie of the beating heart then identify anatomical structures in the movie

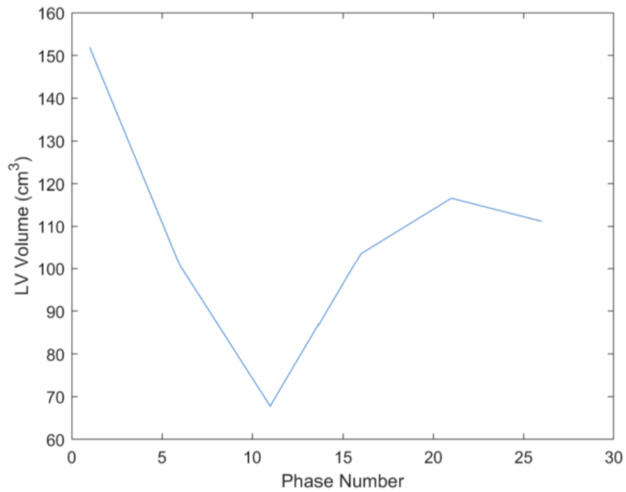




Major and minor axes:



2. Plot of the LV volume as a function of cardiac phase and then calculate the ejection fraction



Ejection fraction = (151.9220 - 67.7925)/151.9220 = 55.38%

Questions:

1) What is the diastolic (i.e., maximum) volume of the LV? (Don't forget the units!)
   151.9220 cm^3

2) What is the systolic (i.e., minimum) volume?
   67.7925 cm^3

3) What is the ejection fraction (i.e., the fraction of the maximum volume that is pumped out of the heart each cycle)?
   Ejection fraction = (151.9220 - 67.7925)/151.9220 = 55.38%

4) Could you use the same approach to estimate the volume of blood ejected from the right ventricle? If not, explain why. Do you expect the right and left ventricular ejection volumes to be equal?

- The same approach would be much less accurate for the right ventricle than for the left ventricle. This is because, while the left ventricle is approximately elliptical in shape, the right ventricle is not (cross section appears crescent-shaped as shown in Fig 1. below). However, there are models which treat the right ventricle as an ellipsoid with relative success.

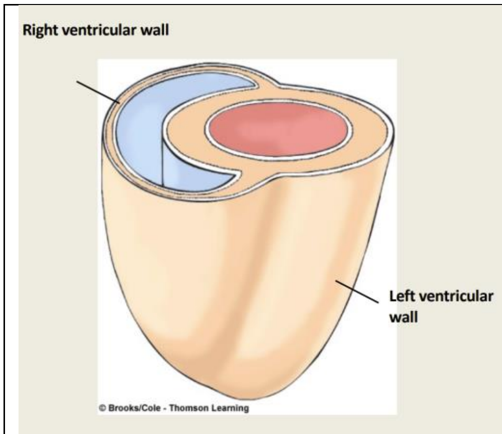


Fig1. Simple Left and Right Ventricle diagram

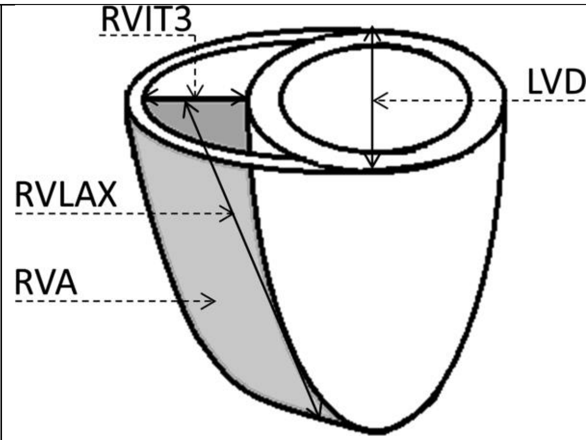


Fig2. Model of Right Ventricle

- One of the modeling approaches our group found [1] (*Echocardiography* 2016; 33: 844–853) was assuming the RV to be part of an ellipsoid (Fig2.). However, there are limitations to this technique as its measurements from different modalities cannot be used. This may cause issues when estimating the distance in the plane of the image. Then RV volume will be estimated as:
-

$$\mathrm{RVV} = \frac{\pi}{6} \times \mathrm{RVIT}_3 \times \mathrm{RVLAX} \times \mathrm{LVD}$$

- Yes, we expect the right and left ventricles to eject roughly equal volumes due to conservation of mass.

5) We assumed that the two minor axes, *b* and *c*, are equal, but this is only approximately true. Let *b* be the measured minor axis and *c* be the unmeasured minor axis (i.e., the minor axis in the direction perpendicular to the image plane). Suppose that in a group of patients *c*=*b* on average, but there is a 20% variation in the ratio, i.e., the standard deviation of *c*/*b* in this group is

$$\sigma(c/b) = \sigma(c)/b = \sigma(c)/c = 0.2$$

Assuming **this is the most important source of errors**, use a 'propagation of errors' approach to predict the errors in ventricular <u>volume</u> estimates for this population. Express your answer as the fractional error in ventricular volume $\sigma(V)/V$.

$V = \frac{4\pi}{3}\left(\frac{abc}{8}\right)$; we assume b=c. What will be the affect on V

$$\theta^2(V) = \theta^2(a)\left(\frac{\partial V}{\partial a}\right)^2 + \theta^2(b)\left(\frac{\partial V}{\partial b}\right)^2 + \theta^2(c)\left(\frac{\partial V}{\partial c}\right)^2$$

we can treat $\theta(a)=0$ and $\theta(b)=0$ because $\theta(a) \lll \theta(c)$ & $\theta(b) \lll \theta^2(c)$, so

$$\theta^2(V) \cong \theta^2(c)\left(\frac{\partial V}{\partial c}\right)^2 = \theta^2(c)\left(\frac{4\pi}{3}\,\frac{ab}{8}\right)^2$$

Divide by V:

$$\frac{\theta^2(V)}{V^2} = \frac{\theta^2(c)\left(\frac{4\pi}{3}\,\frac{ab}{8}\right)^2}{\left(\frac{4\pi}{3}\,\frac{abc}{8}\right)^2} = \frac{\theta^2(c)}{c^2} = \left(\frac{\theta(c)}{c}\right)^2 = 0.2^2$$

$$\boxed{\frac{\theta(V)}{V} = 0.2}$$

6) Besides the possibility that $c \neq b$, what are the most important limitations to the accuracy of your measurement of ejection fraction? What changes to the experiment might improve the accuracy?

- Although we simplified the LV to be an ellipsoid in shape, it is not actually an ellipsoid which reduces our accuracy.
- In addition, there was ambiguity in determining the boundaries of the LV chamber when drawing the major and minor axes on the images. For example, the boundary between the LV and LA was specifically difficult to determine, as most of the slices were taken in a different plane than the mitral valve. This was an issue because the mitral valve was used to define the boundary between the LV and LA.
- It is difficult to exclude the volume of the papillary muscle. Though this volume is small relative to the LV volume, it does add inaccuracy into the model.
- Changes in the experiment that could improve accuracy are the following:
    - Pair ultrasound images with images by MRI, to get the perpendicular plane of the heart. One may be able to better measure the c length. Additionally, one may be able to better estimate the shape of the heart for a more refined volume calculation. Boundaries may also be easier to distinguish.
    - Averaging measurements of a and b during the cardiac phases. I.e., one could extend the recording time to include several cycles, so multiple measurements of a and b can be taken and averaged. Standard deviations of the measured length can be determined so confidence intervals with respect to length and volume can

be created.

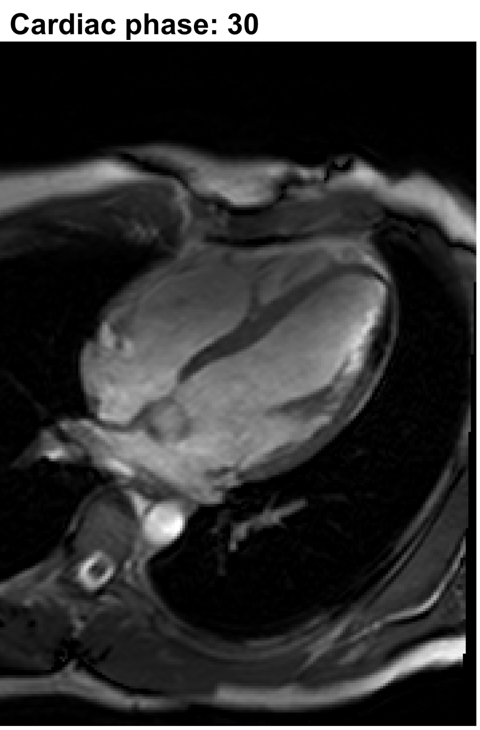
7) What medical conditions (i.e., diseases or cardiac abnormalities) do you think this technique could be used to diagnose or assess?

   LVEF can be useful in the assessment for patients with **congestive heart failure**, after myocardial infarction, and after revascularization due to weakened left ventricular function. Other uses include:

- Ventricular arrhythmias
- Congenital heart disease
- Planned or prior exposure to potentially cardiotoxic therapy

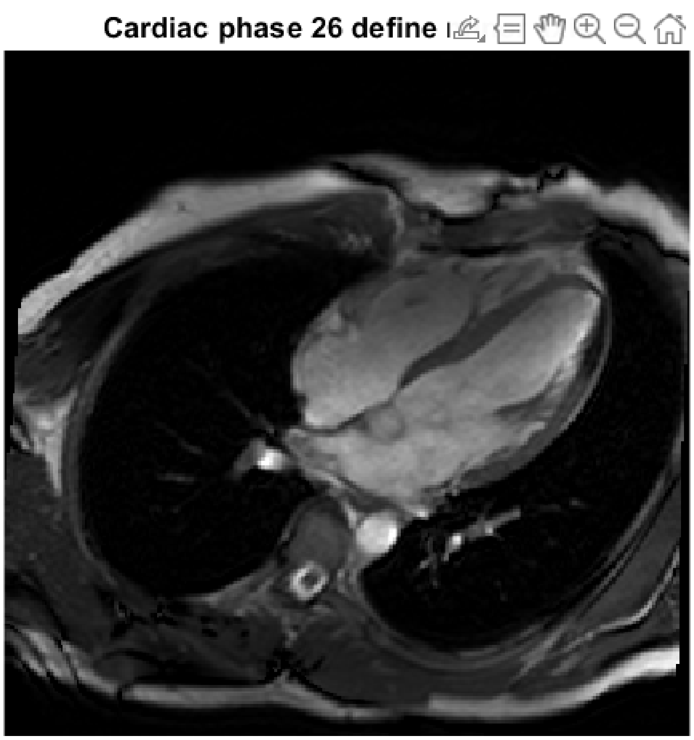
```
load('proj2Data')
```

```
figure
nFrames = 30;
for index = 1:nFrames
    imagesc(squeeze(image_3d(:, :, index)))
    % Set the intensity scale based on the first image:
    if (index == 1)
        cLim_v = get(gca, 'CLim');
    else
        set(gca, 'CLim', cLim_v)
    end
    axis image
    axis off
    colormap(gray)
    title(['Cardiac phase: ', num2str(index)])
    drawnow
    mov(index) = getframe;
end
```



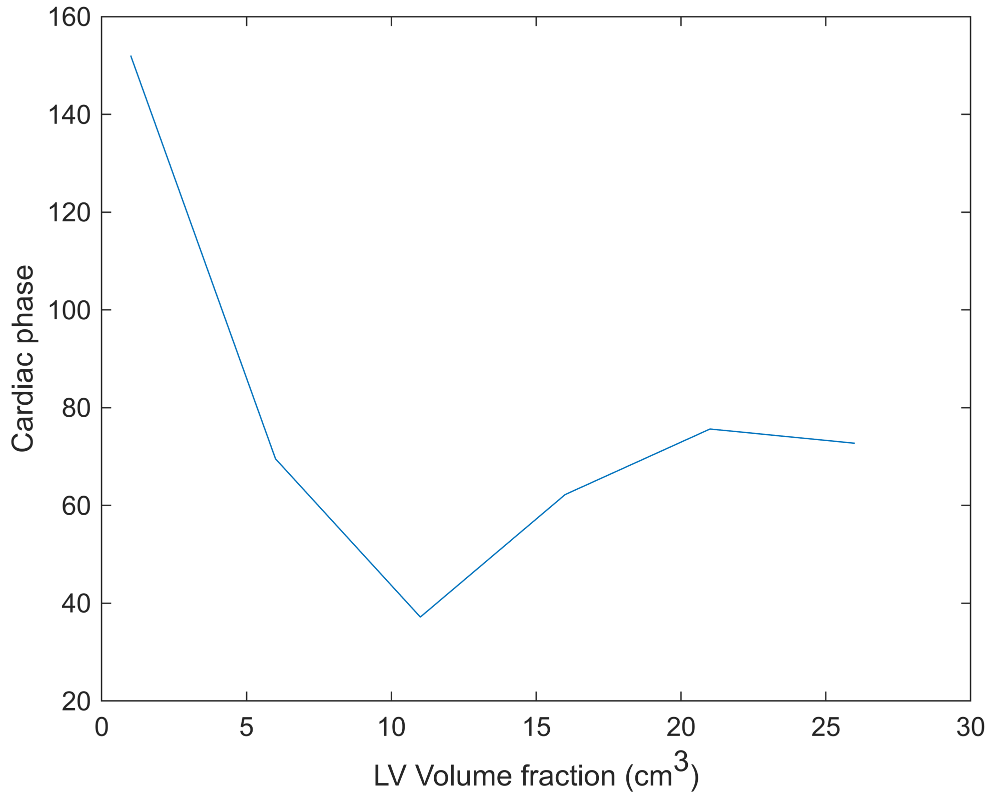

```
fps = 8;           % frames per second.
nReps = 4;     % number of repetitions.
movie(mov, nReps, fps)
```

```
% Define the major and minor axes of the ellipse in each frame:
skip = 5;   % Number of phases to skip.
nVols = length(1:skip:nFrames);
volume_v = zeros(1, nVols);
for index = 1:skip:nFrames
    imagesc(squeeze(image_3d(:, :, index)))
    set(gca, 'CLim', cLim_v)
    axis image
    axis off
    colormap(gray)
    % Get axes:
    title(['Cardiac phase ', num2str(index), ' define major axis'])
    % Insert your code here to measure the major axis:
    a_xy = ginput(2);
    a = pdist(a_xy);
    title(['Cardiac phase ', num2str(index), ' define minor axis'])
    % Insert your code here to measure the minor axis:
    b_xy = ginput(2);
    b = pdist(b_xy);
    volIndex = (index-1)/skip + 1;
    % Enter your code here to calculate the LV volume:
    volume_v(volIndex) = ((dx)^3 ) * 4*pi*a*(b^2)/24;
end
```




```
plot(1:skip:nFrames, volume_v)
```

```
xlabel('LV Volume fraction (cm^3)')
ylabel('Cardiac phase')
```




```
max(volume_v)
```

```
ans = 152.0259
```

```
min(volume_v)
```

```
ans = 37.1790
```