1. Introduction

The aim of this lab is to give you an insight into phase-contrast magnetic resonance imaging (PC-MRI) velocity data and its applicability, as well as an improved understanding of concepts in biofluid dynamics.

The exercise represents a real-world scenario. We are investigating a 43-year-old female with a left atrium aneurysm (a local bulging) and atrial septum shunt flow. The shunt flow is going from the left atrium into the right atrium. Shunts can be assessed by measuring the amount of outflow from the right ventricle into the pulmonary artery (Q_p) and the amount of outflow from the left ventricle into the aorta (Q_s). The shunt ratio (Q_p/Q_s) describes the relative amount of flow to the lungs (pulmonary circulation) and the systemic circulation. When a shunt is present, more blood comes through the pulmonary artery than the ascending aorta.

Based on ultrasound, the shunt (Q_p/Q_s) ratio is 1.2/1. This may motivate intervention. MRI is considered to measure shunt ratios with superior accuracy compared to ultrasound. Therefore, an MRI flow investigation is requested to determine the shunt ratio.

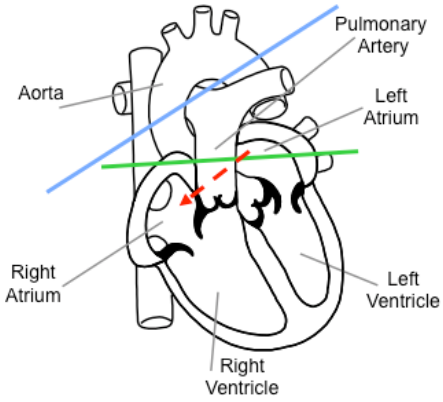

Figure 1. Illustration of the heart and great vessels. The green and blue lines indicate the location of the measurement plane in the pulmonary artery and aorta, respectively. The red dashed arrow indicates the direction of shunt flow from the left atrium to the right atrium.

2. Preparations

The lab is based on knowledge that you gained at the lectures in Biofluid Dynamics and MR Flow Imaging. Before the lab, you are required to read this lab manual and answer the preparatory questions. Responses to the preparatory questions should be submitted to Lisam. For labs on Mondays, the submission deadline is Wednesday before the lab at 23:59. For labs on Thursdays, the submission deadline is Monday before the lab at 23:59. The questions need to be answered individually and in your own words.

3. Preparatory Questions

1. The Q_p/Q_s ratio is a measure of the amount of blood flow to the lungs (pulmonary circulation) relative to the amount of blood flow to the body (systemic circulation).
    a. What (and why) is the normal value of Q_p/Q_s?
2. Assume that you have a 2D time-resolved PC-MRI image of the aorta as shown in Figure 2. How can you use these data to estimate stroke volume?
3. Cine MRI can be used to acquire a set of so-called short-axis images that cover the left ventricle. How can this be used to estimate stroke volume?
4. Ultrasound can measure the maximum velocity in the ascending aorta. How can this be used to estimate stroke volume?
5. When do phase wraps occur in PC-MRI velocity measurements?
6. How would phase wraps in PC-MRI affect stroke volume measurements?

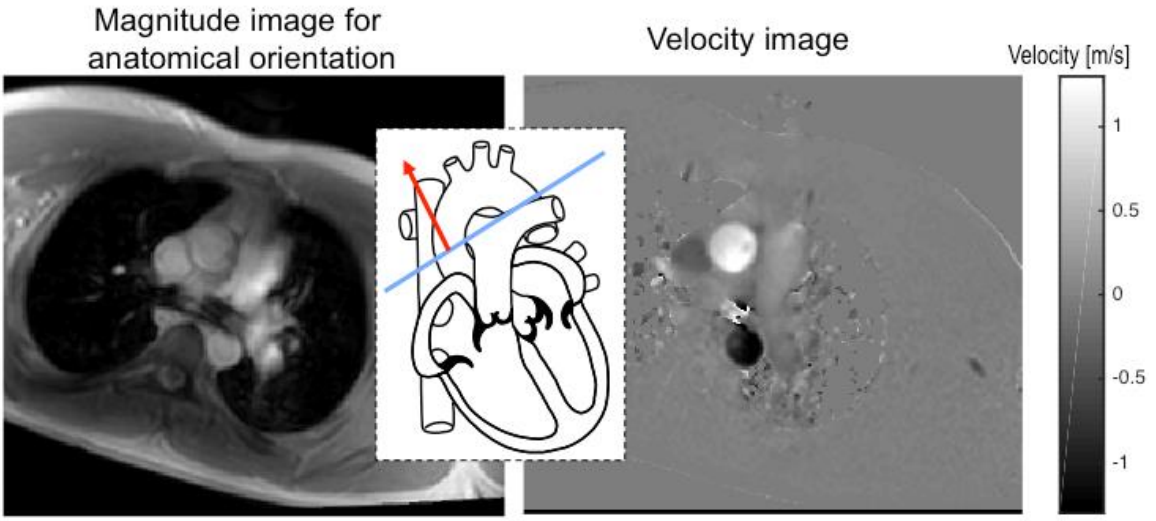

Figure 2. Data from a PC-MRI measurement of the ascending aorta at the location indicated in the middle. Left image: A so called magnitude image is obtained by displaying the magnitude of the complex PC-MRI signal. This image is used for anatomical orientation. Right image: A velocity image is obtained by exploiting that the argument of the complex PC-MRI signal is proportional to velocity. In this image the bright, positive velocity signal is seen in the ascending aorta where blood is moving towards the head. The dark, negative velocity signal is seen in the descending aorta where blood is moving towards the feet. Areas with stationary tissue such as the back and chest have zero velocity (gray in the velocity image).

4. MRI data

Four datasets are used in this lab: Two phase-contrast (PC) MRI datasets, one so-called 4-chamber cine dataset, and one stack-of-short-axis cine dataset. All PC-MRI data sets are 2D through-plane velocity measurements.

- PCMRI_aorta (This is a 2D PC-MRI through-plane flow measurement in the aorta, at the location of the blue line in Figure 1)
- PCMRI_pulmonary (This is a 2D PC-MRI through-plane flow measurement in

the pulmonary artery, at the location of the green line in Figure 1)
- cine_4ch (4ch denotes 4-chamber view, which refers to the fact that four cardiac chambers are visible in this image)
- cine_SA (stack of short-axis images covering the left ventricle)
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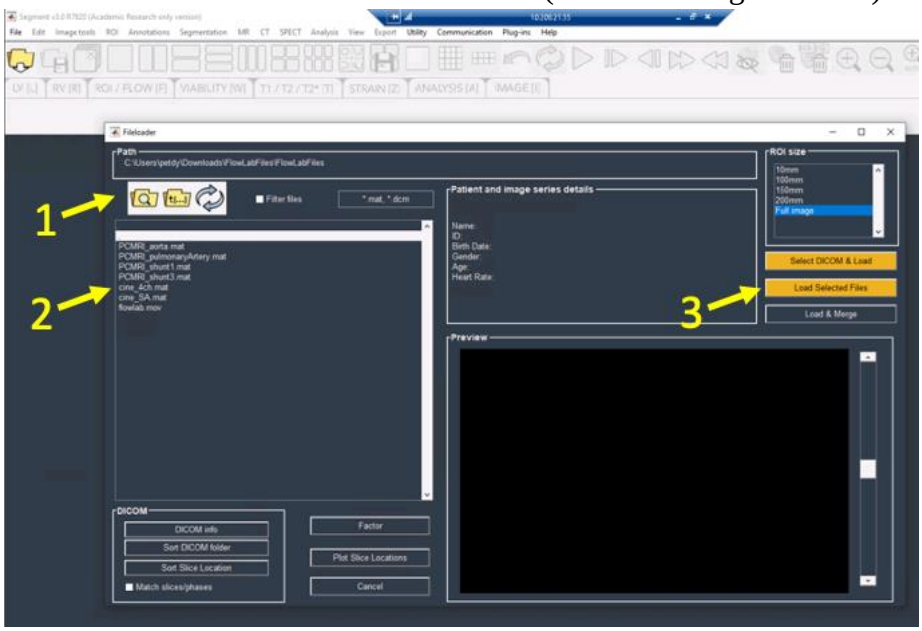
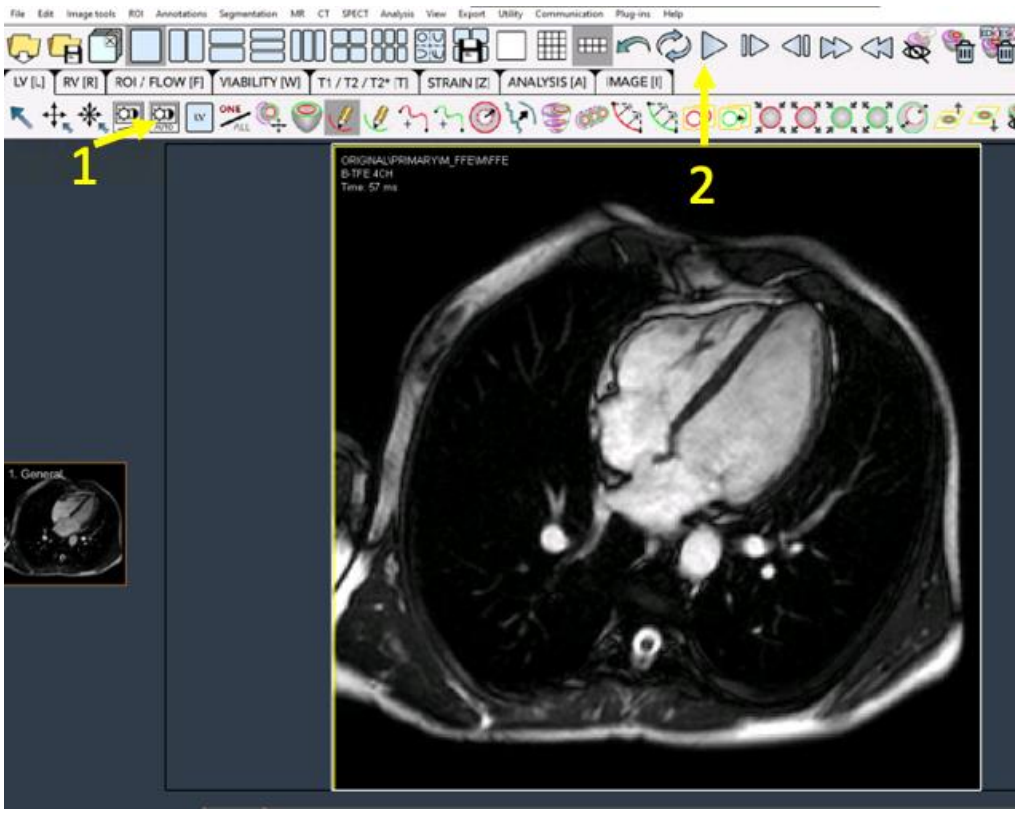
5. Laboratory Exercises

1. Download the files from Lisam. Note that you need to extract the files after downloading.
   https://liuonline.sharepoint.com/:f:/r/sites/Lisam_TBMT09_2022VT_IC/CourseDocuments/LaboratoryExercises/FlowLab/FlowLabFiles?csf=1&web=1&e=sV6LK1
2. Open the Segment app (type Segment in the Windows search function)
3. Load the cine_4ch dataset:
   a. Select *File – Open from Disc*. Click *Browse for folder* (arrow #1 in figure below). Go to the folder containing your files and click *Select folder*.
   b. Select *cine_4ch.mat* (arrow #2 in figure below)
   c. Click *Load Selected Files* (arrow #3 in figure below)



4. Click on AUTO button to adjust contrast and brightness (arrow #1 in figure below). Play the cine_4ch data by pressing the play button (arrow #2 in figure below).

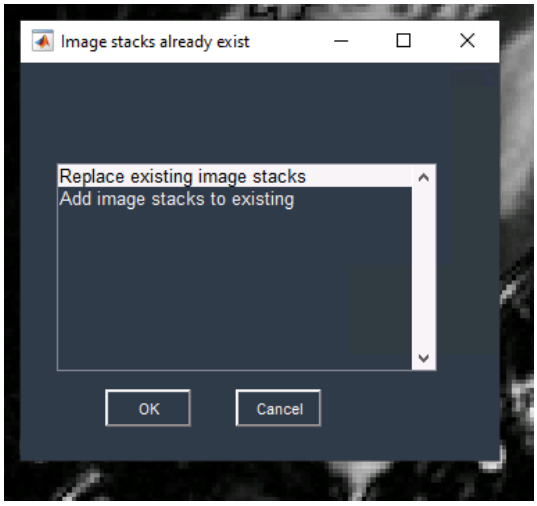


QUESTION 1: Can you identify the location of the following:

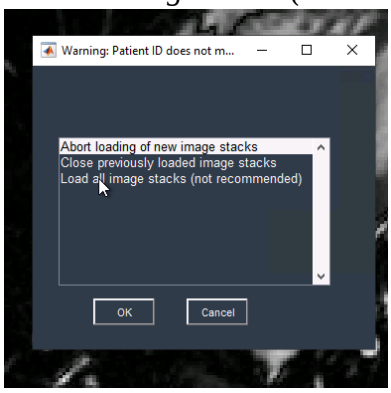
a. Left ventricle
b. Right ventricle
c. Left atrium
d. Right atrium
e. The aneurysm (it is located between the left and right atrium)

5. Look at the movie flowlab.mov (one of the downloaded files – open in media player, not in Segment) to remind yourself about what phase wraps look like in PC-MRI velocity data. The top left panel shows the PC-MRI magnitude image which is used for anatomical orientation. The top right panel shows the PC-MRI velocity data where the pixel value = velocity of the tissue in that pixel. The lower right panel also shows PC-MRI velocity data, but with phase-wraps.

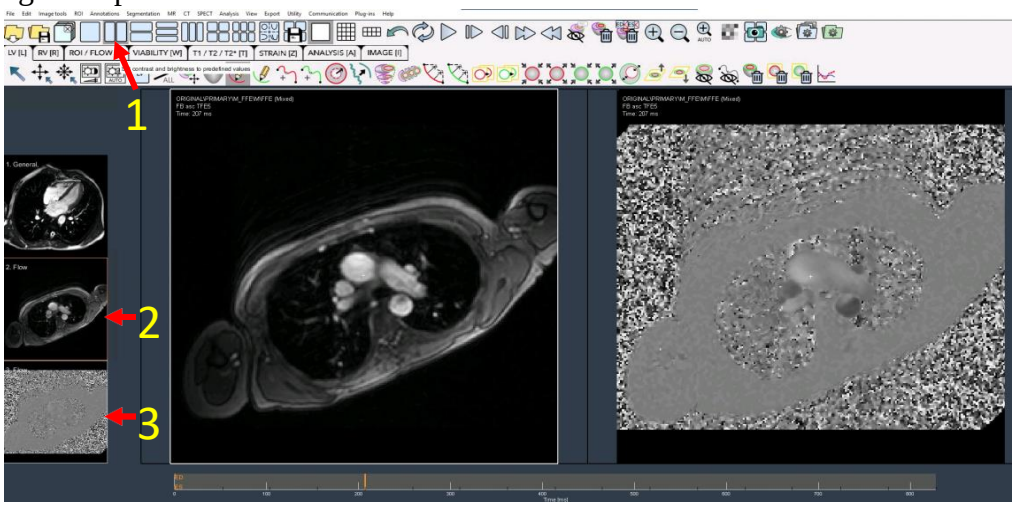
6. Load the PC-MRI_aorta data by clicking *Open File Loader* in the top left corner of the screen. Choose *Add image stacks to existing* in the pop-up window (see below)



7. After selecting the PC-MRI_aorta dataset and clicking *Load Selected Files*, select *Load all image stacks (not recommended)* (see below).



8. Click *View two image panels* (see arrow #1 in figure below). Using the mouse arrow, drag and drop the PC-MRI magnitude image (arrow #2) into the left image panel. Do the same thing to open the PC-MRI velocity image (arrow #3) into the right image panel. Click play to view the images over time. Click the play button again to pause.



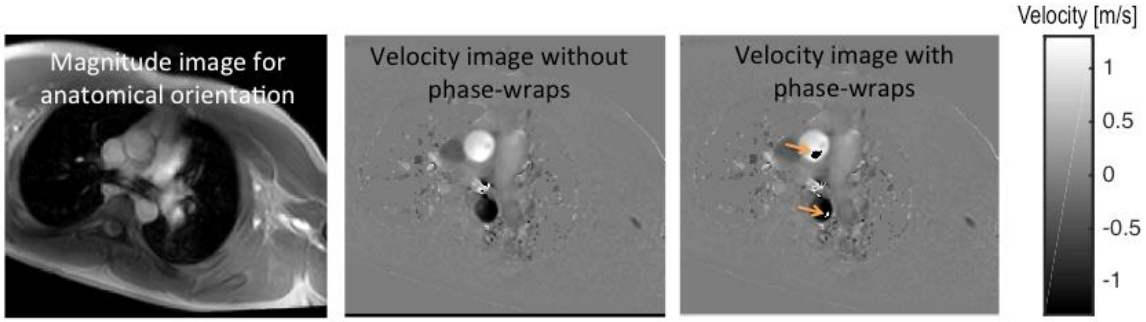
9. Repeat steps 6-8 for the PCMRI_PulmonaryArtery dataset
10. Review the PC-MRI_aorta and the PC-MRI_pulmonaryArtery datasets.

QUESTION 2:

a. Do you see any phase wraps in the aorta or pulmonary artery datasets? (for another

reminder of what phase-wraps look like, see figure below)

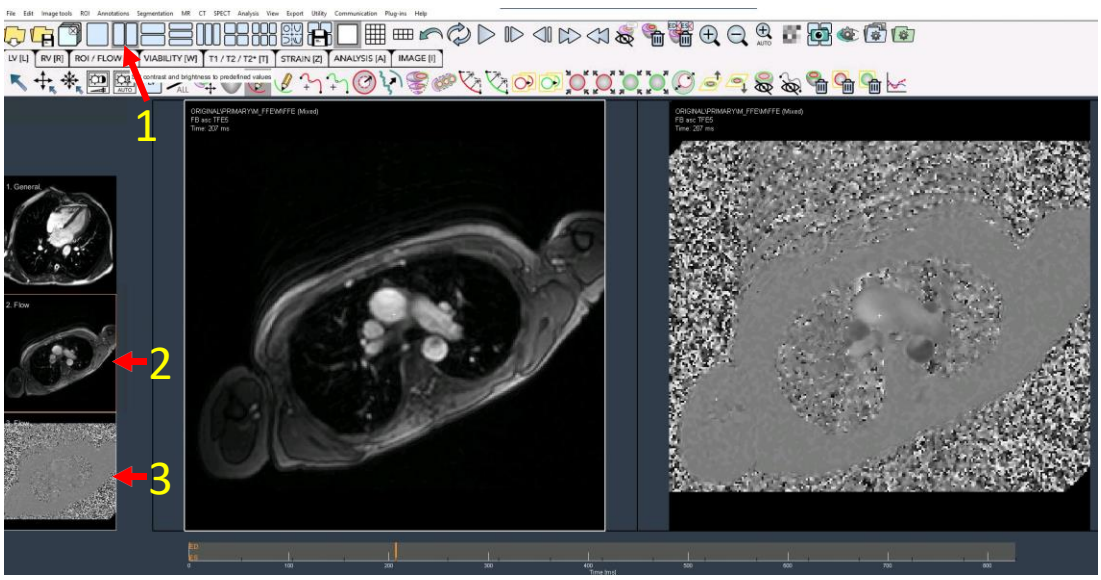
b. In the pulmonary artery dataset, which vessel is the pulmonary artery?



11. Raise your hand to discuss the answers to Question 1 and 2 with us.

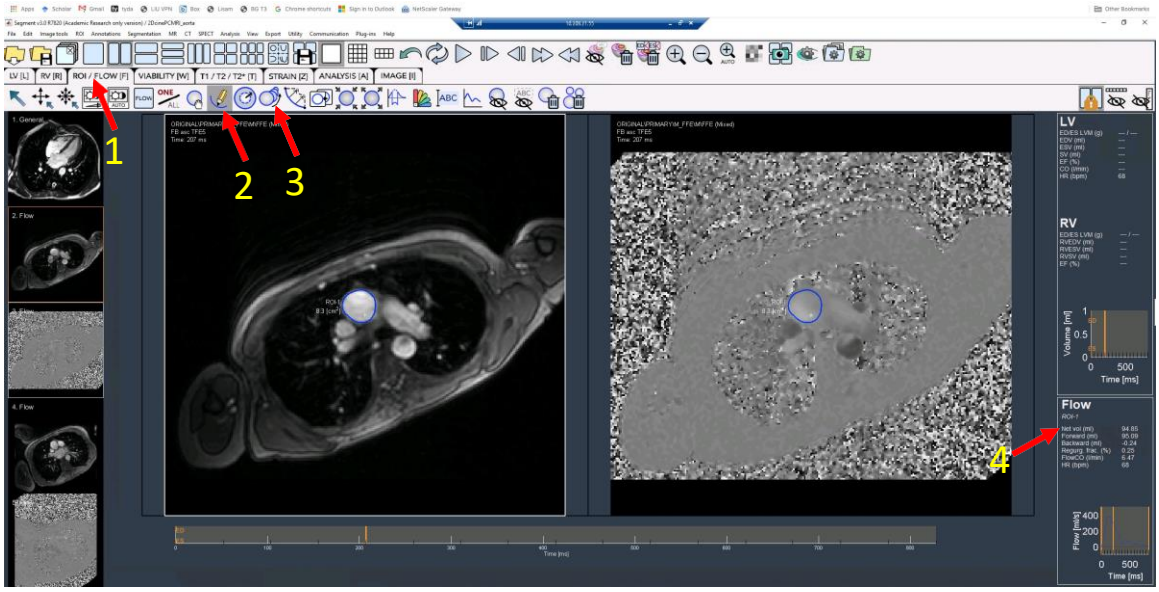
12. Load the PC-MRI_aorta data by repeating steps 6 and 7.

13. Click *View two image panels* (see arrow #1 in figure below). Using the mouse arrow, drag and drop the PC-MRI magnitude image (arrow #2) into the left image panel. Do the same thing to open the PC-MRI velocity image (arrow #3) into the right image panel.



14. Flow volume measurements. Select the *ROI/FLOW* tab (arrow #1 below). You are now going to draw a region of interest (ROI) in order to measure blood flow in the ascending aorta. Click the *ROI pen* tool (arrow #2 below). Now delineate the contours of the ascending aorta in one time frame. Next, click *Track vessel in all time frames* (arrow #3). In this way the software will automatically refine the contour and track it through time. You can now hit play and confirm that the contour follows the motion of the ascending aorta. If necessary, refine using the *ROI pen*.

When you are happy with the contour, direct your attention to the lower right part of the screen where it says *Flow* (arrow #4).

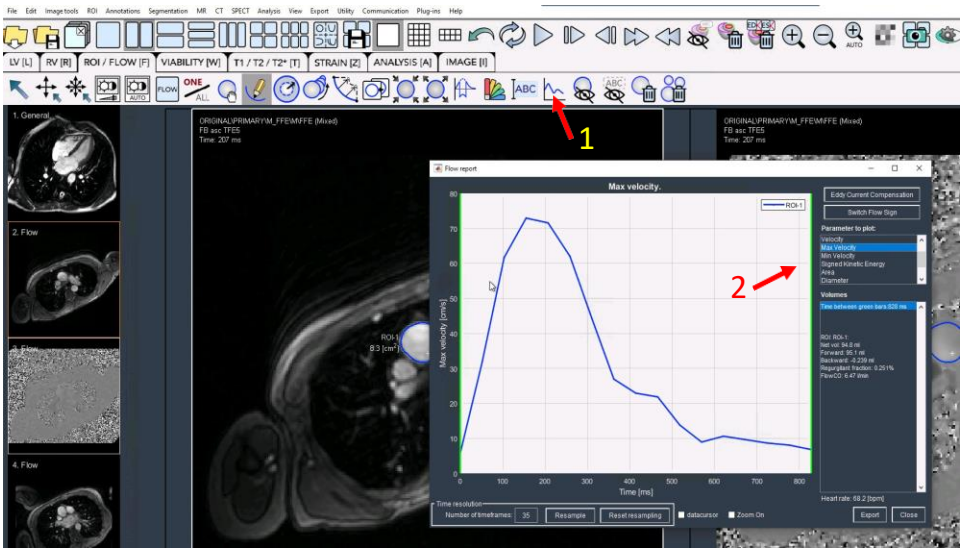


QUESTION 3:

a. How much blood does the left ventricle output to the aorta?
b. What is the Qp/Qs ratio, i.e. the ratio between flow volume through the pulmonary artery and the aorta? (you need to do step 15 for both the 2DcinePCMRI_aorta and 2DcinePCMRI_pulmonary datasets to solve this). Note that Q in Qp/Qs stands for stroke volume (= net flow volume).
c. In patients with cardiac shunts, Qp is always larger than Qs (never the other way around). Why?

15. Raise your hand to discuss the answers to Question 3 with us.

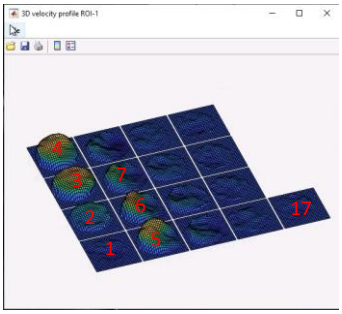
16. You are now going to look at the velocity profile and the effect of assumptions about the shape of the velocity profile. For this you need to find the peak velocity in the ROI. Click on the Flow analysis icon (arrow #1 below), this will open the *Flow report* window. Here, you can plot different variables over time. For exmple, click on *Max Velocity* and *Area* to see how they change over over the cardiac cycle (time axis = one cardiac cycle).



QUESTION 4: Assumptions about the velocity profile

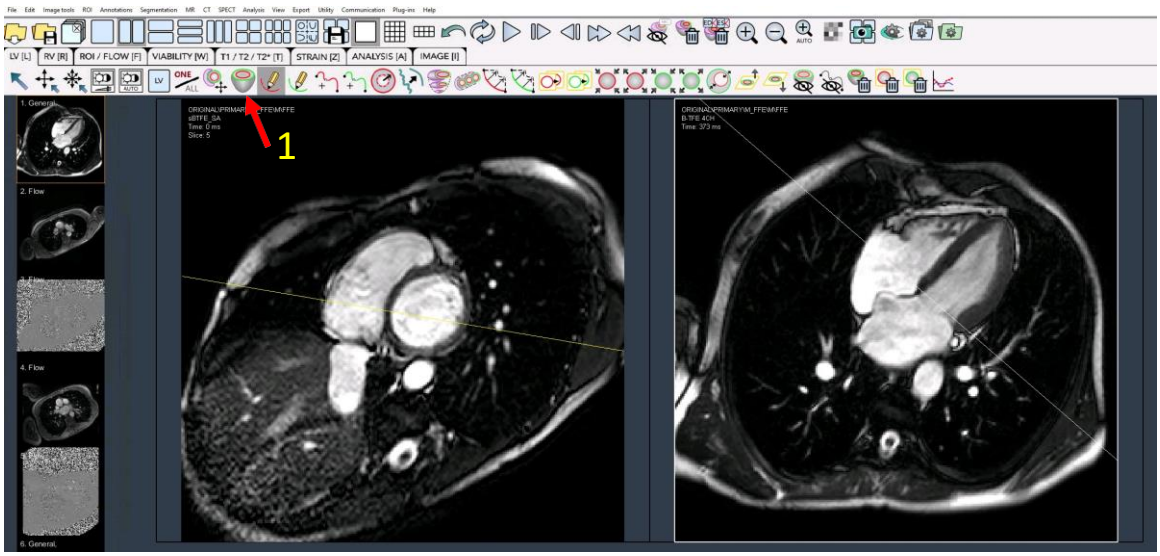
a. Estimate the peak systolic flow rate (note that this is the flow rate at one point in time) in the aorta and the pulmonary artery by using the assumptions in ultrasound flow measurements (Vmean = Vmax/2). How well does it match the flow rate measured by MRI? Can you explain the differences (doing Q4b will help you figure out the answer)?

b. In the *Flow report* window there is an option for viewing the velocity profiles as surface plots (*3D Plot*, see image to the right where the numbers show the time order for the surface plots). Is the assumption about parabolic velocity profiles reasonable in the ascending aorta and pulmonary artery of this patient? Can this explain the differences in stroke volume (net flow volume) that you measured in Q4a ("ultrasound method") and Q3a/b ("MRI method")?



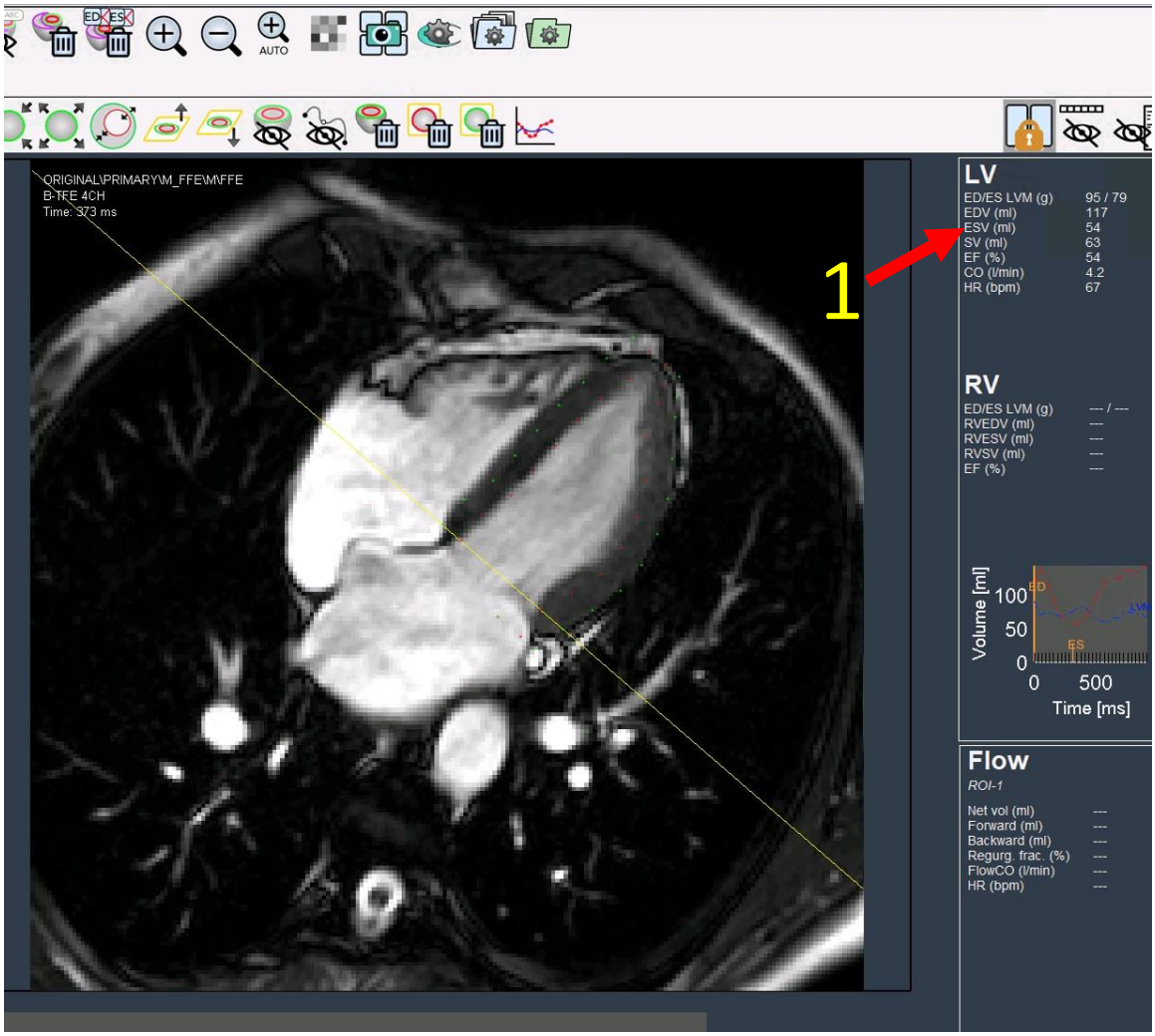
17. Raise your hand to discuss the answers to Question 4 with us.

18. You are now going to measure the stroke volume using the so called planimetry method. This method uses a stack of 2D images that are oriented perpendicular to the long axis of the left ventricle and together cover the left ventricle.
- Load the cine_SA dataset
- Drag and drop the cine_SA dataset in the left image panel and the cine_4ch dataset in the right image panel (as seen in the figure below). You can then hit play to view the images over time.
- If you select the cine_SA dataset (by clicking in the left image panel), you can use the up and down arrows on your keyboard to switch between slices. The location of the slice is shown as the yellow line in the cine_4ch image in the right image panel.



- Click the icon for automatic LV segmentation (arrow #1 in figure above). The first time you do this you are asked to crop LV stacks. Just click OK. Next, you may need to click the icon for automatic LV segmentation again. You should now be in the Automatic LV Segmentation tool (see figure below). Follow the instructions in Step 1 and Step 2 and Step 3.

- Click the icon for automatic LV segmentation (arrow #1 in figure above). The first time you do this you are asked to crop LV stacks. Just click OK. Next, you may need to click the icon for automatic LV segmentation again. You should now be in the Automatic LV Segmentation tool (see figure below). Follow the instructions in Step 1 and Step 2 and Step 3.
The results of the segmentation appear under LV in the upper right corner of the window (see figure below).



Question 5: Planimetry.

a. How many slices are there in the cine_SA dataset?
b. What is the left ventricular stroke volume (Qs) as obtained with the planimetry method.
c. Does this value of Qs match the value you obtained from the flow measurement in Q3a?

Question 6: Bernoulli Equation

d. Compute the pressure gradient over the aortic valve at peak systole by using the modified Bernoulli equation.
e. The velocity in the left ventricle is 0.6 m/s. Compute the pressure difference using the Bernoulli Equation (**p + ρv2/2 + ρgh = constant**)
f. Which of the results (a or b) is most valid?

19. Raise your hand to discuss the answers to Question 5 and 6 with us.