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# Synopsis

This is a MATLAB script for calculating aortic Pulse Wave Velocity (PWV) from cine 2D phase contrast (2DPC) and balanced Steady State Free Precession (bSSFP) data using the Flow-Area (QA) method [paper citations]. This tool was originally written by myself and Grant Roberts for use in the LIFE study as an alternative to the PWV-2DPC (time-shift) tool [Grant paper citation]. The primary difference between these methods is that the QA method calculates a local PWV using cross-sectional areas and local flow values at each region of interest (ROI) while the time-shift tool calculates PWV over segments between each ROI. Additionally, this tool utilizes our own mixed modality pipeline for calculating PWV-QA as described in our ISMRM abstract [ISMRM citation]. We use bSSFP images with their high spatial resolution and image contrast to perform semi-automated segmentation that would otherwise be impossible on the magnitude 2DPC scans. The QA method depends heavily on accurate cross-sectional area and flow calculations, so the improved segmentation quality dramatically improves PWV results as well reducing analysis time compared to using 2DPC images alone. Additionally, this tool is capable of calculating certain cardiac flow parameters such as stroke volume. The general workflow is as follows:

* Create save directory for analysis data
* Load cine bSSFP images
* Perform semi-automated segmentation on the bSSFP data to find the aorta ROI(s) in each frame
  + Multiple automated segmentation algorithms are available to aid in segmentation
  + Manual segmentation is also available
* Load cine 2DPC images
  + Both image sets are automatically interpolated down to 1 ms to ensure matching temporal resolutions
* Calculate flow
* Shift flow curves as needed to accommodate gating lag
* Calculate PWV
  + Circle all points in the early systole region (upslope of the flow curve)
  + If calculating cardiac flow parameters, circle points in all of systole and diastole as well
* Results are saved to an excel file in the analysis folder

# Analysis

### Set Up

* To install the tool for the first time or to update it from an older version, navigate to <https://github.com/tnaren97/PWV_QA/tree/master>
  + Click the green Code button, download the zip file, and extract it to

$ C:\Users\<username>\Documents\MATLAB

* + Alternatively, if you are using a shared computer and someone is maintaining the code, save it to

$ C:\Users\Public\MATLAB\_QA

* If you do not have admin access on your computer, you will need to add the tool to your path every time you open MATLAB. This allows MATLAB to access the tool without needing to be in the same folder as it
  + In the toolbar at the top of the screen, select Home > Set Path and then click Add with Subfolders
  + Navigate to the folder where you saved the QA tool and click Select Folder
  + MATLAB will prompt you to save the path. Unfortunately, you can’t as you don’t have admin rights so just hit close.
* In the file browser on the left side of the screen, navigate to the directory containing the data you want to analyze
* When ready to start, type QA\_auto in the command window

### Using the Tool

* You will first be prompted to choose a directory to save the analysis results. All the results will be saved in a folder called 2DPC\_QA\_Analysis. If you are reanalyzing a case, you can select the existing 2DPC\_QA\_Analysis folder and it will save the data there.
* Next you will be prompted to type in an analysis region name. Pick a name that describes the ROIs you plan to analyze. For example, if you are analyzing the ascending and descending aorta, maybe something like “arch”. Doesn’t matter as long as it’s descriptive and consistent.

A screenshot of a computer error

Description automatically generated

* You will then be prompted to type in the number of ROIs in the image you’re analyzing. For example, if you’re analyzing a slice that contains both the ascending and descending aorta, you would type in “2”

A screenshot of a computer error

Description automatically generated

* Now you will be asked to choose a segmentation method. There are a couple of options for you to pick (hough+contours currently gives the best results so choose that)

A screenshot of a computer

Description automatically generated

* + kmeans (currently not working)
    - K-means clustering and then contouring
  + otsu (currently not working)
    - Otsu thresholding and then contouring
  + circle+contours
    - Draw circles manually and then do dilation and active contours to automatically adjust the contours to the ROI
  + hough
    - Hough transform to find circles in the image
  + hough+contours
    - Hough transform plus dilation and active contours
  + edge+hough+contours
    - Find edges in the image, then do Hough transform and dilation and active contours
* Lastly, you will be asked If you want to do cardiac output analysis. This calculates a few additional cardiac parameters related to blood flow such as stroke volume and cardiac output. If you click yes, you’ll be asked to do a few extras steps at the end of the analysis.

### Segmentation

* To begin the segmentation process, first select the folder containing the bSSFP images you want to segment
* You will then be prompted if you want to load masks.
  + If you have already segmented this dataset, you can click Yes and load the masks.mat file that should be stored in 2DPC\_QA\_analysis/<analysis region name>/bssfp/. This will allow you to skip ahead to the analysis part of the process.
  + If your segmentation was interrupted part way through, you can click Yes to load the mask file and continue where you left off
  + If you are analyzing this case for the first time, or want to redo the segmentation, click No.
* An image will pop up and you will be prompted to select a region to zoom in on. Select a rectangle around the ROIs you wish to analyze. Refer to the figure below for an example containing the ascending and descending aorta.

*Note: If you chose a method involving Hough transforms, try and avoid including the spine in your selection. The Hough transform is designed to recognize circles so the spine will often be erroneously recognized as an ROI.*

A screenshot of a computer

Description automatically generated

* You will now begin segmenting the ROI for each frame in the image sequence. Two dialogue boxes will pop up.

A screenshot of a computer

Description automatically generated

* On the left is the cropped image of the region you selected previously.
  + The red circles refer to the automatically detected circles from the circle finding algorithm. You might see more or less circles than the number of ROIs you are interested in; this depends a lot on the quality of the image.
* On the right is a dialogue box that allows you to adjust the parameters of the circle finding algorithm. There are a couple of parameters you can adjust:
  + Lower and upper radius range
    - These parameters control the minimum and maximum allowed radii of detected circles. If you’re finding circles that are much larger or smaller than the ROI, you can limit the range to mitigate that.
  + Sensitivity
    - This parameter controls how strictly circular the object needs to be to be recognized as a circle. The lower the sensitivity, the more circular the object needs to be. Try increasing this (to a maximum of 1) if you aren’t finding any circles or vice versa if you’re finding too many.
* Every time you adjust a parameter click OK to rerun the circle finding algorithm. If you are satisfied with the found circles, type 1 in the Accept field to accept them and move on to the next frame.
  + If you’re struggling to get the algorithm to find any circles, you can also just manually draw the circles around the ROIs. Type 1 in the Draw manually field and then use the cursor to drag a circle around the ROIs one-by-one.
  + If you try to continue on to the next frame but have more or less circles than the number of ROIs you defined at the beginning, the script will warn you and bring up the frame again.
* Once an initial circle has been found, you will then manually adjust the contour to more accurately fit the ROI. Remember, the QA method relies on accurate segmentations so try your best with these. A new image will pop up and go full screen. The circle you found early will appear over the ROI but this time it has been deformed to better match the ROI. This algorithm is not perfect so odds are you will need to do some adjustment to better match it.

A close-up of a person's head

Description automatically generated

* + You can click and drag the waypoints on the edge of the circle to adjust the contour. If you need more granularity, right click on an edge of the contour to add a waypoint or right click on a waypoint to delete it.
  + When you’re satisfied with the contour, double click anywhere in the contour to save it. If you have multiple ROIs in the image, you’ll repeat the same process.
* Repeat this for every frame in the bSSFP sequence (usually 20-30 frames)

### Flow Analysis

* You will then be prompted to select the folder containing the 2D Phase Contrast images
  + Once you have done so, you will likely need to wait a few seconds while some calculations happen in the background.
* Eventually, a new set of figures will pop up

A screen shot of a graph

Description automatically generated

* Your flow curve should look something like above. If it looks like it’s been shifted horizontally, then you’ll need to adjust that here.
  + You can enter a shift amount in milliseconds to shift the curve forward or backwards in time. Try to get it so the systole portion of the curve is at the beginning of the plot like above.
  + Once you’re satisfied with the shift, type 1 in the Accept field
* Another plot of the flow curve will appear

A screen shot of a graph

Description automatically generated

*Systole (red), early systole (black), diastole (green)*

* For the QA analysis, we need to select the early systole portion of the flow curve. Use the above diagram to determine where exactly that is.
  + Once you’ve decided, use your mouse cursor to draw around that region
* If you selected to also do the cardiac output analysis, you’ll be prompted to do the same for the systole and diastole portions of the curve. The tool will calculate the integral of the region of the curve you select to determine the volume of blood flow.
* If you have multiple ROIs in this image, you’ll need to then repeat the previous 2 steps for each one.
* Congrats! You have officially finished the QA analysis

### Results

* The calculated values will be displayed in the command window but they are all also saved in the analysis folder you picked at the beginning. Open a file browser and navigate to wherever you chose to save the 2DPC\_QA\_Analysis folder.
* An example layout of this folder is as follows:
  + 2DPC\_QA\_Analysis
    - abd
      * bssfp
      * hough+contours\_2024-03-22-1702
      * pc
    - arch
      * bssfp
      * hough+contours\_2024-03-22-1653
      * pc
* The arch and abd folders are analysis region names chosen at the beginning of the analysis. In this case they refer to the aortic arch and abdominal aorta.
* The bssfp and pc folders contain various output files generated during analysis such as the segmentation masks and raw flow values.
* The folders in the format [<segmentation method>\_<date-time>] contains the analysis results. You can reanalyze a case as many times as you want and new folders will be generated for each. Inside each folder, you’ll find an Excel file called results.xlsx. This contains the saved PWV-QA results as well as any cardiac output results and the interpolated area and flow values.
  + If you want to see the flow plots or QA plots again, you can open the \*.fig files and they will open in MATLAB allowing you to edit them