Project update: Using ScanIP and OpenFOAM to estimate FFR values using patient specific data.

David Tranter

University of Exeter

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Overview of project

In this project we have been given 35 dicom images of patients with a suspected stenosis that have had the FFR values obtained through surgery.

First we must design our simulations by addressing the physics of the problem. Then we can run our simulations and investigate which model, if any, produces an accurate estimation of the FFR values.

Overview of workflow of an individual simulation

Import dicom images into ScanIP software

$\downarrow$

Isolate artery with stenosis

$\downarrow$

Generate mesh of the model

$\downarrow$

Run simulation on mesh

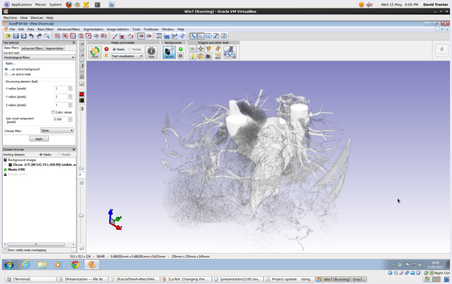
$\downarrow$

Post process simulation to investigate pressure values to calculate FFR

Overview of workflow of an individual simulation: pre processing

In ScanIP we can import the dicom files to being the processing of the image.

Setting the windowing levels is crucial to producing a good model. We need it narrow enough to isolate the artery but wide enough to fully capture the volume of the artery that blood can occupy.

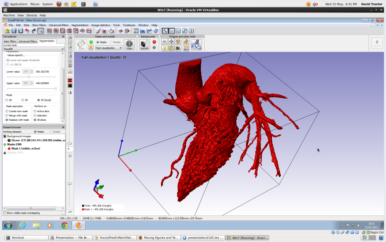


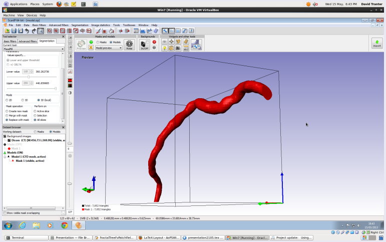
Overview of workflow of an individual simulation: pre processing

We can then isolate the artery by using various tools in ScanIP.

The result is a model which can be exported as an stl file for meshing in another program.

However ScanIP can generate good quality meshes with the +FE grid module.

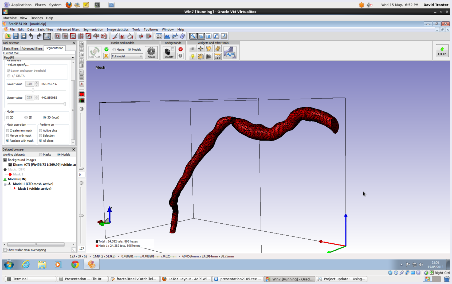




Overview of workflow of an individual simulation: pre processing

ScanIP uses the model to generate a mesh and can export to a format that OpenFOAM recognises.

We can adjust the size of the elements in the mesh easily and can also run additional algorithms to ensure mesh quality.



Overview of workflow of an individual simulation: run time simulation

One of the biggest challenges in this project is identifing suitable boundary conditions for the simulation.

The boundary conditions uniquely define the model and thus uniquely define the solution generated by the simulation.

In this project we will need a boundary condition for the inlet that will define how the blood enters the artery. We will also need a boundary condition that defines how blood leaves the artery. It is possible that we need to apply the outlet condition to many boundaries.

Overview of workflow of an individual simulation: boundary conditions

Candidates for the boundary conditions can be split up into two groups

- Time independent
- Time dependent

Overview of workflow of an individual simulation: boundary conditions

For time independant boundary conditions we assume:

- Prescribed constant flow rate at the inlet
- Constant pressure at the outlet

For this project we are not necessarily interested in the absolute values of the simulation solution, but the relative values of pressure generated by the stenosis.

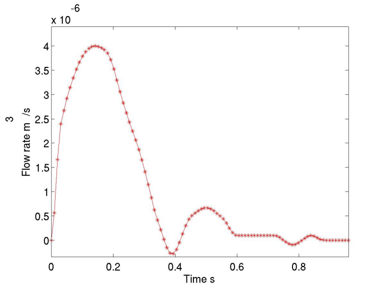
This suggests that we might be able to use simplified models to understand the effect a stenosis might have on the relative pressure drop and that this may be insensitive to the boundary conditions.

Overview of workflow of an individual simulation: boundary conditions

For time dependent inlet boundary conditions we assume that the inlet flow rate is periodic and pulsatile rather than purely sinusoidal.

Here we can use defined data points to prescribe a pulsatile flow inlet at each period in the simulation.

We can define different flow rates to match the expected physics of the inlet of the artery.



Overview of workflow of an individual simulation: boundary conditions

There is not necessarily an obvious choice for a time dependent outlet boundary condition.

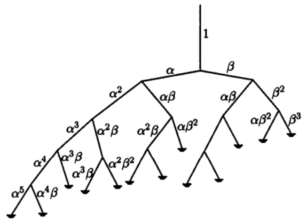
We could prescribe a constant pressure boundary condition like before, however we are not modelling possible downstream influences.

We could implement a 3d - 1d model whereby we model a 1 dimensional theoretical downstream and translate this to a time dependent pressure condition, however this is more complicated and computationally expensive.

Overview of workflow of an individual simulation: boundary conditions

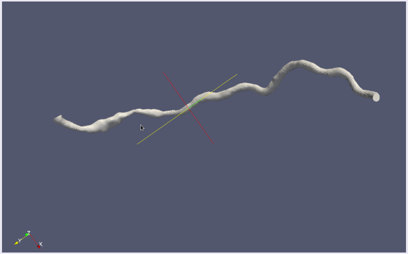
A candidate for a 3d-1d model to represent our truncated network is one based on a fractal tree. Here we create a tree of arteries to represent the rest of the network and derive what the pressure value would be at the root of the tree.

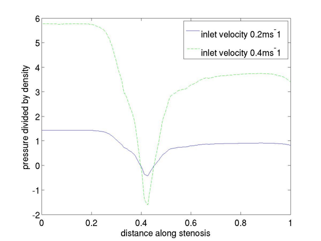
This then becomes our pressure value at the boundary of our computational domain.



Example simulation: steady flow

In this example we run a simulation with a constant inlet velocity and pressure outlet. The left image shows a 3d rendering of the model and the right image is a plot of pressure values of the middle of the artery across the stenosis. As we enter the stenosis we can see a drop in pressure and as we leave the stenosis the pressure recovers, but by not as much.



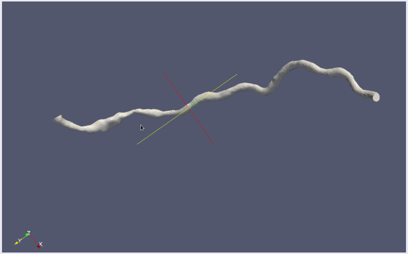


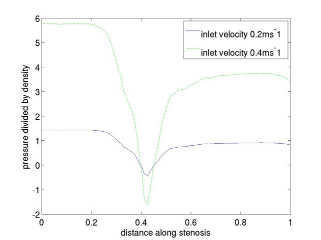
Example simulation: steady flow

In the plot we can see that, whilst the individual values of pressure differ across the two simulations, the profile and importantly the relative values of pressure before and after the stenosis are similar.

For inlet velocity of $0.2ms^{-1}$ the FFR can be taken as roughly 0.9/1.4 and for inlet velocity of $0.4ms^{-1}$ the FFR can be taken as roughly 3.73/5.77 which gives 0.64-0.65 respectively.

The FFR obtained through procedure was given as 0.67.





Simulation times and progress so far

On my personal computer the simulation times for the different types are listed below

- Time independent   0-3 minutes
- Time dependent   1-3 hours

So far in the project I have been able to run 10 cases through the time independent simulation. The rest of the time has been spent designing and coding the custom boundary conditions in OpenFOAM.

Next steps in the project

For the remainder of the project I plan on running simulations on the 35+ stensoses for 3 different simulation designs:

- Time independent inlet with constant pressure outlet
- Time dependent pulsatile inlet with constant pressure outlet
- Time dependent pulsatile inlet with fractal tree pressure outlet

Then we will compare the FFR values for each simulation to the ones obtained through procedure.

It will also be worth investigating the sensitivity of the FFR calcuation to different processing attempts in ScanIP.

Conclusion

- Establishing suitable boundary conditions crucial to the project
- Need to investigate behaviour of non-physical vs physical simulations
- Simulations to be done in blind runs on the remaining data

Open questions

- Can we confirm the accuracy of the flow rate inlet profile?
- Can we investigate the effect of the pressure instrument to the flow?

The End

References

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