Investigating Blood Pressure Losses at Junctions in Patient-Specific Simulations

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Research Objectives

- To compute blood flow with greater accuracy than existing reduced-order computational models by:
  1. Programming a junction model that measures blood pressure drops at bifurcations
  2. Assessing the accuracy of the junction model using data from a repository of time-dependent and patient-specific vascular models
  3. Implementing this junction model to an existing 0D and 1D reduced-order model

A Computational Approach to Cardiovascular Research

- 17.9 million people globally die from cardiovascular diseases each year. However, experimental cardiovascular research methods can be difficult and expensive.
- Reduced-order computational models allow for the study of real-world phenomena while using minimal computational resources.
- 0D and 1D reduced-order models offer a robust approach for predicting blood flow. However, existing models do not account for pressure changes at bifurcations*.

*A bifurcation is the splitting of blood vessels into two parts.

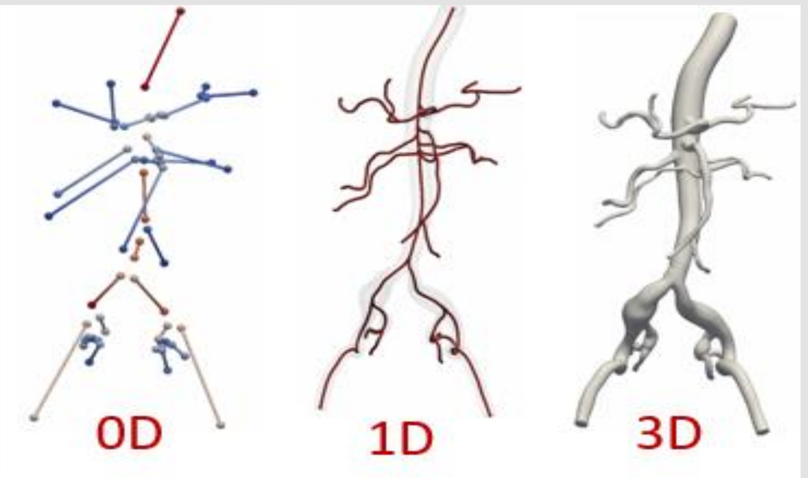


Figure 1: An example of 0D, 1D, and 3D models

Junction Model to Calculate Bifurcation Pressure Changes

- According to the approach of Mynard and Valen-Sendsatd (2015) resistance R_k at outlet k can be calculated using the following equation:

$$R_k = \frac{\rho Q_i}{2\Pi^2 r_i^4}\left[\frac{1}{Q_k} + \frac{Q_o r_i^4}{Q_i r_k^4} - \frac{2r_i^2}{Q_i r_k^2}\cos(\alpha_{(i,k)})\right]$$

- The Hagen-Poiseuille equation relates change in pressure P_k to flow rate Q_k and resistance R_k.

$$\Delta P_k = Q_k R_k$$

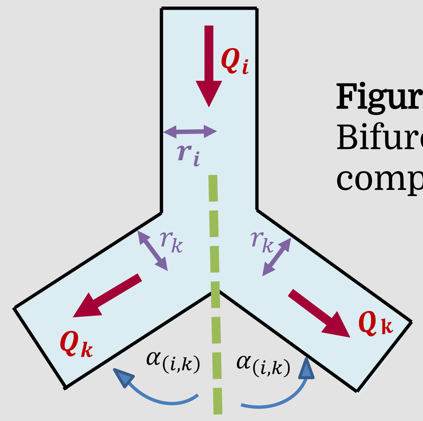


Figure 2: Bifurcation components

Q_i = inlet flow rate
r_i = inlet radius
Q_k = outlet flow rate
r_k = outlet radius
ρ = density of fluid
$\alpha_{(i,k)}$ = supplementary angle between inlet & outlet
R_k = outlet resistance
ΔP_k = change in pressure at outlet

Applying the Junction Model to Time-Dependent Patient-Specific Data

- The OSMSC* Cardiovascular Pulmonary Model Repository is composed of 105 vascular models with pressure and flow data from each model captured at different timestamps.
- Figures 3 and 4 demonstrate the same model at two different timestamps. Pressure_0.07500 contains pressure measurements with a greater maximum and greater minimum than Pressure_0.55000.
- These models are also patient-specific, with anatomies from seven categories: aorta, cerebrovascular, animal and misc, aortofemoral, congenital heart disease, pulmonary, and coronary.
- <u>Prior research has tested the junction model using steady state and not time-dependent data</u>

*OSMSC = Open Source Medical Software Corporation

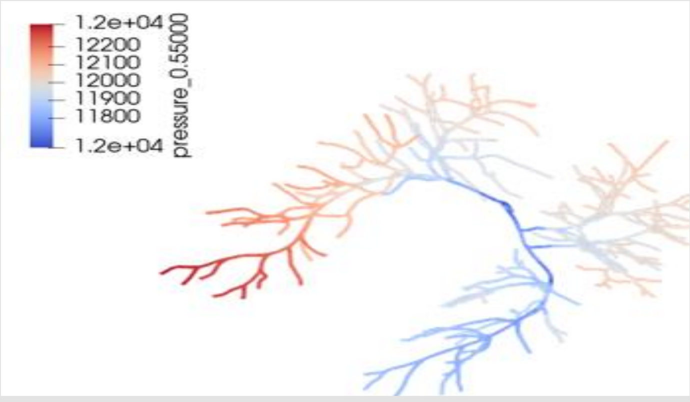


Figure 3: Pulmonary Model at timestamp pressure_0.55000

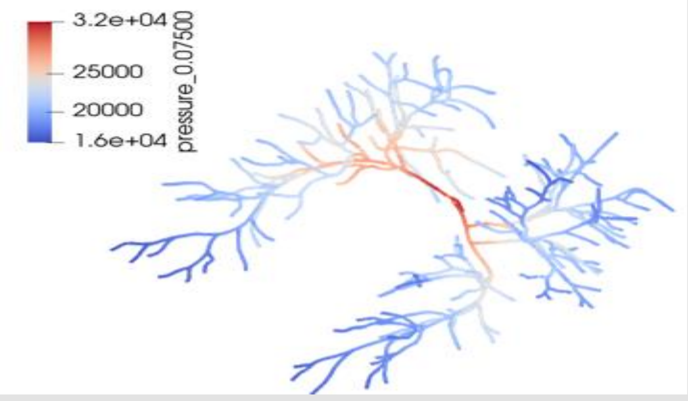


Figure 4: Pulmonary Model at timestamp pressure_0.07500

Analysis of Performance of Junction Model

$$\text{percent error} = \left|\frac{\text{junction} - \text{actual}}{\text{actual}}\right|(100)$$

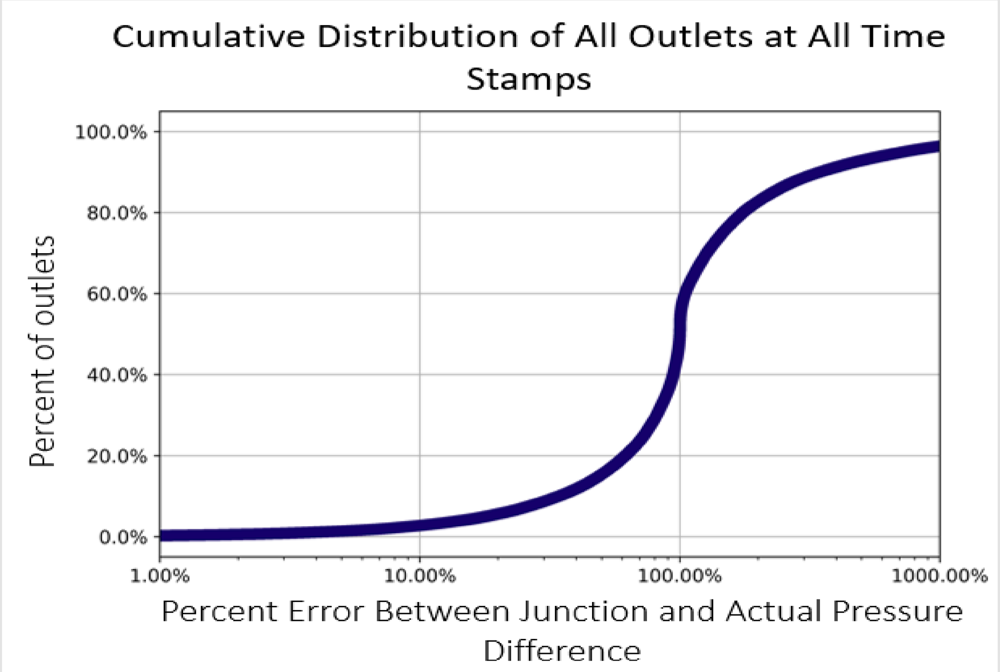


Figure 5: Cumulative distribution graph of the percent error of the junction model applied to each timestamp of every outlet

- We calculated the accuracy of the junction model using the formula on the left, where actual is found by calculating the difference between inlet and outlet pressure of the given model repository data.
- The graph illustrates the percent error calculated at each timestamp for each outlet.
- Since multiple timestamps exist for each model, this approach produced a total of close to **200,000 data points.** Of these points, close to 60% produced an error of 100% or less.
- Existing models do not take pressure change into consideration at all so current error is always one hundred percent $\frac{0 - actual}{actual}(100) = 100\%$

Further Analysis – Selecting a Specific Timestamp

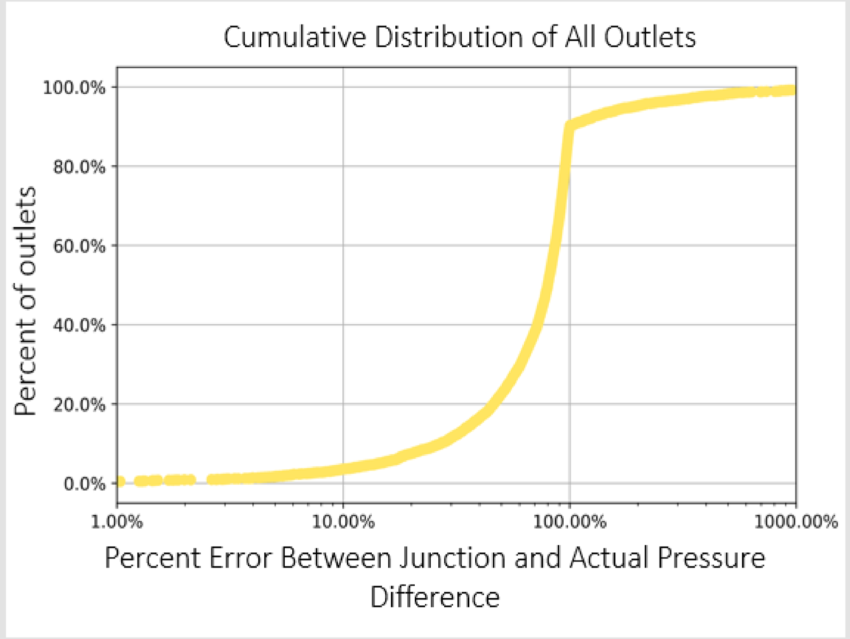


Figure 6: Data found at specific timestamp

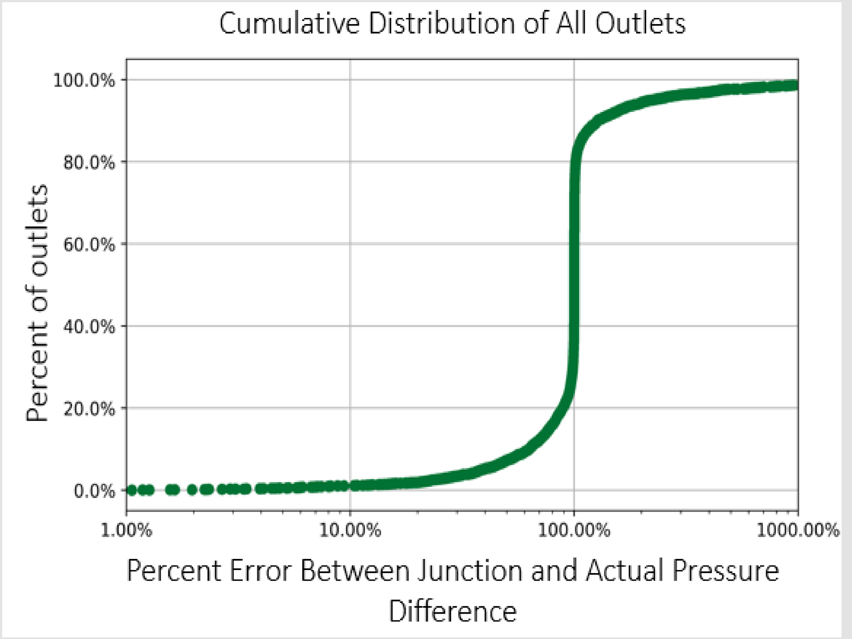
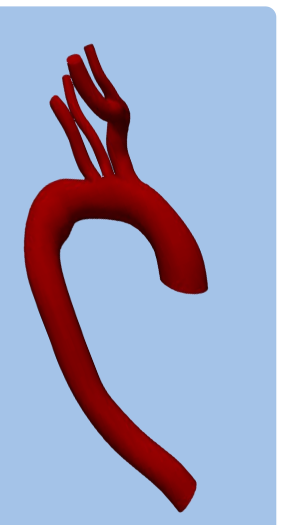


Figure 7: Data found at specific timestamp

- Figure 6 uses the timestamp that produces the largest difference between inlet and outlet pressure measurements. It demonstrates that around 80% of the outlets have an error of below 100%.
- Figure 7 uses the timestamp that produces the smallest difference between blood flow measurements at the inlet and outlet. Although roughly 80% of the data is at or below 100%, over 60% of it is closer to 100%

Conclusion and Next Steps



- There is a great variability between timestamps. Before we can implement the junction model, we must identify what is causing these large errors.
- Our next step is to check whether this formula works better for some anatomy types over others. We will be creating graphs for each of the 7 anatomy types.
- Finally, in order to see the full effect the junction model has on analyzing cardiovascular flow, we must implement it into the 0D and 1D solver and analyze the results.

Resources

1. Chnafa, C., et al. "Improved Reduced-Order Modelling of Cerebrovascular Flow Distribution by Accounting for Arterial Bifurcation Pressure Drops." *Jounrals of Biomechanics*, vol 51, 2017.
2. Mirramezani Mehran, et al. "A Distributed Lumped Parameter Model of Blood Flow" *Annals of Biomedical Engineering*, 2020.
3. Mynard, Jonathan P, and Kristian Valen-Sendstad. "A Unified Method for Estimating Pressure Losses at Vascular Junctions" *A Unified Method fo Estimating Pressure Losses at Vascular Junctions*, 2017.

Acknowledgements

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