A Numerical Study of Bypass Graft Geometry Effects on Graft Longevity in Coronary Artery Bypass Surgery

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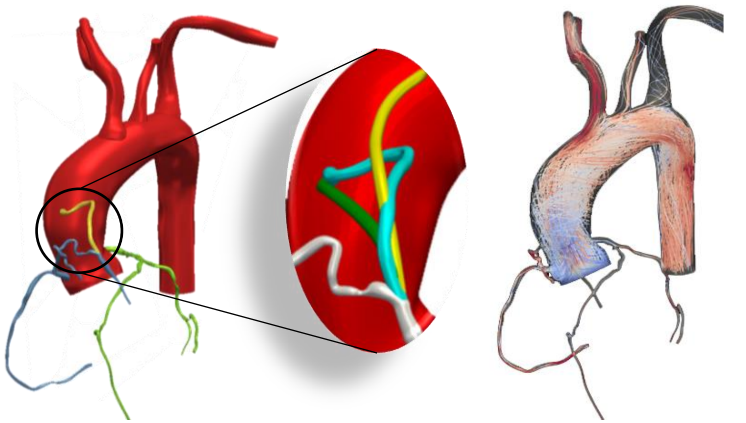
Background & Objectives

- Coronary artery disease (CAD) is the leading cause of death worldwide.
- Coronary artery bypass graft (**CABG**) surgery is an effective treatment of severe, and multi-vessel disease.
- With time, the **bypasses degenerate** via the same mechanisms as the native vessels.
- Graft complications require further medical intervention; **increasing the costs** of treatment and care, and **decreasing the patient's quality of life**.

- Several modes of **vessel occlusion** have been **linked** to disturbed and **unfavourable haemodynamics**.
- Computational Fluid Dynamics (**CFD**) can be used to **non-invasively** estimate the haemodynamics through a virtual reconstruction of a patient's anatomy.
- We aim to use CFD to assess the impact of a CABG's bulk-body geometry on the local haemodynamics that dictate its long-term performance.

Methodology

- Post-operative volumetric images captured via coronary computed tomography angiography (**CCTA**) were supplied alongside **4D MRI** data for several CABG recipients.
- Their anatomy (aorta + branches, coronaries & bypasses) were reconstructed using **SimVascular** (SV).
- Each model was tuned to match their clinical dataset, by applying accurate inlet flowrates and outlet boundary conditions (3-element Windkessel & SV's specialised coronary outlet).
- A healthy comparative case was prepared by removing the native-vessel stenosis and in-situ bypasses.
- A single native-vessel was returned to severe occlusion and virtual surgery was then performed.

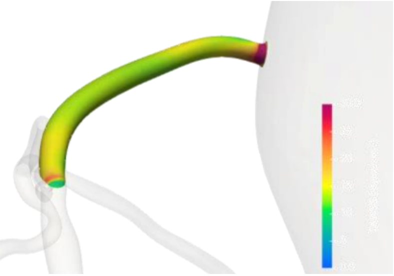


- Several CABG designs were created by modifying the length, shape, and proximal anastomosis location of each graft.
- Each design maintained a uniform diameter, proximal and distal anastomosis angle, and distal anastomosis location.
- Time-averaged wall shear stress (TAWSS) and oscillatory shear index (OSI) have been used to evaluate the total surface area of each bypass at-risk of degeneration, based upon literature values.

$$\mathbf{TAWSS_{Prone}} = \left(\frac{\int_{A_{graft}}^{1} \mathbf{f}\, dA}{\int_{A_{graft}}^{1} dA}\right), \qquad \mathbf{f} = \begin{cases} \mathbf{1}, & \overline{\tau_w} < \ \mathbf{4\ dyn \cdot cm^{-2}} \\ \mathbf{1}, & \overline{\tau_w} > \mathbf{25\ dyn \cdot cm^{-2}} \\ \mathbf{0}, & \boldsymbol{otherwise} \end{cases}$$

$$\boldsymbol{OSI_{prone}} = \left(\frac{\int_{A_{graft}}^{1} \mathbf{f}\, dA}{\int_{A_{graft}}^{1} dA}\right), \qquad \mathbf{f} = \begin{cases} \mathbf{1}, & \boldsymbol{OSI > 0.15} \\ \mathbf{0}, & \boldsymbol{otherwise} \end{cases}$$

Results



- Each CABG configuration has been compared against the healthy baseline model, the in-situ bypass, and each other.
- Preliminary results have demonstrated a profound impact of graft shape to the observed haemodynamics.
- Time-averaged velocity, observed across the anastomoses and through at the middle of the bypass, differed by 227% between configurations, changing the distal coronary perfusion by 45%.
- The total surface area deemed 'at-risk' due to pathological levels of TAWSS and OSI had upper and lower values of 30% and 2% respectively between designs.
- Similarly, regions susceptible to thrombus formation, identified via the endothelial cell activation potential (ECAP) metric, also had variations of 30%.

Discussion & Conclusion

- These results evidence the large impact bulk-body shape has on the local haemodynamics, and therefore CABG longevity.
- Current surgical practice relies on the surgeon's intuition and experience in determining a CABG's shape.
- This research aims to expand to present a surgical guideline where there currently is none.

References:

Ghista, D. N et al. 2013. Biomed Eng Online. doi: 10.1186/1475-925X-12-129.

Ramachandra, A. B. et al. 2016. JCTR. doi: 10.1007/s12265-016-9706-0.