The impact of boundary slip conditions on vortex formation and vorticity in aortic flow simulations

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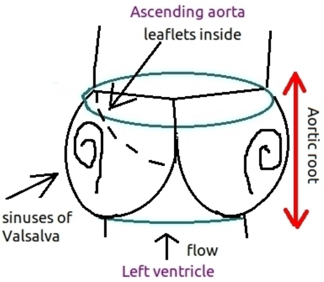
VPH 2020, August 26, 2020

Motivation - Aortic root

Leonardo da Vinci hypothesis:

- Sinuses of Valsalva are required for vortices formation
- vortices are required for normal aortic valve closure



B. J. Bellhouse and F. H. Bellhouse. (1968): *Mechanism of Closure of the Aortic Valve.* In: Nature, 217(5123),86–87.

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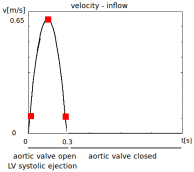
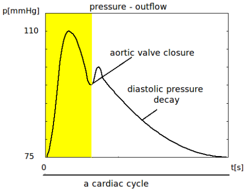
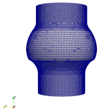
Model







$$\operatorname{div} \mathbf{v} = 0 \quad \& \quad \rho_* \left(\frac{\partial \mathbf{v}}{\partial t} + (\nabla \mathbf{v})\, \mathbf{v} \right) = \operatorname{div} \mathbf{T}$$

$$\mathbf{T} = -p\mathbf{I} + \mu_* \left(\nabla \mathbf{v} + \nabla \mathbf{v}^T \right)$$

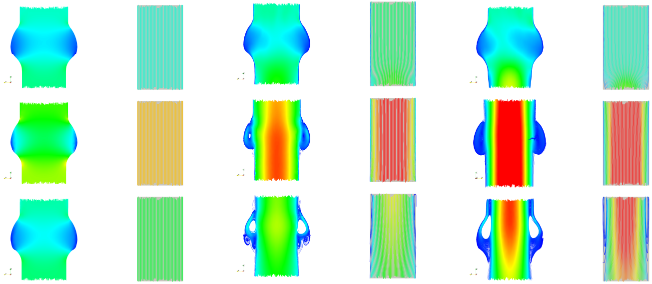
$$\mathbf{v} \cdot \mathbf{n} = 0 \text{ and } \theta \mathbf{v}_\tau = \gamma_* (1-\theta)(\mathbf{T}\mathbf{n})_\tau \qquad \text{on } \Gamma_{wall}$$

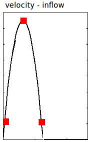
$$\mathbf{v} = -\overline{V(t)} \frac{4\mu_* R(1-\theta) + 2\theta(R^2 - \rho_X^2)}{4\mu_* R(1-\theta) + \theta R^2} \mathbf{n} \qquad \text{on } \Gamma_{in}$$

$$\mathbf{T}\mathbf{n} = -\frac{\overline{P(t)}}{\rho_*} \mathbf{n} + \frac{1}{2} (\mathbf{v} \cdot \mathbf{n})_- \, \mathbf{v} \qquad \text{on } \Gamma_{out}$$

Tubular vs. sinus containing - velocity

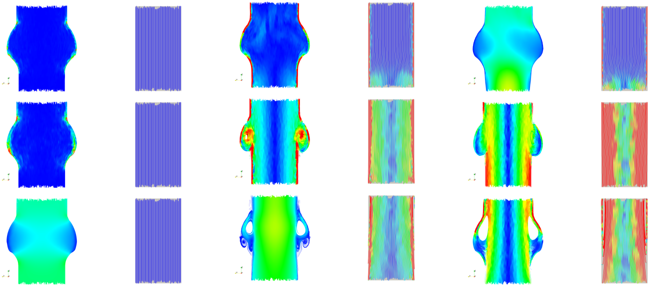
$\theta = 0$ slip	$\theta = 0$ slip	$\theta = 0.500$	$\theta = 0.500$	$\theta = 1$ no-slip	$\theta = 1$ no-slip

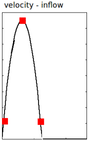




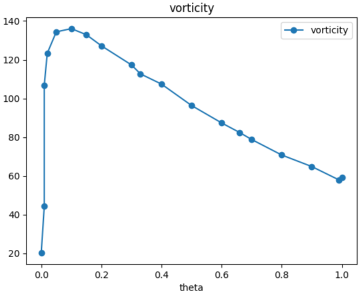
Tubular vs. sinus containing - vorticity

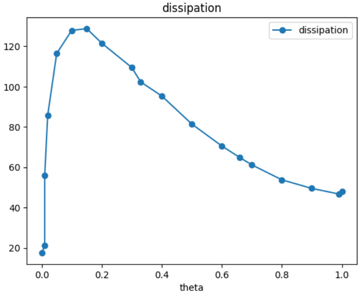
$\theta = 0$ slip	$\theta = 0$ slip	$\theta =$ 0.500	$\theta =$ 0.500	$\theta = 1$ no-slip	$\theta = 1$ no-slip





Vorticity and dissipation





$$vorticity = \frac{1}{SEP} \int_{\mathrm{SEP}} \frac{\int_{sinuses} \mathrm{mag}(\mathrm{curl}\mathbf{v})\, \mathrm{dx}}{volume(sinuses)}\, dt$$

$$dissipation = \int_{\mathrm{SEP}} \frac{\int_{\Omega} 2\mu_* |\mathbf{D}(\mathbf{v})|^2\, dx}{volume}\, dt$$

Conclusion

- Sinuses of Valsalva are required for vortices formation
- the function of the vortices remains unclear, the results suggest that their presence lowers the pressure difference between the proximal and distal part of the aortic root but long term results (15years) show similar aortic valve functionality for tubular and sinus containing Dacron graft
- model with no-slip parameter on the boundary does not have the highest vorticity in the sinuses in comparison with the models with the partial slip
- no-slip is probably not the best boundary condition for computational models as some slip occurs at the boundary

Funding

This work was supported by the project 18-12719S financed by GAČR, the project no. 17-32872A financed by AZV ČR and the Inria-UT Southwestern Medical Center Dallas associated team TOFMOD.