DATA-DRIVEN GENERATION OF INLET VELOCITY PROFILES FOR CFD MODELLING IN THORACIC AORTIC ANEURYSMS

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Introduction

Computational fluid dynamics (CFD) has emerged as a powerful tool to investigate development and growth of aortic aneurysms. Previous works [1,2] showed that inlet boundary conditions (IBC) are crucial to accurately reproduce blood flow features in the ascending aorta. However, the availability of *in vivo* measurements to be used as IBC is limited. This hinders progress of research on ascending aortic disease. With this work, we aimed to address this issue by proposing a data-driven generative model of 4D aortic velocity profiles suitable for use in CFD modelling of the ascending aorta.

Methods

By exploiting principal component analysis (PCA), a statistical shape model (SSM) of 4D aortic inlet velocity profiles was developed starting from 4D flow magnetic resonance imaging scans of 30 subjects with ascending thoracic aortic aneurysm. Using the SSM, a dataset of 500 synthetic cases was generated. Velocity profiles from both the clinical and synthetic cohorts were extensively characterized by computing flow morphology descriptors (e.g., flow jet angle – FJA, retrograde flow index, secondary flow index) of both spatial and temporal features. The synthetic dataset was then further refined by excluding generated profiles which presented flow descriptors outside the physiological range observed in the clinical cohort. This selection resulted in the acceptance of 437 synthetic profiles with realistic properties.

Results

Statistically significant correlations were found between PCA principal modes of variation and flow descriptors in the synthetic cohort: mode 1 strongly correlated ($p<0.0001$) with positive peak velocity (PPV, $r=0.94$) and with the spatial heterogeneity of the velocity magnitude (quantified by the flow dispersion index, FDI [2], $r=0.99$), mode 2 strongly correlated with the FJA ($r>0.99$). The average velocity profile (Fig.1) obtained by the conducted PCA qualitatively resembled a parabolic-shaped profile but was quantitatively characterized by more complex features, such as 13° FJA at peak systole and non-null in-plane velocity. T-tests and Mann–Whitney U tests confirmed that no significant differences ($p>0.05$) existed between the clinical and synthetic cohorts (Fig.2), except for PPV ($p = 0.040$; clinical: 0.59 ± 0.12 m/s, synthetic: 0.56 ± 0.08 m/s).

Discussion

We investigated features of velocity profiles in the ascending aorta using SSM. Our results show significant inter-patient variability in eccentricity and orientation of these velocity profiles. This further supports the need for more realistic IBCs for CFD simulations of the ascending thoracic aorta. From the SSM we generated a cohort of 437 synthetic profiles with features overlapping the original cohort and that are suitable for use as IBC. We believe that the present work will contribute to the replacement of idealized IBCs in numerical simulations of blood flow with more realistic conditions. To this end, we have released all synthetic profiles [3].

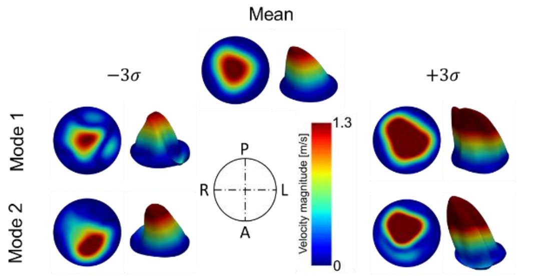

Figure 1: 2D and 3D visualizations of peak systolic velocity profiles: mean profile (top) and profiles deformed towards ± 3 standard deviations (σ) for the first 2 modes (central and bottom rows). Profiles are colored by velocity magnitude.

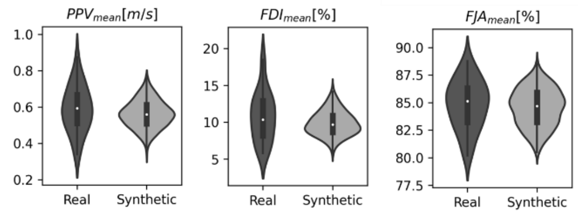

Figure 2: Violin plots showing distributions of 3 time-averaged flow descriptors for real and synthetic cohorts.

References

1. Pirola S, et al. *APL Bioeng*. 2018;2(2):026101
2. Youssefi P, et al. *J Biomech Eng*. 2018;140(1):011002
3. Saitta S, et al. arXiv 2022, https://arxiv.org/abs/2211.00551

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