4D FLOW MRI & NETWORK-BASED ANALYSIS OF THE HEMODYNAMIC CORRELATION PERSISTENCE LENGTH IN THE HEALTHY AORTA

Karol Calò (1), Andrea Guala (2), Diego Gallo (1), Jose Rodriguez Palomares (2), Stefania Scarsoglio (1), Luca Ridolfi (3), Umberto Morbiducci (1)

1. PoliTo^{BIO}Med Lab, Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Italy; 2. Department of Cardiology, Vall d'Hebron Institut de Recerca, Spain; 3. PoliTo^{BIO}Med Lab, Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, Italy

Introduction

The approaches currently adopted to characterize the large-scale aortic flow structures are mainly based on integral quantities. Thus, they do not fully capture the complexity of the aortic hemodynamics. To contribute to close this gap, this study proposes a novel network-based approach [1] to characterize the spatiotemporal aortic flow coherence in a 4D flow MRI dataset of healthy human aortas. The correlation between the subject-specific inflow rate $Q(t)$ waveform and the axial velocity waveforms obtained from *in vivo* velocity data at each voxel was used to build a *"one-to-all"* network [2]. The anatomical length of persistence of this correlation was then quantified using an ad-hoc network metric to explore its association with the flow rate waveform cycle-average value and dynamics.

Methods

The study population comprises 41 healthy volunteers. The 4D flow MRI acquisition protocol is described in [3]. For each subject, the thoracic aorta lumen was reconstructed. The inflow rate $Q(t)$ waveform at the sinotubular junction (STJ) section and the axial velocity component $V_{\mathrm{ax}}(t)$ waveform in each voxel of the aortic fluid domain were extracted from the measured phase velocity data (**Fig.1**). To study the effect of the subject-specific $Q(t)$ waveform's shape on the large-scale aortic flow, a *"one-to-all"* network was built for each subject. The network nodes are represented by the center of mass of the STJ section (where $Q(t)$ is measured) and by all the voxels of the aortic domain. The link between the STJ node and each voxel *i* was weighted by the Pearson correlation coefficient R_i^Q between $Q(t)$ and $V_{\mathrm{ax}}(t)$ at that voxel. To quantify the length of persistence of the $Q(t)$ *vs.* $V_{\mathrm{ax}}(t)$ correlation, the curvilinear distance s_{i-STJ} between the STJ node and each voxel i was calculated along the centerline, weighted by the R_i^Q value and averaged over all the N voxels, obtaining the ad-hoc network metric *Averaged Weighted Curvilinear Distance AWCD* [2] (**Fig. 1**). To account for geometric intervariability, *AWCD* was normalized to the curvilinear length l of the aorta.

Results

The R_i^Q volumetric maps (only values above the median value $\widehat{\mathrm{R}^Q} = 0.69$ of the combined distribution of all subjects are visualized), together with *AWCD* values are presented in **Fig. 1** (lower panel) for three explanatory cases. In subject A, the dynamical similarity between axial flow and inflow rate waveforms only persists for 13% of the aorta full length; in subject B, the anatomical persistence length of the correlation extends to the entire ascending aorta; in subject C, it extends to 39% of the entire aortic length. Notably, *AWCD* was positively associated with the cycle-average flow rate $\bar{Q}$ (R=0.66, p<0.001), as well as with $Q(t)$ peak-to-peak amplitude Q_{p-p} (R=0.42, p<0.01). Significant differences (p<0.05) emerged in *AWCD* values when the 41 subjects were stratified in three groups based on $\bar{Q}$ or Q_{p-p} tertiles (Q_{p-p}: box plot in **Fig.1**).

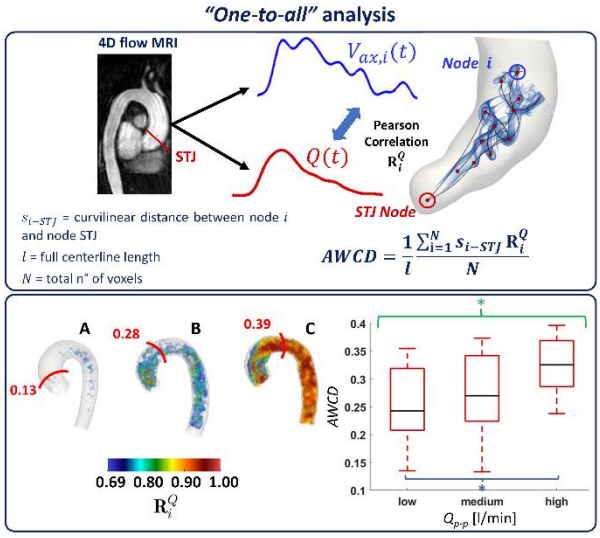

*Figure 1: Overview of methods and results. Lower panel: R_i^Q volumetric maps with AWCD (red line); box plots of AWCD stratified by Q_{p-p}. * p<0.05.*

Discussion

The applied network approach allows to quantify *in vivo* the physiological anatomical length over which the inflow rate waveform markedly shapes the large-scale flow in aorta. Such correlation persistence length is positively correlated with the flow rate waveform cycle-average value and dynamics. In the future, the *AWCD* could be applied to not invasively measure the impact of aortic pathologies or surgical interventions on the spatiotemporal aortic flow coherence.

References

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