IN VIVO AORTIC HEMODYNAMICS ANALYSIS COMBINING COMPLEX NETWORKS THEORY AND 4D FLOW MRI

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Introduction

In the progression of the ascending aorta (AAo) dilation a relevant role is played by local adverse hemodynamics, which in turn stimulates adverse biological reactions ultimately leading to fatal events such as aneurysms rupture. In this study, the spatiotemporal heterogeneity of large-scale aortic flow features is investigated *in vivo* for the first time applying the Complex Networks (CNs) theory [2] to 4D flow MRI data of ten patients, five of them presenting with AAo dilation [1]. Technically the acquired time-resolved phase velocity data were used to build correlation-based CNs. Then, the anatomical and functional length of persistence of the correlation of velocity time histories were quantified and their association with *in vivo* measurable hemodynamic quantities as well as AAo dilation was explored.

Methods

Study methods are summarized in **Fig.1**. The study population comprises five patients presenting with AAo dilation and five with no AAo dilation. Full details on 4D flow MRI acquisition protocol are exhaustively reported elsewhere [1]. For each patient, the thoracic aorta lumen geometry was reconstructed and three CNs were built on the time-resolved waveforms obtained from *in vivo* data of: velocity magnitude |V|; (through-plane) axial velocity component V_{ax} [3]; (in-plane) secondary velocity component V_{sc} [3]. Each node of the CNs was defined by the voxel where the velocity-based time history is acquired. Two nodes were connected by a topological link if the Pearson correlation coefficient R_{ij} between the time histories at nodes i and j was greater than a threshold $\hat{R}$ (**Fig. 1**). For each CN an adjacency matrix A_{ij} was built and three metrics were computed [2] (**Fig. 1**): (1) the *degree centrality* (DC_i) of node *i*, measuring the homogeneity/heterogeneity of the time history in *i* with respect to the whole fluid domain; (2) the *normalized average Euclidean distance* (AED_i) between node *i* and all its nearest neighbours, and (3) the *average shortest path length* ($ASPL$). AED_i and $ASPL$ quantify the anatomical and topological length of persistence of the correlation between velocity time histories in the aorta, respectively [2].

Results

DC volume maps, displayed in **Fig.1**, show that |V| and V_{ax} CNs are scarcely connected (low DC), reflecting from very poor to moderate homogeneity of velocity time history shapes. The CNs of V_{sc} time histories presented patterns of connections between nodes denser than |V| and V_{ax}. Notably, AED was negatively associated with AAo maximum diameter D_{max}, whereas $ASPL$ was positively associated with D_{max} only in |V| CNs, indicating that, in general, high D_{max} values reduce the anatomical extension of the correlations among velocity waveforms and increase voxels topological separation. No links emerged between CNs metrics and kinetic energy and flow eccentricity.

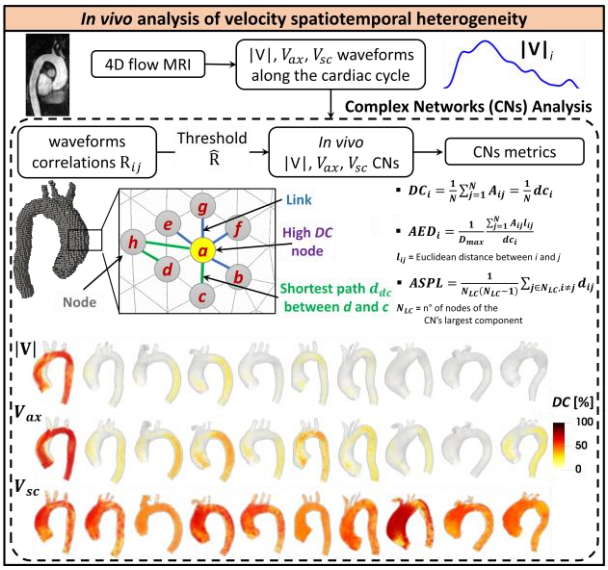

Figure 1: Schematics of the study design and DC maps.

Discussion

The CNs-based analysis of 4D flow MRI aortic data suggests that AAo dilation plays a major role in disrupting spatiotemporal similarity in velocity waveforms, causing a marked reduction of the physiological Euclidean and topological length of correlation persistence in patients with larger maximum AAo diameter. Apart of basic knowledge of the aortic hemodynamics, our findings suggest that *in vivo* measurable CNs distance metrics may contribute to a finer risk stratification of AAo disease.

References

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3. Morbiducci et al., J Biomech, 48.6:899-906, 2015.