A STATISTICAL SHAPE MODELING FRAMEWORK TO CORRELATE MORPHOLOGY AND HEMODYNAMICS OF COMPLEX GREAT VESSELS

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Introduction

Statistical Shape Models (SSMs) are well-established tools for assessing the variability of vascular geometries. Starting from a heterogenous population, SSMs can provide useful biomarker information, in terms of geometrical features (i.e. size, curvature, orientation). This technique is based on a non-rigid registration, which may be challenging to perform with complex anatomies. In the context of vascular anatomies, several studies have been presented [1,2], mainly focused on the aorta with the exclusion of the supra-aortic branches. To overcome this limitation, which is also reflected in the subsequent Computational Fluid Dynamics (CFD) clustering studies, we developed a non-rigid registration algorithm. The purpose of this work is to demonstrate the potentiality of this novel algorithm as applied to a different great vessel, the pulmonary artery. Moreover, a correlation study between the morphological and hemodynamic features is reported, obtained from SSMs and CFD simulations, respectively.

Methods

A total of 21 segmented pulmonary arteries and 28 aortas were considered, originated from MRI and CT images respectively. All the pulmonary arteries were affected by Tetralogy of Fallot. The dataset of thoracic aortas included both healthy and aneurysmatic cases. All the datasets were segmented in 3D-Slicer using a region-growing algorithm. The segmented geometries were used to develop the SSM, by registering a template geometry on all the other target geometries of the dataset. Starting from previous work [3], we developed an in-house algorithm for the non-rigid registration based on (i) a modified second order gradient descent approach, (ii) a loss function based on the minimization of chamfer distance and (iii) four steps of remeshing. The second step was performed to achieve the dimensionality reduction of the problem to few meaningful geometric features through the application of Principal Component Analysis. The first principal components (or modes), significant for about 98% of the total variance, were used to reconstruct 5 new geometries by varying the most significant mode from -2 to +2 standard deviation (SD). A progression in the shape was observed for both pulmonary artery and aorta and the resulting geometries were used to assess the effects of morphological variability on the correspondent CFD models. Simulations were carried out using ANSYS Fluent, considering the fluid as Newtonian and a laminar flow. For the hemodynamic analysis the wall shear stress, its related indexes (i.e. OSI, TAWS) and the flow split (only for the pulmonary arteries) were evaluated. Finally, an analysis of correlation was performed between the morphological and the hemodynamic features to derive a relationship between shape, fluid dynamics and pathology.

Results

Although most of the target geometries presented very peculiar shapes, different from source mesh one, a maximum error of 0.7 mm in the registrations was obtained by applying the proposed novel algorithm. By varying the first mode, a progression in the shape from a short, straight and corrugated to a long and curved pulmonary artery was observed; meanwhile, for the thoracic aortas it was noticed a progression from healthy to completely aneurysmatic aorta. All these results were in perfect agreement with the composition of our initial datasets. Moreover, significant correlations between the variation of the first mode, and hence the variation in size, and hemodynamical parameters were discovered (example on OSI variation reported in Figure 1).

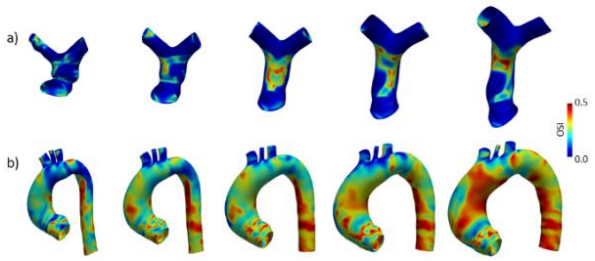

Figure 1: OSI values on geometries generated by the variation of the first mode from -2 (left) to +2 (right) SD for pulmonary vessel (a) and aorta (b).

Discussion

In this work we aimed to highlight the potential of SSMs to generate new realistic vascular anatomies for CFD simulations and the versatility of the presented novel algorithm. In fact, good non-rigid registration results were achieved not only over widely different geometries but also between different vascular districts.

References

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