A MULTI SOURCE STATISTICAL SHAPE ANALYSIS FRAMEWORK FOR COMPLEX CARDIOVASCULAR STRUCTURES

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Introduction

Tomographic clinical datasets such as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) provide fundamental information regarding diagnosis and treatment management. However, in clinical practice, anatomical analyses are carried out via simple morphometric parameters measured in 2D. Statistical shape modelling (SSM) provides a powerful tool for describing and analysing shape complexity. In the context of cardiovascular districts, several studies have been presented [1], mainly applied to the aorta. However, they present several limitations since they do not include the whole complexity of the thoracic aortic tract, excluding the supra-aortic vessels from analysis. In order to overcome this limitation, we developed a non-rigid registration algorithm. The purpose of this work was to demonstrate the power of this innovative algorithm by applying it to a different cardiac district, the pulmonary artery.

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 vessels. All the datasets were segmented in 3D-Slicer by using a region-growing algorithm. The segmented geometries were used to develop the SSM, where a template geometry has to be registered on all the other target geometries of the dataset. Starting from previous work [2], we developed an in-house algorithm for non-rigid registration based on (i) a modified gradient descent approach of the second order, (ii) a loss function based on the minimization of chamfer distance and (iii) four steps of remeshing. First of all, we carried out a rough preliminary non-rigid registration. Then, we built a new template as the mean shape of the registered meshes. This template was used to achieve a final, finer and more accurate non-rigid registration on all the target meshes, even on those where the initial registration was not correct. The second step was the use of PCA to achieve dimensionality reduction of the problem to few meaningful features that accurately represented individual characteristics in terms of size, curvature, orientation and so on. The results of our code were also compared with those obtained using the most widely used software in the literature for the non-rigid registration, such as Deformetrica and Gias2.

Results

It can be observed that, even though most of the target geometries presented very peculiar shapes, different from the one of the source mesh, excellent registration results were obtained by applying the proposed novel algorithm, as reported in Figure 1. The first 15 principal components (or modes), significant for more than 98% of the total variance, were used to reconstruct new geometries varying the first modes from -2 to +2 standard deviation. 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, a significant improvement was detected with our code in comparison with the software available in literature through which most of the registrations failed.

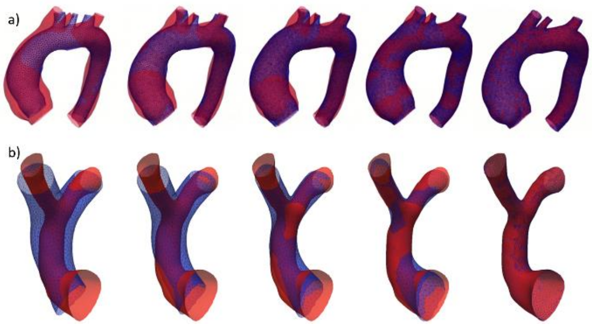

Figure 1: Examples of five frames of the registration process from CT for aortic (a) and from MRI for pulmonary vessel (b).

Discussion

In this work we wanted to highlight the power and the versatility of our innovative algorithm. In fact, the presented algorithm was able to provide excellent non-rigid registration results not only over widely different geometries but also between different cardiovascular districts.

References

1. Bruse et al, J Thorac Cardiovasc Surg, 153.2: 418-427, 2017.
2. Nicolet et al, ACM Trans Graph, 40(6):1–13, 2021.