A MRI-based framework for the analysis of aortic morphometry: a first application to diastolic dysfunction.

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INTRODUCTION Whole heart MR imaging is regarded as a valuable tool for the diagnosis of cardiac and coronary artery pathologies [1]. The acquired datasets can be further processed offline to investigate on the existence of relationships between the morphology of the thoracic anatomy and diastolic dysfunction [2]. In diastolic dysfunction a set of changes in the cardiac mass, orientation and function has the potential to affect the mechanical loading and morphology of the aorta. In parallel, induced alterations in the arterial reflections and in the aortic geometry may result in unfavorable late systolic pressure augmentation, a factor that promotes diastolic dysfunction [3]. As a result, it becomes relevant to consider a morphometric analysis of the aorta as a possible factor for risk stratification. In this study we developed a platform to analyze aortic morphologies with the final aim to identify, if any, those parameters presenting marked differences between healthy and diastolic dysfunction subjects.

METHODS We retrospectively analyzed 3D datasets of thoracic anatomy of 10 subjects with suspected diastolic dysfunction and of a control group (10 subjects, matched for age and gender) with normal LV geometry and function. Diastolic dysfunction was considered in the presence of (1) normal LV end-diastolic volume, normal LV ejection fraction and increased LV mass (>78 g/m^2 in men; >70 g/m^2 in women), (2) increased LV wall thickness (>12 mm), or (3) concentric remodeling (mass to LV diastolic volume ratio >1). 3D MR datasets were acquired for all subjects on a 1.5T clinical MRI scanner (MAGNETOM Aera, Siemens AG, Healthcare Sector, Erlangen, Germany). Data acquisition was performed with a 3D radial trajectory implementing a spiral phyllotaxis pattern, adapted to self-navigation [4]. The 3D SN ECG-triggered acquisition started approximately 4min after injection of a 2mmol/kg bolus of Gadobutrol (Gadovist, Bayer Schering Pharma, Zurich, Switzerland). Imaging parameters were: TR/TE 3.1/1.56 ms, FOV (442 mm)^3, matrix 384^3, acquired voxel size (1.15 mm)^3, radio frequency (RF) excitation angle 115°, and receiver bandwidth 900 Hz/Pixel. The trigger delay was set to mid-diastole. The segmentation of the aorta was performed with the 3D active contour toolbox of ITK-snap and it was based on intensity regions. The aortic centerline, **C,** was calculated within the Vascular Modeling ToolKit (VMTK, www.vmtk.org) as the geometrical locus of the centers of the maximal inscribed spheres in the geometry. The morphometric analysis of the centerlines was performed after obtaining an analytical curve formulation where the 3D free-knots regression splines were selected as a basis of representation for the centerline [5]. The curvature κ and the torsion τ were defined along **C** as:

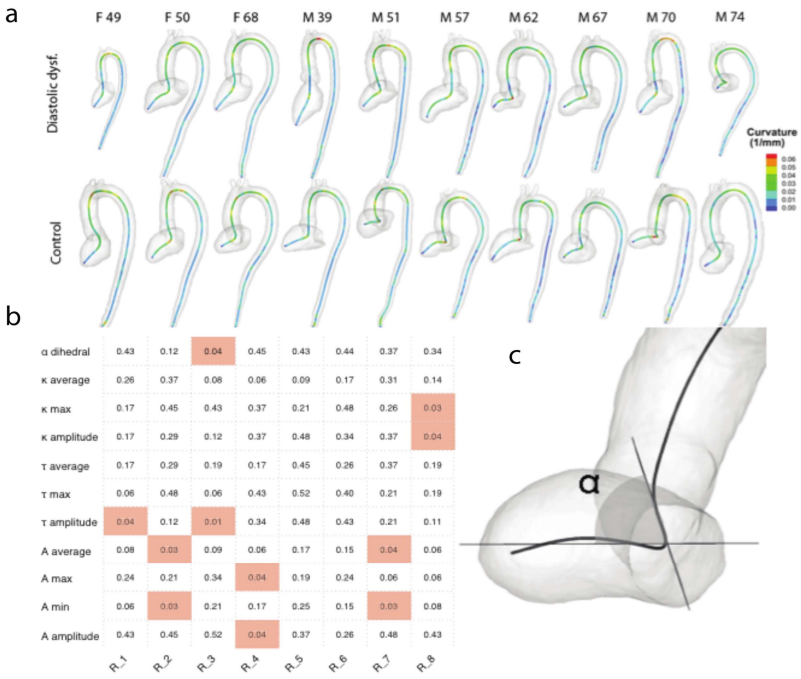

Figure 1 a) 3D visualisation of the geometries for both groups where M stands for male and F for female. The number indicates the age. b) Tabularised version of p-values for all the regional variables (shaded stand for p<0.05) c) Graphic explanation of dihedral angle α

$$\kappa(s) = \frac{|\mathbf{C}'(s)\times\mathbf{C}''(s)|}{|\mathbf{C}'(s)|^3} \quad \text{and} \quad \tau(s) = \frac{[\mathbf{C}'(s)\times\mathbf{C}''(s)]\cdot\mathbf{C}'''(s)}{|\mathbf{C}'(s)\times\mathbf{C}''(s)|},$$

where primes denote derivatives of the curve **C** with respect to the curvilinear abscissa s. Cross-sectional areas were adjusted for BSA. To simplify statistical analysis, we subdivided the aortic trunk in 8 regions (R_1 to R_8) corresponding to the landmarks positioned in: ventricle apex, ventricle base, aortic valve, ascending aorta, brachiocephalic trunk, left subclavian artery, descending aorta, diaphragm and renal level. Over each segment of **C**, the maximum, average and amplitude values were estimated for curvature, torsion and cross-sectional area. The dihedral angles (Fig. 1c), α, between planes best fitting consecutive centerline segments were evaluated as a measure of orientation change along the centerline. The BSA-adjusted values of total aortic volume were also estimated. The Mann-Whitney non-parametric U test was applied in order to test for differences between the groups, for all the vascular segments and variables.

RESULTS Figure 1a presents the 3D reconstructed geometries for both groups along with the corresponding centerlines. As main findings here, we report that both the dihedral angle and the dynamic range of torsion resulted to be significantly different between the control and diseased group (p<0.05) in the segment between the aortic valve and the ascending aorta (R_3). Total aortic volume was found to be significantly different (p<0.05).

DISCUSSION In this preliminary study we proposed a method for regional 3D morphometric analysis of the ventriculo-aortic region. We applied this method to identify for the first time those morphometric features, which make diastolic dysfunction patients different from their age matched healthy counterparts. The analysis identified significant differences in the total aortic volume, the dihedral angle and the dynamic range of torsion in the region of the ascending aorta. The observed differences could imply unfavorable hemodynamics, since the ascending aorta (1) plays a major role in the efficient blood conveying towards the major branches and (2) is a major contributor to the total systemic compliance of the arterial tree [6]. Further initiatives should focus on processing larger databases in order to evaluate any diagnostic or risk stratification value of the parameters.

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