Automated Segmentation of 4D Cine MRI: Application to the Aortic Root and Quantitative Comparison of Normal Subjects and Patients with Marfan Syndrome

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Purpose: Aortic root dilatation is a major cause of morbidity and mortality in patients with Marfan syndrome and other familial connective tissue disorders. Serial echocardiography (Echo) with 4-point measurement and Roman-Devereux graphs is used to monitor aortic root dimensions and identify the need for surgery.[1] Cine MRI provides a robust alternative to Echo, which can be limited by a poor acoustic window.[2] The 4-point measurement provides only a static view of the aortic root in diastole and fails to capture important temporal information in 4D (i.e., 3D+time) cine MR datasets. Novel indices of aortic function, such as distensibility, centroid displacement, and phase velocity, could impact prognosis and treatment, especially in patients with only mild aortic root dilatation who develop complications.[3] Highly automated segmentation methods allow rapid 4D analysis of cine MR data and facilitate the development of robust, reproducible, and practical quantitative clinical tools. The purpose of our study was to demonstrate the feasibility and performance of automated segmentation for quantitative 4D analysis of cine MR data of the aortic root in normal subjects and patients with Marfan Syndrome.

Methods:. Ten normal volunteers and 10 Marfan patients underwent MRI of the aortic root on a 1.5T scanner. Breath-hold cine imaging was performed with a segmented 2D steady state free precession sequence with 20-24 cardiac phases. The entire aortic root was imaged with 6-8 contiguous 6 mm slices in the parasternal long axis LVOT view. Cine MR data were transferred offline for analysis. The 4D MR image data were interpolated spatially to form isotropic 3D voxels and temporally to 16 cardiac phases to ensure consistent partitioning of the R-R interval. A region of interest was generated by interactively specifying the aortic annulus and sinotubular junction in end-diastole. A previously developed and validated 3D graph-search algorithm identified the aortic luminal surface.[4] Using the segmentation results from end-diastole, a preliminary segmentation for all cardiac phases was generated by deriving the region of interest for the next phase from a 3D rigid registration algorithm that tracked the movement of the aortic root and propagated the segmentation from the previous phase. This process proceeded sequentially through all 16 phases to yield an initial per-phase 4D segmentation. A final 4D graph search over the full data set refined the segmentation and ensured the correct temporal context between phases. The combination of preliminary 3D graph search, rigid registration, and final 4D graph search generated an accurate 4D rendition of the aortic surface. A 3D skeletonization algorithm was then applied to the aortic lumen to obtain the centerline of the root. Displacement along the centerline from the annulus to the sinotubular junction was normalized to 12 locations, which enabled direct comparison between subjects with aortic roots of different lengths. Thus, each 4D data set contained 12 locations and 16 phases. Image data was then resampled perpendicular to the centerline to generate cross-sectional areas (CSA) that were geometrically correct and free from distortions due to oblique cutting angles. To reduce noise while following the CSA of a given slice over the cardiac cycle, averaging was performed using a 3-phase moving window. Automated segmentation was applied to the 4D cine MR data from normal subjects and Marfan patients and used to quantify absolute CSA in end-systole and end-diastole as well as distensibility along the length of the aortic root. Agreement between the automated analysis and the manual "4-point" measurement in diastole was assessed using linear regression and Bland Altman.

Results: The automated segmentation result is presented as a wire frame plot of the aortic root (Fig. 1). The absolute CSA of the aortic root in end-systole and end-diastole (Fig. 2A) and the aortic root distensibility (Fig. 2B) are shown at each location for normal subjects and Marfan patients. Comparison of aortic root diameters obtained by automated segmentation analysis and manual "4-point" measurements showed good correlation ($r=0.80$, $p<0.01$) and a modest negative bias for the segmentation method (mean difference ± SD = 4.1 ± 3.1 mm).

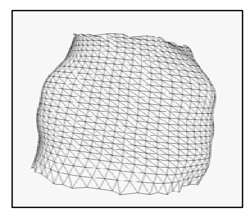

Fig. 1 Wire mesh plot of aortic root from automated segmentation

Conclusions:

- Automated segmentation is feasible for quantitative 4D analysis of the aortic root from cine MR data.
- Marfan patients show greater CSA and distensibility than normal subjects at all aortic root locations except for the sinuses of Valsalva, where distensibility differences in were less apparent.
- There is good agreement/correlation between automated analysis and standard manual "4-point" measurement

References:

1. Roman MJ, et al. Am J Cardiol (1989) 64:507.
2. Stolpen AH, et al. AJR (2005) Suppl:186:A33.
3. Elefteriadas JA. Ann Thorac Surg (2005) 80:1098.
4. Li K, et al. IEEE Transactions Pattern Analysis Machine Intelligence (2006) 28:119.

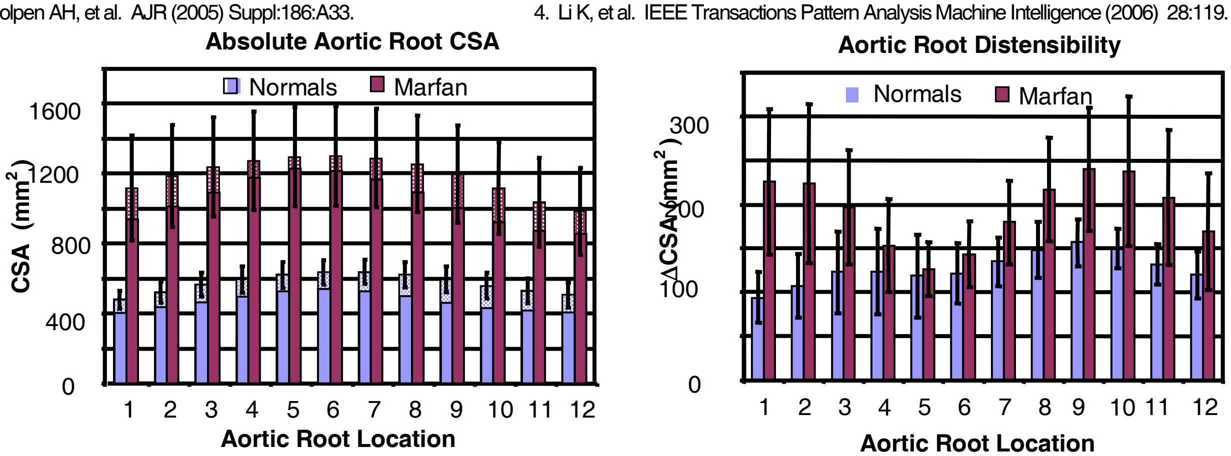

Fig. 2. Aortic root CSA (**A**) and distensibility (**B**) from automated segmentation of cine MR data; location #1 = annulus and location #12 = sinotubular junction; ΔCSA = CSA(end-systole) – CSA(end-diastole); error bars denote SD for 10 subjects.