MRI-based Pulse Wave Velocity Measurement Using a 4D Aorta Model

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Introduction

Change in vascular distensibility can be an indicator for coronary artery disease, atherosclerosis or connective tissue disorders [1,2] and is directly related to pulse wave velocity (PWV), the speed of arterial wave propagation. PWV can be measured by detecting and timing arterial pulse waves, which is commonly done by pressure-sensitive transducers, Doppler US, or applanation tonometry. Methods for PWV estimation using MR velocity imaging have also been reported. A common problem of these approaches is the uncertainty about the distance traveled by the wave, i.e. the length of the vessel.

We present an approach for PWV calculation using a geometrical 4D model of the aorta, which is fitted to 4D MR image data. The PWV is then extracted from the model parameters, i.e. local change of vessel diameter and vessel length.

Because the vessel geometry is implicit to the model, the distance traveled by the pulse wave is known very accurately. Furthermore, the velocity can be estimated locally, taking into account reflections at points of higher impedance (e.g. vessels branching off).

Methods

The basis for the calculation is a stack of TrueFISP cine slices of the thoracic aorta. A series of artificial MPR slices are computed perpendicular to the aortic axis. A level-set based 2D segmentation algorithm extracts the boundary of the aortic cross-sections and adds the boundary elements to a 4D point cloud.

A time-dynamic generalized cylinder model is adapted to the outlining points by a PDE motivated gradient descent optimization procedure [3]. It subdivides the thoracic aorta into 150 segments (~ 1mm/segment), each characterized by a local diameter. Implicit spatial and temporal regularization is performed to reduce the effects of segmentation outliers.

The PWV is then calculated locally from the model parameters. A linear model is used to find the onset of the wave in the series of time-dependent diameter functions. Robust and accurate detecting of onset times is achieved by quadratic sub-frame interpolation.

Results

The method was verified on a stack of 21 TrueFISP cine series with 40 frames per cardiac cycle acquired from a healthy, 48 year old female volunteer. The data was acquired during breath-hold on a Siemens 1.5T Espree scanner with TE/TR/FL 1.51/48.86/70. Image matrix was 108x192, reconstructed pixel size 1.7x1.7 mm, slice thickness 6mm with 2 mm overlap.

Model fitting was performed automatically with some minor manual interaction. Analyzing the model resulted in a PWV of 12.2 m/sec for the described dataset, which is in the normal range for a healthy adult [1]. Computation time for the segmentation, model fitting and PWV calculation is in the order of seconds.

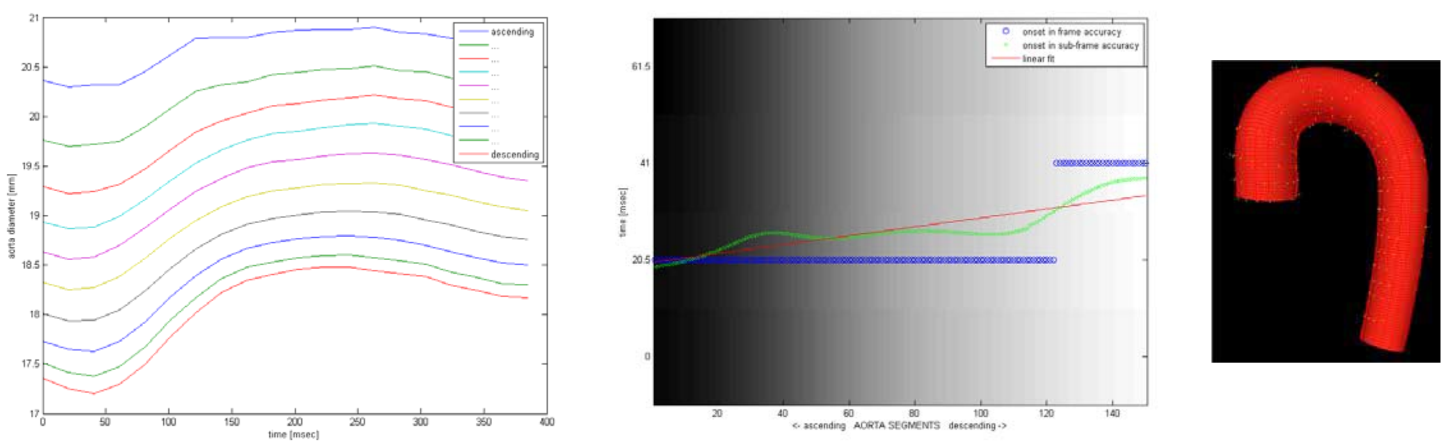

Figure 1: (left) Radius function for ten aorta segments; (middle) onset timing estimates in frame and sub-frame accuracy, linear interpolation; (right) sample aorta model

Discussion

We demonstrated the use of a dynamic geometrical model to calculate pulse wave velocity in the aorta. Compared to conventional methods, the model allows a higher accuracy estimate of the pulse wave's traveled distance. However, the temporal resolution of the scan should be improved, for example with parallel imaging, to increase confidence of the travel time measure.

References

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