NONINVASIVE MEASUREMENT OF INTRAVASCULAR PRESSURE GRADIENTS BASED ON 3D ANATOMY AND 4D FLOW IMAGE FUSION

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Introduction

Cardiovascular pressure gradients are an important clinical marker for the evaluation of the severity of diseases such as aortic valve stenosis and aortic coarctation (CoA). The gold standard for determining intravascular blood pressure in clinical practice is an invasive measurement using a pressure catheter. Invasive catheter measurements, however, expose the patient to radiation and risk of severe side effects. Noninvasive methods for estimation of pressure differences have been developed based on both ultrasound and magnetic resonance imaging techniques. In this regard, a promising method is spatially and temporally resolved phase-contrast (or flow-sensitive) magnetic resonance imaging (4D PC MRI), which provides three-directional blood flow velocities in reasonable scan times[1]. The pressure estimation techniques based on the MRI velocity data[2], however, demand accurate segmentation in order to set the boundary conditions. Segmentation is difficult to perform with the so-called PC MR angiography (PC MRA) images computed based on the flow data due to minimal contrast between blood and vascular anatomy. Alternatively, imaging sequences such as 3D whole heart (anatomy) are more suitable for geometry extraction. In this work, we propose to enhance noninvasive pressure measurements through a fused anatomy and flow image data. To this end, 3D whole heart and 4D PC MRI of patients with coarctation of the aorta were acquired and pressure difference maps and time-resolved pressure curves were reported.

Method

3D whole heart and 4D PC MRI of 5 patients with coarctation of the aorta were acquired on a 1.5-T Philips Achieva (5-element torso coil) with prospective ECG-gating (Heart Center (DHZB) Berlin, Germany). The 3D volume in 4D PC MRI measurements covered the thorax from apex of the heart to the aortic arch in the feet-to-head direction, the external border and spine in the anterior-posterior direction, and the ascending and descending aorta in the right-left direction (voxel size 1.4x1.4x2.3 mm^3, temporal resolution 40 ms, and venc = 150 cm/s). 3D whole heart covered the left ventricle and the aortic arch. It was taken in a monophasic (diastole) scan (voxel size 1.4x2.0x1.4 mm^3). The semi-automatic segmentation of the aorta was performed on the 3D whole heart images using a watershed transformation with manual correction tools[3]. After the routine pre-processing of the PC MRI data including phase-offset error correction and antialiasing, the extracted aortic anatomy is fused with the flow data for one heart cycle. As both anatomy and flow measurements are acquired in the same session using gated imaging sequences, only small perturbations occur between the two. To account for these deviations, a rigid transformation is applied to the world matrix of the anatomic image. The transformation is computed through the application of a registration framework with the normalized gradient field similarity (NGF) measure[4,5] to the PC MR angiography (derived from 4D PC MRI) and anatomy images. Based on this fusion, relative pressure maps and curves are then computed using the Navier-Stokes equations as performed previously[2].

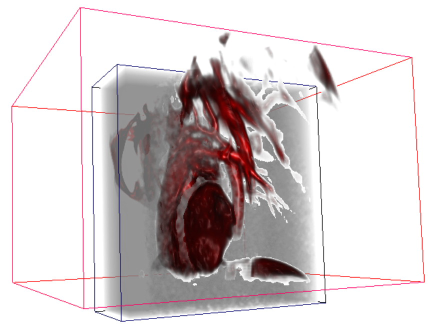
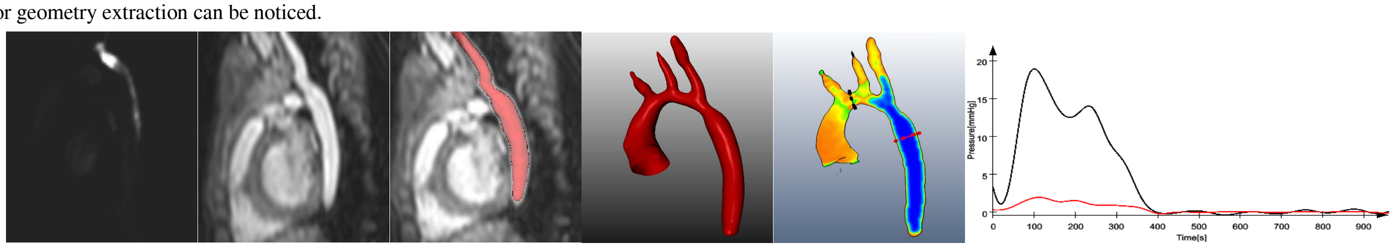


Figure 1. Coregistration of 3D whole heart dataset and 4D PC MRI. The red and blue boxes represent the corresponding bounding boxes, which clearly depict the differences in coverage.

Results

The proposed method was applied successfully to the all CoA datasets. Figure 1. depicts the coregistration of the anatomy and flow datasets. The segmentation could successfully be performed in all whole heart datasets. The interaction took 3 min on average. The registration took 1 min on average and clearly improved the subsequently calculated pressure map in 2 of 5 cases, where patient motion had happened between the acquisition of the whole heart volume and the 4D PC MRI sequence. Figure 2. demonstrates the resulting relative pressure map and curves for one such patient. The superiority of the 3D whole heart data to PC MR angiography for geometry extraction can be noticed.



(a) (b) (c) (d) (e) (f)

Figure 2. Computation of relative pressure maps using 3D anatomic and 4D flow data. (a) depicts the corresponding PC MR angiography. (b) shows the 3D anatomic data. It is apparent from these two images that the whole heart data is more suitable for segmentation. (c) and (d) represent segmented vessel anatomy. (e) depicts the relative pressure map computed based on the anatomic and flow data fusion. (f) represents time-resolved mean pressure curves for the corresponding marked locations. A peak pressure gradient of around 15 mmHg between the two curves can be noticed.

Conclusion

In this work we suggested a method for the combined analysis of aorta anatomy and pressure differences based on an image fusion between 3D anatomic and 4D flow MRI data. The implemented tool was successfully applied to a number of CoA patients and the necessity of using a more suitable image data for geometry extraction was demonstrated. The fused information enables the visual and quantitative assessment of diameter changes as well as the pressure gradient caused by the coarctation.

References

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