Nonrigid registration based segmentation for the analysis of real-time cardiac flow images.

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INTRODUCTION

Phase contrast MRI is used clinically for measuring flow in great vessels. Conventionally, images are acquired with cardiac gating and averaging, but when dealing with irregular heart rates or during physical exercise, an alternative is to use real-time acquisition [1]. Analysis of phase contrast MRI data requires a segmentation of great vessels (e.g. the aorta) in the whole time series of (magnitude) images. The post-processing of these real-time images is challenging because, due to the compromised resolution and signal-to-noise ratio, the border with other structures is not always well defined and changes markedly over time, especially in stress studies. In this work, we propose to address the problem with a registration-based segmentation propagation technique [2-4]: the magnitude images of the whole time series are subjected to nonrigid registration; the aorta region of interest (ROI) needs to be segmented manually in one frame only, and the segmentation is propagated to other frames using the displacement fields given by the registration. Compared to usual registration techniques, the one we use here considers the whole time series (as opposed to registering pairs of frames independently).

METHODS

Real-time phase contrast data from 10 volunteers were acquired on a Siemens 1.5T Avanto scanner (Erlangen, Germany), using an undersampled spiral sequence described in [1]. Data were acquired at rest and during physical stress (pedaling exercise). The sequence results in a temporal resolution of 40.4 ms/frame and a spatial resolution of 3.9x3.9 mm². Nonrigid registration was achieved with an optical flow based algorithm designed for 2D time series registration. This means that a displacement field of the form $u(x,y,t) = [u_x(x,y,t), u_y(x,y,t)]$ (two spatial dimensions x, y, and time t), was searched for by minimizing a conventional optical flow energy term (E_{OF}), subject to a smoothness constraint in both space and time on the displacement fields (E_{reg}). The problem is solved iteratively and in a multi-level manner, so that at each iteration k, the displacement field u is updated as follows:

$$u_{k+1} = u_k + \arg\min_{\delta u}\left\{E_{OF}(\delta u) + \lambda E_{reg}(\delta u)\right\}, \quad (1)$$

with $E_{OF}(\delta u) = \left\|(I_{ref} - I_k) - G_{xy} I_k \cdot \delta u\right\|^2$,

and $E_{reg}(\delta u) = \left\|G_{xyt}\,\delta u\right\|^2$.

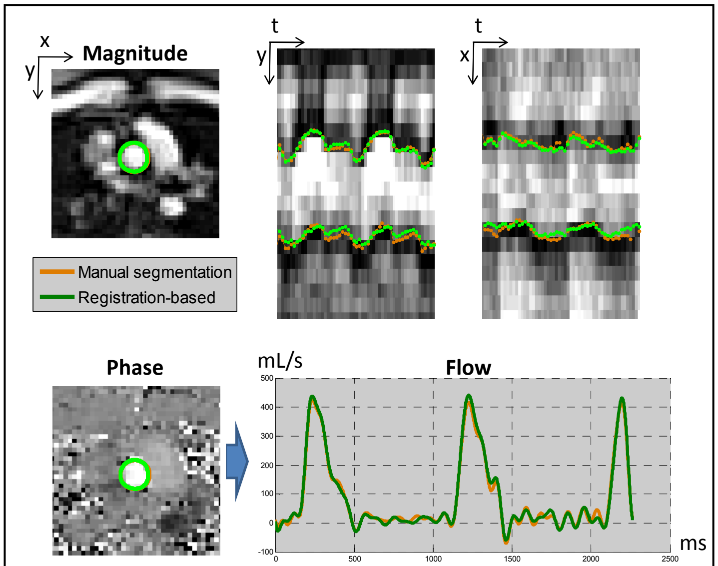

Fig.1 Manual VS registration-based segmentation of the aorta for flow measurement.

I_k stands the registered image series at iteration k, I_{ref} is the reference image (or target), G_{xy} is the gradient operator in space, and G_{xyt} is the gradient operator in space and time. Equation (1) leads to solving a linear algebraic system. Here we used the conjugate gradient for this task. The performance of the segmentation propagation was assessed by comparison with manual segmentation performed with the Osirix software (Osirix Foundation, Geneva, Switzerland). Flow curves were computed by integrating the velocity over the segmented aorta (see Fig.1), and the stroke volume (SV) was given by time-integration of the flow over the cardiac cycle. We also propagated the aorta ROI in the time series without registration, and compared the agreement between flow curves (manual vs unregistered ROI, and manual vs registered ROI) by Bland-Altman analysis, as well as the agreement between the corresponding SV.

RESULTS

The mean absolute distance between the manually segmented and registration-based contours ranged from 0.7 to 2.5 mm. The Bland-Altman analysis showed improved agreement between flow curves after registration (see example curves in Fig.1). At rest, the mean error (bias) was reduced from -6.8 mL/s (± 18.7 mL/s) to -2.2 mL/s (± 11.2 mL/s) after registration. During exercise, the mean error was reduced from -10.4 mL/s (± 20.6 mL/s) to -3.8 (± 14.1 mL/s). SV was also improved, with a bias reduced from -6 mL (±4.2mL) to -2.1 mL (±3.7 mL) at rest, and from -6.7 mL (±4.1) to -2.5 mL (±4.4 mL) at exercise. The registration needed 4 to 17 seconds for complete dynamic series of 148 frames, in a 12x12 cm region surrounding the aorta.

CONCLUSION

The registration based segmentation provides a useful tool for the analysis of real-time cardiac flow images, as the aorta needs to be segmented in one frame only. The method allows computing flow measurements and SV automatically with minimal bias. In future work, we plan to use the tool in patient studies.

REFERENCES

[1] Edgar *et al.*, ISMRM 2009, 1855 ; **[2]** Rueckert et al., ISBI 2002, 481-484, ; **[3]** Lorenzo-Valdes et al., MICCAI 2002, 642–650 ; **[4]** Zhuang et al., MICCAI 2008, 5242, 425-433