

Time-resolved Blood Flow Quantification Without Gating

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Introduction

Temporally resolved blood flow can provide clinically useful information complementing structural measures such as those provided by MR angiography since arterial flow rates are affected by physiologic and pathologic changes, e.g. lumen size and vessel wall stiffness. Doppler ultrasound is the standard technique for real-time flow measurements but lack the spatial resolution for quantifying the velocity distribution across the vessel lumen that permit calculation of blood volume flow rate, which is more relevant than flow velocity. In MRI, gated phase-contrast (PC)-MRI [1] is the standard approach to resolving pulsatile blood flow but arrhythmia can significantly affect accuracy and reproducibility since each phase-encoding takes one heartbeat. Further, the modulation of amplitude and phase produce ghosting artifacts that may interfere with the flow measurement. To address these issues we describe a flow quantification technique with velocity-encoded projections where the reference image is used to remove signals from the background, e.g. tissue, prior to taking the phase difference. We demonstrate the technique's practicality by time-resolving the triphasic pulsatile blood flow in the femoral artery of healthy subjects and compare it to flow profiles derived using PC-MRI.

Methods

Fourier transform (FT) of a center k-space line $k_y = 0$ sums the complex signal along the phase-encoding direction. Flow quantification with high temporal resolution would thus be possible if the tissue contribution could be removed from the $k_y = 0$ data prior to FT. In order to achieve this goal we first acquire a flow-compensated reference image (Figure 1a), mask out the artery of interest (Figure 1b) and FT back to k-space (Figure 1c). Finally, the resulting centerline is subtracted from the velocity-encoded projections prior to computing the phase difference (Figure 2a). The spatially averaged velocity within the artery is computed by averaging the phase along the readout direction within the vessel boundaries. All experiments were performed on a 3T Siemens Trio and axial images of the femoral vessels were acquired using a phased-array eight-channel knee coil (Invivo Inc., Pewaukee, WI). The following imaging parameters were used: FOV=128 x 128 mm², voxel size = 1 x 1 x 5 mm³, TE/TR = 4.8/10 ms, BW = 521 Hz/pix, Flip angle = 20°, VENC = 70 cm/s and total scan time ~ 10 s. The pulse sequence was programmed using SequenceTreeTM [2], a custom-designed pulse-sequence design and editing tool.

Results and Discussion

In the representative reference image (Figure 1a) the readout direction is medio-lateral. In Figure 2a the phase differences of 256 projection-pairs are oriented vertically to match the time axis of the average velocity profile (Figure 2b) of the artery. The black rectangle represents the area where the phase was averaged along the readout direction to compute the average velocity. The plot of the result is shown in Figure 2b, which is averaged and compared to the flow profile derived from gated PC-MRI (Figure 3).

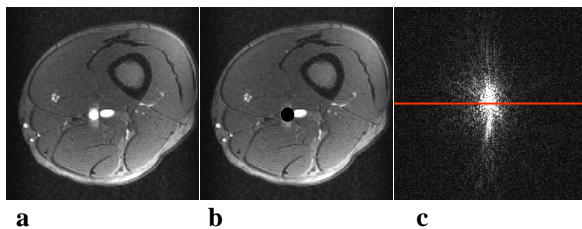


Figure 1 a) Axial flow-compensated reference complex image at the mid-thigh acquired with a spoiled-GRE pulse sequence. b) Artery masked out. c) Inverse FT of b). The resulting center k-space line (red line) contains only the background signal. It is subtracted from the velocity-encoded projections.

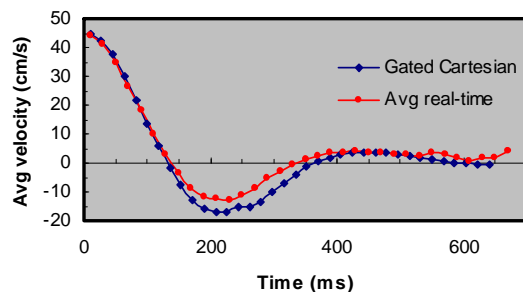


Figure 3 Comparison between flow profiles derived from the gated Cartesian scan and proposed projection technique. In the latter case, flow profiles were averaged.

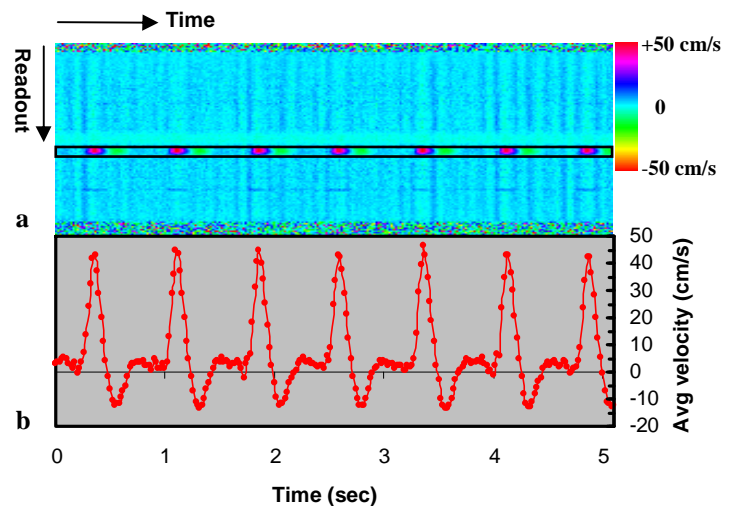


Figure 2 a) Phase difference between velocity-encoded projections and free of background signal. Each vertical line represents a time point; 256 time points are shown. Pulsatile ghosting artifact is avoided since phase-encoding is not used. b) Blood flow velocity in the femoral artery averaged over the vessel projection at a temporal resolution of 20 ms.

Conclusion

The new projection-based method allows time-resolved measurement of blood flow without the need for gating at high temporal resolution. Velocity waveform as well as peak and average velocity are in good agreement with literature data [3, 4]. Discrepancies mainly occur during the diastolic phase where the effects of arrhythmia are most pronounced. The new method is highly efficient; it is possible, in principle, from a single heart beat and applicable to other vessels (aorta, carotid arteries).

References [1] Nayler et al., J Comput Assist Tomogr 1986;10:715-722; [2] Magland et al. Seattle, WA. Proc. ISMRM.2006, p 578; [3] Fronek et al., Circulation 1976; 53:957-960; [4] Dousset et al., Radiology 1991; 179:437-441.

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