The impact of vessel motion and flow variability on MR-based wall shear rate measurement in the carotid artery

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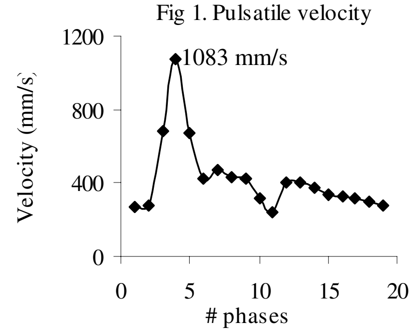
Abstract: This study investigated the effect of beat-to-beat changes of vessel position and blood-flow (e.g., related to respiration) on the MR measurement of wall shear rates (WSRs) in the common carotid artery (CCA). Both factors were found to change WSRs only slightly (~ 1%). In conclusion, the CCA WSR can be measured accurately in the present of normal CCA motion and flow variability using MRI.

Introduction: Vascular wall shear rate (WSR), which is related to the tangential friction force from flowing blood against a vessel wall, is a key factor in atherogenesis. WSR can be calculated by fitting phase-contrast (PC) MR images using established models (1). However, because accurate estimation of WSR requires the ECG gated PC MR acquisition at high spatial resolution (e.g., 0.25 mm in-plane), subtle changes in vessel position or blood flow between successive heartbeats may blur the measured flow profile and impact the WSR calculation. In this study, we calculate the magnitude of this effect through simulated WSR measurements in the CCA.

Methods: The effect of normal vessel motion and blood-flow variations on ECG gated PC MR images were simulated in MATLAB (Mathworks Inc.), based on previously published in-vivo MR and Ultrasound data (1-3). Pulsatile flows were constructed assuming a parabolic velocity profile within a vessel of 7 mm inner diameter and circular cross-section (Wormsley's equations were not considered). The pulsatile flow pattern shown in figure 1 was obtained from the CCA of a normal volunteer, and was used to scale the maximum velocity profile at each heart phase (2). A peak systolic velocity of 1083 mm/sec was used, based on population averages (3). A 0.25 mm² in-plane spatial-resolution was assumed, similar to that used for in vivo studies.

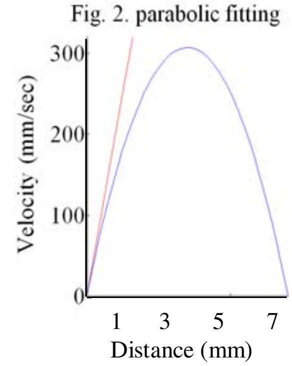
Fig 1. Pulsatile velocity



A Cartesian k-space acquisition was assumed for these simulations. Various combinations of motion and flow corruption were analyzed: no motion, motion in the frequency-encoding direction, motion in the phase-encoding direction, perfectly periodic flow, and beat-to-beat scaling of the velocity pattern. Motion corruption was simulated by calculating the Fourier transform of an ideal (complex) velocity image, and multiplying the k-space by a phase-ramp appropriate for the given displacement. A row of data was extracted from this k-space to simulate data acquisition. This step was then repeated for a different velocity and displacement until simulated data acquisition was complete. Flow variability was simulated by randomly scaling the flow waveform each heartbeat, based on the normal population variances in CCA velocity: SD = 38 mm/s (3).

After inverse Fourier transformation of the corrupted k-space, velocity profiles were re-fitted to a parabolic profile. The tangents in the frequency and phase encoding directions were used to calculate the wall shear rates at the vessel wall. An example of fitting is shown in figure 2. The pulsatile WSRs were characterized as mean, maximum and minimum WSR. Due to lack of regurgitation in the CCA, oscillation shear index (OSI) was neglected.

Fig. 2. parabolic fitting



Results and Discussion: All data are summarized in Table 1. Motion in phase encoding direction slightly changed WSR values (mean WSR 263 s^{-1}) compared to the values with no motion (261 s^{-1}, difference: 0.86%). Motion in the frequency direction changed mean WSR by a negligible amount (0.02%). Irregular pulsation of blood flow also had little effect on WSR values (mean WSR: 260 s^{-1}) comparing to regular condition of pulsatile flow (mean WSR: 261 s^{-1}, change = 0.49%) without motion. The combination of phase direction motion and irregular pulsation changed the resulting values (mean WSR: 258 to 261 s^{-1}, 1.12%) more than any one factor. In conclusion, the CCA WSR can be measured accurately in the present of normal CCA motion and flow variability using MRI.

Reference:
1. J Magn Reson Imaging, 2004, 19:188-193;
2. Magn Reson Med, 2004, 52:605-611;
3. Physiol Meas, 1999, 20:219-240.

Table 1. Wall shear rates (WSR) with and without motion and pulsation (numbers in bold considered reference)

WSR (s^{-1})	No motion		motion			
			Phase direction		Frequency direction	
	Pulsation		Pulsation		Pulsation	
	Reg.	Irreg.	Reg.	Irreg.	Reg.	Irreg.
Mean	**261**	260 (0.18%)	263 (0.86 %)	258 (1.12 %)	261 (0.02%)	262 (0.50%)
Max	**618**	616 (0.05%)	627 (1.40%)	611 (1.13%)	618 (0.01%)	621 (0.37%)
Min	**163**	163 (0.93%)	165 (0.88%)	161 (1.15%)	163 (0.06%)	164 (0.55%)