Clinical Utility of Flow Encoding Phase Contrast - MRI to Quantify the Exercise Induced Flow Reserve in Lower Extremities

H. M. Nagaraj[1], A. Pednekar[2], C. Corros[1], H. Gupta[1], and S. G. Lloyd[1]

[1]Division of Cardiovascular Medicine, Department of Medicine, University of Alabama at Brmingham, Birmingham, AL, United States, [2]Phillips Medical Systems, North America, Bothell, WA, United States

Synopsis: A reliable estimate of maximal recruitable flow would be of considerable benefit in the management of patients with Peripheral arterial disease (PAD). The cine flow velocity over the cardiac cycle is measured using MR phase contrast flow encoding at the level of superficial femoral artery: a) pre-exercise; b) during exercise; c) immediate post-exercise; d) during recovery; and e) post-recovery. The flow waveform transforms from triphasic at rest to monophasic on exercise and recovers to baseline. In 10 healthy volunteers the mean flow reserve was 167 % (1.67 ± 0.9). In 4 healthy volunteers reflective reverse flow recovered in less than 90 seconds.

Introduction: Peripheral arterial disease (PAD) is a common disorder, but establishing the clinical or functional significance of a discrete arterial stenosis can be difficult. A reliable estimate of maximal recruitable flow would be of considerable benefit in the management of these patients but such a measurement is not routinely done. Here we have used phase contrast (PC) MRI with flow encoding for quantification of exercise induced flow reserve in lower extremities.

Materials and Methods: Ten healthy volunteers (4 females) with a mean age of 30 years (range 22-38) were studied. All subjects performed unilateral plantar flexion exercise for 4 minutes on a custom built MR compatible calibrated ergometer. The lower extremity cine flow velocity over the cardiac cycle was measured using PC-MRI flow encoding at the level of superficial femoral artery: a) pre-exercise; b) during 4 min. unilateral plantar flexion at sub-maximal levels of exercise; c) immediate post-exercise; d) during 3 min. recovery and e) post-recovery.

MR Sequences: PC-MRI was performed on a 3T Philips Intera clinical scanner, using a 6-element phased-array surface coil. A transverse axial plane was prescribed at the level of the superficial femoral artery (SFA). Retrospectively vector-cardiographic (VCG) gated multi-phase PC images (fast gradient recalled echo (GRE), 7 lines per k-space segment, Venc = 100 cm/sec, TR/TE/flip: 6.1 msec/3.6 msec/10 deg; acquired temporal resolution: 55.6 msec; acquired spatial resolution: 1.67 x 1.73 x 8 mm^3; acquisition time 25 heart beats) were acquired pre-exercise, immediately post-exercise, and post-recovery. Prospectively VCG gated dynamic multi-phase PC images (GRE, 11 k-space lines per echo, Venc = 100 cm/sec, TR/TE/flip: 22 msec/12 msec/10 deg; acquired temporal resolution: 44.4 msec; acquired spatial resolution: 1.67 x 1.76 x 8 mm^3; 8 heart beats per dynamic; 25 dynamics) were acquired during recovery. All the acquisitions were done with free breathing.

Data Analysis: Analysis was performed using CV Flow (version 2.0; Medis, Inc.) after semiautomatic contour detection and manual correction of the vessel lumen traced on all cardiac phases and dynamics. The flow reserve (FR) was calculated as [(post-exercise flow – pre-exercise flow)/pre-exercise flow] x 100%. The reflective flow index was calculated as (early-diastolic reverse flow / systolic forward flow).

Results: Example data of a resting triphasic flow waveform in the SFA, in which the flow velocity increases and changes the waveform to monophasic or biphasic during the exercising phase, is shown in Fig. A. The mean absolute blood flow in the exercising leg SFA for all subjects at pre-exercise, post-exercise and after recovery is depicted in Fig. B. The exercise induced mean flow reserve was 167 % (1.67 ± 0.9). The flow in SFA during the post-exercise resting phase regains the triphasic pattern with the diastolic reverse flow resuming gradually (in less than 90 seconds) as shown in Fig.C. In 4 of these 10 healthy volunteers the reflective flow index as plotted in Fig. D demonstrates the variable rate but uniform pattern of recovery.

Conclusion: This study indicates that 1) the flow waveforms show a triphasic pattern at rest which transforms into a monophasic or biphasic pattern on exercise and returns gradually during the resting phase with resumption of the diastolic reverse flow; 2) the regional blood flow in the exercising leg SFA increases with unilateral plantar flexion at sub-maximal levels of exercise and returns to the baseline with a brief recovery, allowing reliable estimation of exercise induced FR 3) the quantification of exercise induced FR and analysis of flow waveform transformations in the lower extremities using velocity encoding PC-MRI is feasible in clinical practice and appears promising to evaluate the functional significance of a discrete arterial stenosis in patients with PAD

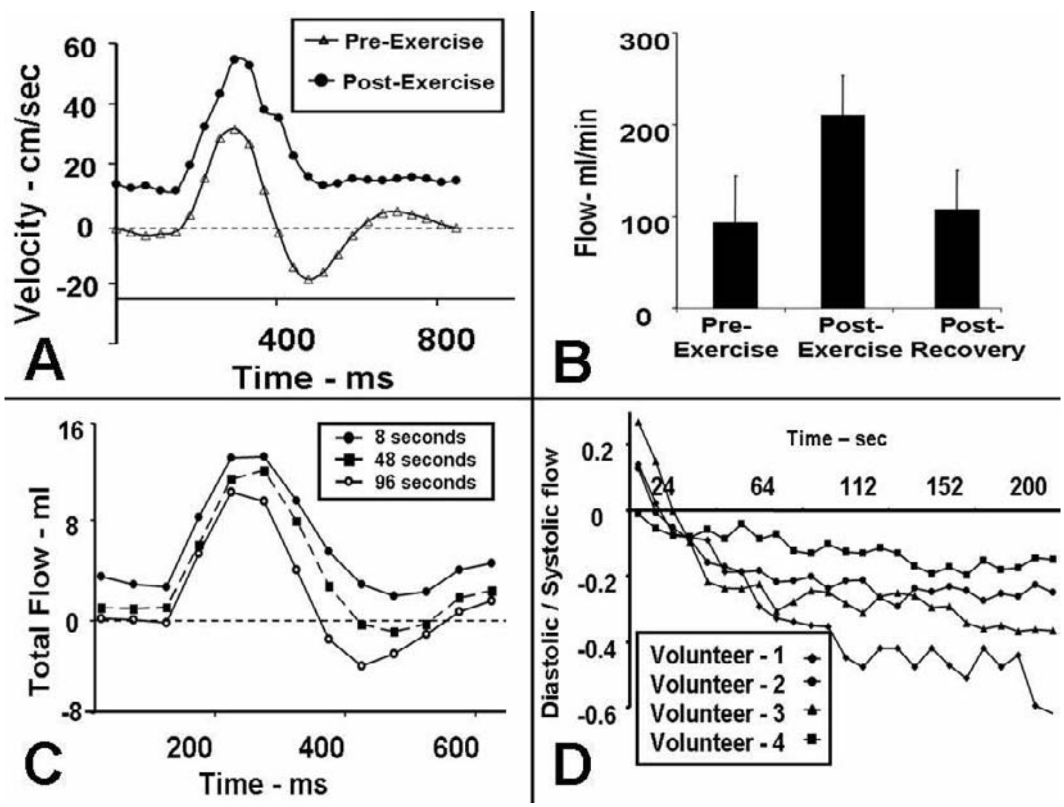

Fig. A: Example data of resting high-resistance triphasic flow waveform in the exercising leg SFA shows an increase in forward flow velocity and absence of reflective reverse flow after 4 minutes of sub-maximal exercise. Fig. B: The mean absolute blood flow in the exercising leg SFA for all subjects at pre-exercise, post-exercise and after recovery. Fig. C: The blood flow in the exercising leg SFA during recovery phase - note the diastolic reverse flow, which was absent during the exercise phase returns gradually and quickly in less than 90 seconds. Fig. D: The ratio of diastolic reverse flow to the systolic forward flow during recovery phase in 4 subjects demonstrates the variable rate but uniform pattern of recovery.