Magnetic Resonance Velocity Mapping during Intermittent Pneumatic Compression of the calf and foot

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Background & Aim: Deep vein thrombosis (DVT) and any resulting pulmonary embolism (PE), also called venous-thromboembolism (VTE), has been described as the most common preventable cause of hospital death in the US [1] and estimated to cause 25,000 preventable hospital deaths per year in the UK [2]. Intermittent Pneumatic Compression (IPC) devices and compression stockings are used in the prevention of DVT have been previously evaluated by venous Doppler and anatomical magnetic resonance imaging (MRI) [3,4,5,6]. Measurement of the venous blood flow using Magnetic Resonance Velocity Mapping (MR-VM) can provide both the velocity and anatomical changes in real-time, required because of the variability of flow response. We present an initial investigation of the potential of direct venous flow MRI during sequential IPC, in this case establishing the individual contributions of foot and calf compression.

Method: Twelve normal subjects (6 male, ages 28-82) were scanned supine [1.5T Siemens Avanto]. Foot and calf compression cuffs [ArtAssist AA-1000e®, ACI Medical] were applied to the right leg, with raised support at the ankle and an MR receiver-coil wrapped lightly above the knee. Flow measurements were taken using a previously validated in-house developed real-time MR-VM, utilising spiral readouts and optimised for venous flow in the leg [7]. {Sequence parameters: FOV 150x150 mm, RES 1x1 mm, 4 interleaf spiral readout with duration 27.5 ms (x2 for +/- 'symmetric' velocity encoding), Timings for VENC = 8 cm/s: TE 5.2, TR 38.5 ms, TA = 308.0 ms} Baseline venous flow was measured using 8 cm/s VENC for 30 seconds. IPC was then started and several compression cycles were allowed for stabilisation before any further scanning. Imaging then commenced for 60 seconds to capture three, 20 second compression cycles with VENC's of 15 cm/s, 20 cm/s, 40 cm/s and 55 cm/s. This was repeated using each individual cuff separately. Images were reconstructed using an offline Matlab program with sliding data window and the optimum velocity range selected. ROIs were drawn on the magnitude images and copied to the corresponding velocity maps. Flow per cycle was measured in the popliteal vein (and secondary if present) and the average of flow from the three IPC cycles taken.

Results & Discussion: Figure 1 shows the mean velocity waveforms (staggered) from each IPC cuff mode from one subject. Table 1 shows the average results (and ranges) for flow and velocity measured in the 12 subjects, which have a large range. IPC using both cuffs produced ≈ 2.7 x baseline flow and ≈20 x baseline peak velocity, with similar results using the calf cuff alone. When the foot cuff was used alone the peak velocity increased by ≈15% of the increase when using both cuffs, although the foot cuff flow was not significantly different to baseline*.
In some subjects, large secondary veins (Fig 2a) diverted flow from the main vein and MR allowed the measurement of the flow through both deep veins simultaneously. Complex spatial distributions of flow were sometimes seen (Fig 2b), which could affect ultrasound flow accuracy as it makes assumptions of the spatial flow distribution. Also, popliteal arterial flow was reversed briefly by the calf cuff inflation in all subjects.

	IPC off	IPC both cuffs	IPC calf cuff	IPC foot cuff
Flow per IPC cycle (range) ml/cycle	2.3 (0.5-11.4)	6.1 (2.5-24.6)	6.3 (2.4-24.5)	2.6 (1.2-10.7)
Peak velocity (range) cm/s	2.0 (1.1-3.5)	41.5 (17.9-58.1)	40.6 (18.1-62.2)	7.9 (3.7-15.3)

Table 1: Mean flow volume per IPC cycle, and the peak pixel velocity in the vein.

Conclusions: The results produced in this study have been similar to those previously reported [3,4,5] measured using ultrasound but with no assumptions about the flow profile. Additionally, real-time MR-VM can measure the flow in a full cross section of the leg, allowing measurements from secondary veins, and can therefore visualise complex distribution of flow within a vein. This could enable further research into the flow physiology, and optimisation of the cuff design, pressures and timings used by IPC devices.

References:
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* =Wilcoxon rank sum test, n=12

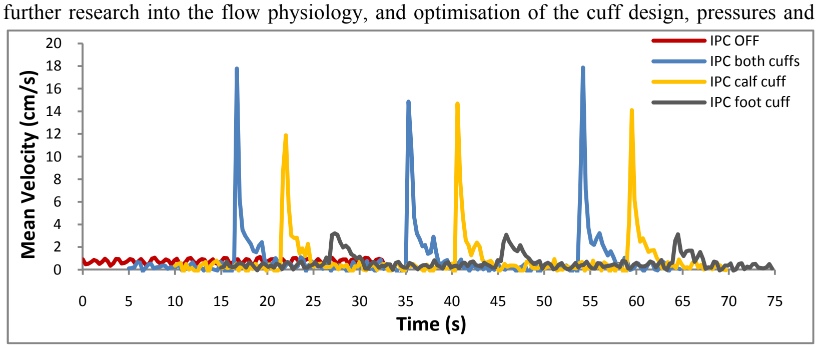

Figure 1: Example mean velocity waveforms from one subject showing each mode of compression (with staggered start).

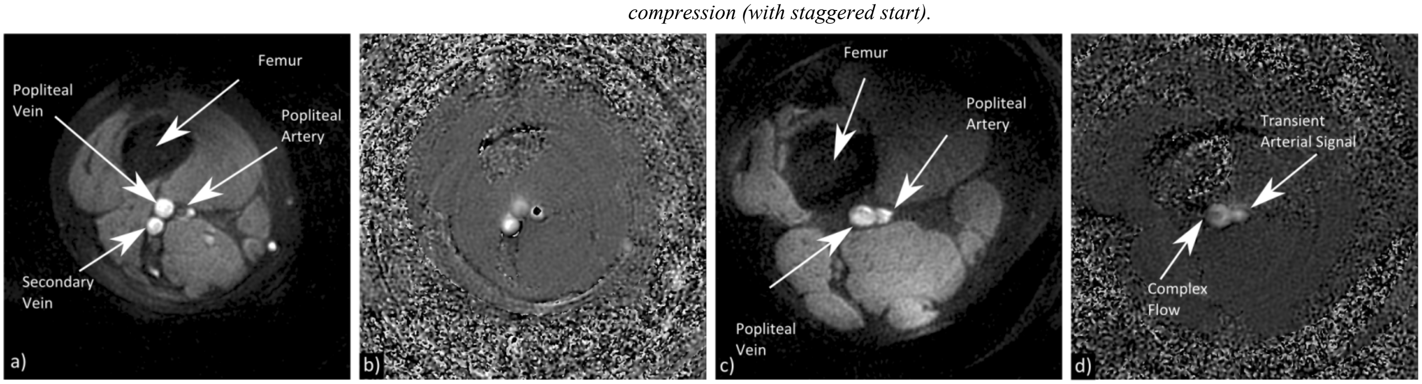

Figure 2: Anatomical images and corresponding velocity transverse images (grey = stationary tissue, white = flow towards head) of the thigh during calf inflation phase of an IPC cycle, showing a),b) presence of a large secondary vein and c),d) the popliteal vein with complex cross-sectional flow profile and transient reversed flow in the popliteal artery.