The use of MRI to monitor blood flow and oxygenation changes accompanying hyperaemia in human foot muscle

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Introduction:

Vascular changes in the foot are of particular importance in diseases such as Diabetes and Peripheral Arterial Disease, which can lead to ischaemia, gangrene, and hyperperfusion (Charcot Foot – Diabetic complication) leading to deformity and amputation [1]. Recently ASL techniques [2] have been employed to study blood flow changes in calf muscle [3,4], but these techniques have not been used to study perfusion in the skeletal tissue of the foot. The rate of perfusion in the foot is very low and hence quantitative values of absolute baseline perfusion and oxygenation in this region are difficult to measure. However induced changes in these parameters may provide a more sensitive method of probing function. In this study changes in perfusion in skeletal tissue of the foot were induced using ankle arterial occlusion (AO). After the release of AO there is a hyperaemic response (increased blood flow) in skeletal foot tissue. This study aimed to assess whether the hyperaemic response could be detected in healthy human skeletal foot tissue using perfusion-weighted signals and T_2* measurements, and whether differences in responses to 2- and 5-minute ankle AOs could be detected.

Methods:

Experiments were performed on 2 healthy volunteers using an in-house built, 3.0 T scanner. Prior to scanning, each volunteer's systolic, brachial blood pressure was measured, and the arterial occlusion pressure used in the study was 50 mm Hg higher than this value, to ensure full arterial occlusion. The pressure cuff for these experiments was placed just above the ankle. The occlusion paradigm consisted of a 2-minute AO, followed by instantaneous release of the pressure cuff, and a subsequent 5-minute recovery period (to monitor parameter changes and return to baseline). This was followed by a second 5-minute AO and a further 5-minute recovery period. Imaging commenced 60 seconds prior to the first occlusion to measure baseline parameters, and image acquisition continued until the end of the experiment. A multi-gradient-echo EPI technique [3,5] was used to measure, M_0 (related to flow in this single slice sequence) and T_2* (related to oxygenation and blood volume) in response to an AO. The experimental parameters for the multi-echo EPI sequence were: 4.0 kHz EPI, TE_{eff} = 9, 18, 27, 36 ms, TR = 1 s, single slice imaging, resolution 3.5x3x5 mm^3, 64x64 matrix. For each of the four echo images M_0 and T_2* maps were calculated using a pixel by pixel least squares fitting algorithm. M_0 and T_2* time courses were plotted for both skeletal tissue and an artery in the foot.

Results and Discussion:

Figure 1 shows the typical time courses for both the tissue and artery in the foot pre-, during, and post- ankle AO. The decrease in M_0, observed during the occlusion, results from the cessation of arterial blood flow and tissue perfusion. On release of the pressure cuff a hyperaemic peak is observed. Changes in the maximum signal and time to hyperaemic peak (TTP) of M_0 and T_2* parameters following a 2- and 5-minute occlusion are shown in Table 1. Changes in T_2* follow a much slower response curve with a delayed TTP compared to M_0 (Table 1). These changes reflect both an increase in oxygenation of the tissue and an increase in blood volume from vasodilatation. The influence of these two factors on T_2* is a balance between opposing effects of capillary volume and haemoglobin saturation changes [3]. It can be seen that T_2* values do not fully return to baseline in the five minutes between occlusions and this may have influenced the maximum percentage change detected during the second occlusion.

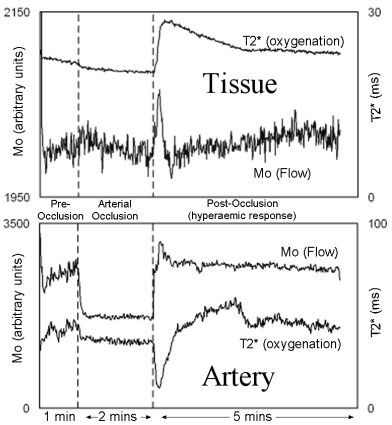

Figure 1. Time courses of M_0 and T_2* for skeletal tissue and artery in the foot showing baseline, 2-minute AO and hyperaemic response.

Conclusions:

This study has shown the feasibility of monitoring the reactive hyperaemic response of skeletal foot tissue to ankle AO. The results suggest that tissue oxygenation and blood volume remain elevated considerably longer than the hyperaemic peak in blood flow. Differences were observed between the responses to 2- and 5-minute AOs. The method described is very sensitive, and has high temporal resolution, but is not quantitative as currently implemented and is susceptible to drift. Further studies will relate the MR signal changes to perfusion and blood volume changes. The application of this technique will be directed towards providing an alternative method to venous occlusion plethysmography (current standard technique - which has low temporal resolution and hence cannot study physiological responses) with which to assess blood flow in the foot, in normal and diabetic subjects.

	Volunteer 1		Volunteer 2	
	2-min AO	5-min. AO	2-min. AO	5-min. AO
TTP – M_0 (s)	10	18	9	13
Max. % change – M_0	3.4	3.4	4.5	5.6
Peak duration – M_0 (s)	18	35	18	23
TTP – T_2* (s)	21	30	26	26
Max. % change – T_2*	42	23	10	19

Table 1. Key parameters measured from skeletal foot tissue M_0 and T_2* time courses. (TTP – time to peak.) Max. % change measured from average of final 30 seconds of occlusion to peak hyperaemic value.

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