Arterial spin labeling in exercising calf muscle with prospective motion correction

Céline Giraudeau[1,2], Benjamin R. Knowles[3], Thomas Lange[3], Michael Herbst[3,4], Maxim Zaitsev[3], and Pierre Carlier[1,2]

[1]NMR Laboratory, Institute of Myology, Paris, France, [2]NMR Laboratory, CEA, I2BM, MIRCen, Fontenay-aux-Roses, France, [3]Department of Radiology, University Medical Center Freiburg, Freiburg, Germany, [4]John A. Burns School of Medicine, Uni Hawaii, Honolulu, Hawaii, United States

TARGET AUDIENCE: ASL or motion correction methodologists and muscle perfusion physiologists.

PURPOSE: Acquiring clean ASL perfusion data in exercising skeletal muscle is highly desirable and would have significant impact for the pathophysiological mechanisms of many conditions affecting the skeletal muscle, primarily or secondarily. However, except for the study of Frank et al., in which perfusion measurements in arbitrary units in the working calf muscle with CASL are shown [1], studies have been limited to post-exercise data due to motion that dramatically impairs perfusion curves. Recently, real-time prospective motion correction (PMC) with optical tracking has been proposed for brain [2] and knee MRI [3]. In this work we investigated the potential of PMC-augmented ASL to improve the quality of perfusion curves acquired during calf muscle exercise.

METHODS: The experiments were performed on a Magnetom Trio 3T system (Siemens Healthcare, Germany), using a flexible surface coil for signal reception. PMC was realized with a moiré phase tracking (MPT) system [4] consisting of a single in-bore camera and a tracking marker, which was glued to the shin approximately 3cm away from the imaging slice so as to minimize the effect of non-rigid muscle motion on the marker motion. A PMC-enabled SATIR PASL sequence [5] with 1.2 s evolution time was used with the specific parameters for the HASTE readout: TE_{eff} = 20 ms, FOV 290*145 mm², matrix size 128*64 pixels, one 10-mm thick slice. A 0.4 s pause was taken after each scan, resulting in a temporal resolution of 1.8s. PMC updates of the slice position were performed before tagging and before slice excitation of each shot. For exercise, 14 volunteers (10 m, 4 f) were asked to perform plantar flexion on a home-built NMR-compatible ergometer delivering a force of 50 N in the pedal. The exercise was synchronized with the NMR sequence so that plantar flexion took place in between the tagging and the slice excitation of each scan. The exercise protocol consisted of 1 min of rest, 4 min of exercise and 5 min of recovery. Perfusion images were calculated as proposed by Raynaud et al. [5], and perfusion curves were derived from signal averages in ROIs within the gastrocnemius medialis (GM), gastrocnemius lateralis (GL), and peroneus muscles. For each volunteer, acquisitions were conducted with and without PMC. Rigid registration was also performed to assess if perfusion curves could be further improved.

***Fig.1** Experimental setup.*

RESULTS: One volunteer was poorly synchronized with the sequence and excluded. Mean rigid motion obtained from the tracking camera was found not to be significantly different during exercise with or without PMC (paired t-test, p>0.05), and was found to be small compared to in-plane resolution (up to 0.5 mm translations and 0.3° rotations in each direction in average). The perfusion curves show a marked decrease of up to 50% for the ratio *standard deviation/mean perfusion* during exercise in four volunteers (Fig 2.B and 2.C). No or negligible improvement was found for the other nine volunteers (Fig 3.B and 3.C). Slight non-rigid muscle deformation was observed in the datasets of nine volunteers (three volunteers with improvement and six without). In two perfusion curves acquired with PMC, rigid registration decreased the standard deviation.

DISCUSSION & CONCLUSION: In our study, PMC had limited benefits on the quality of perfusion curves. Most volunteers stayed synchronous with the ASL sequence, giving rise to only very little motion between successive shots. On visual inspection, motion-corrected images show less motion than non-corrected images. However, motion reduction was much lower than the pixel size, which is probably too small to improve the quality of perfusion curves. However, it has to be noted that only low intensity exercise was performed in our study, and it needs to be evaluated if high-intensity exercise gives rise to more motion with a greater expected benefit of PMC. For the 4 volunteers showing significant decrease of the standard deviation of perfusion during exercise (3 m, 1 f), motion was not found to be lower than for the other volunteers and their calves are visually not less affected by deformations. As indicated by the improvement that can be seen with rigid registration when PMC was used, coupling between the marker and the tissues of interest within the imaging slice may be somewhat more complex for the calf than for other parts of the body. Further testing should tell us more about the effect of morphology and marker positioning on tracking efficiency.

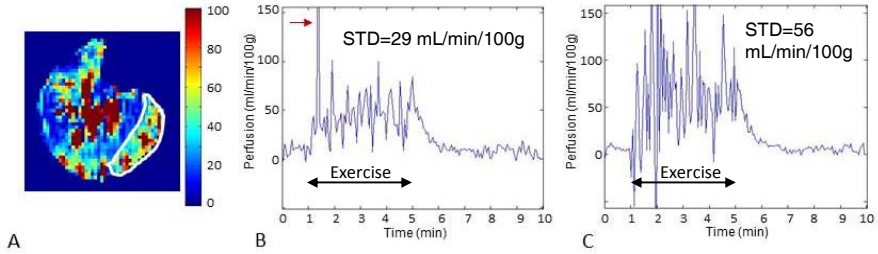

***Fig 2**. Perfusion map and ROI delineated in white in the GM muscle (A), and derived perfusion curve with PMC (B) showing lower standard deviation (STD) during exercise than without PMC (C). The red arrow indicates an erroneous peak caused by deformation of the GM muscle.*

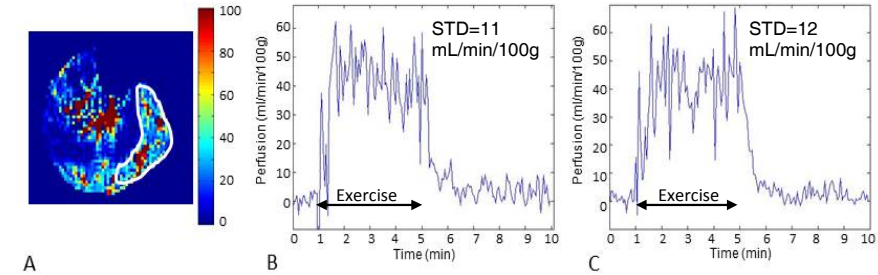

***Fig 3**. Perfusion map and ROI delineated in white in the GM muscle (A), and derived perfusion curve with PMC (B) showing no significant difference with the perfusion curve obtained without PMC (C).*

Even in case of very little motion the perfusion curves during exercise can remain noisy, which may at least in part be ascribed to the sensitivity of ASL to fluctuations due to cardiac pulsations [6]. Future studies should include cardiac triggering to investigate the effect of cardiac phases on the ASL signal in the exercising calf muscle. Retrospective motion correction including non-rigid registration may also be helpful to assess the effects of small deformations.

REFERENCES: [1] Frank et al., MRM 1999; 42:58-267. [2] Zaitsev et al., Neuroimage 2006; 31:1038-1050. [3] Lange et al., MRM 2014; 71:516-523. [4] Maclaren et al. PLoS One 2012;7(11):e48088. [5] Raynaud et al., MRM 2001; 46:305-311. [6] Wu et al., IEEE Trans Med Imaging 2007; 26:84-92