Measurement of resting perfusion and perfusion anisotropy in muscle with velocity selective ASL

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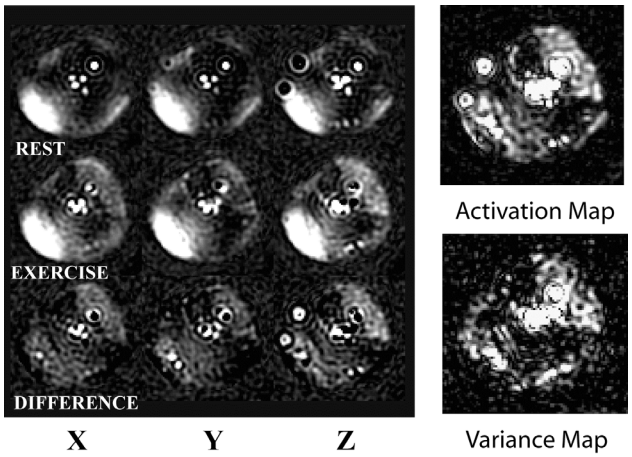
Introduction Arterial spin labeling (ASL) provides a method by which to non-invasively measure the spatial and temporal characteristics of local tissue perfusion, which is important in the study of muscle physiology where traditional techniques are typically invasive or do not employ imaging methods and are thus not able to discern either spatial or temporal heterogeneity. We have previously shown the utility of ASL in measuring dynamic muscle perfusion [1] using a standard spatial tagging scheme. However, spatial tagging schemes depend upon the spatial separation of the inversion and imaging regions and are thus susceptible to artifacts due to spatial variations in the transit delay (the time between the tagging of the blood and its arrival in a voxel) and low SNR from T1 decay during the transit delay. An alternative approach is Velocity Selective ASL (VS-ASL) [2,3] in which the tagging depends upon velocity profile such that decelerating spins below a specified cutoff velocity Vcut are tagged. This method has the advantages that the tagging is independent of delay times, can be velocity encoded for perfusion sensitivity in any direction, and can be encoded at selective ranges of velocity. It thus provides a very sensitive method for perfusion imaging particularly suited for application to muscle perfusion, where the ability to measure resting perfusion and perfusion anisotropy has important physiological implications [4] but has remained elusive. In this abstract we demonstrate both on a normal human volunteer.

Methods Images were collected on a GE SIGNA Lx Clinical Imager with EchoSpeed gradients, using a standard knee coil receiver. The VS-ASL pulse sequence was that proposed by Wong [2] using a spiral acquisition and modified to encode velocity in arbitrary directions, using the following imaging parameters: FOV=24cm, thickness=10mm, matrix=64x64, Vcut=2.7cm/s, TR=4000ms, Tv=1000ms, reps=100. Measurements were made in three orthogonal directions (physical (x,y,z)) under conditions of rest and exercise. For the exercise condition, the subject performed plantar-flexion against no resistance. A rope tied around the foot and held by the subject helped insure a consistent position between repetitions. The exercise was performed in the period between the end of the data collection and the beginning of the velocity selective pulse. The total time from the VS pulse to the end of imaging was approximately 1.1sec, so the TR of 4sec allowed 2.9sec of exercise, during which the subject performed two plantar-flexions. Because the VS tag is very sensitive to motion, it was important to make sure the exercise finished well before the start of the VS tag and that the subject remains still in a consistent position in between repetitions. This required significant dorsi-flexion and isometric contraction in the dorsi-flected position during scanning, and thus significant use of the tibialis anterior and the extensor group.

Results. Figure 1 (left) shows perfusion images during (top) rest, (middle) exercise, and (bottom) the difference between exercise and rest. Significant perfusion in the gastrocnemius is evident in the "rest" state, presumably because the subject had been walking around prior to scanning. While further work clearly merits a more well defined "rest" state, this image clearly shows the sensitivity of the technique. During exercise, there is an increase in flow (as seen in the difference images) in the gastrocnemius, soleus, tibialis anterior and extensor group. While the amount of perfusion appears greatest in the gastrocnemius, the largest change is evident in the tibialis anterior and extensor group, consistent with the subjects doral-flexion and subsequently isometrically holding the leg in a dorsal flexed position for the time during tagging and imaging (approx 2sec). The subject confirmed that the exercise was significantly more strenuous on these muscle groups. There is an apparent lack of perfusion in the posterior region of the gastrocnemius because it is resting on the coil. These results are summarized in an "activation" map, formed as the norm of the difference images (upper right). Perfusion anisotropy (lower right) was characterized by computing the variance between the average exercise and rest images in each direction: Var = $\sqrt{\sum_k (excercise_k - rest_k)^2}$ where k is the number of velocity encoding directions (3) and is clearly evident, particularly in the tibialis anterior and the extensors.

Conclusion We have demonstrated the ability of VS-ASL to measure both resting perfusion and anisotropic perfusion during exercise in normal human muscle. The advantage over our previous method [1] is the velocity selectivity, the insensitivity to transit delays, and the flexibility to encode velocities in arbitrary directions, all of which facilitate a greater sensitivity to local perfusion characteristics. This is important in the study of muscle physiology in that it allows the measurement of spatial and temporal flow heterogeneity as well as the direction of flow feeding each region, which is a question of significant interest in muscle physiology. Future work will include more precise experiments and a quantitative comparison of results with direct flow measurements. Potential clinical applications of resting perfusion measurements include a range of medical conditions, such as muscular dystrophy, and compartment syndrome.



References

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