In Vivo Lipid Diffusion Coefficient Measurements in Rat Bone Marrow

R. V. Mulkern[1], Z. Ababneh[2], H. Beloeil[3], C. Berde[3], S. E. Maier[4]

[1]Radiology, Children's Hospital, Boston, MA, United States, [2]Physics, University of Massachusetts, Lowell, MA, United States, [3]Anesthesia, Children's Hospital, Boston, MA, United States, [4]Radiology, Brigham and Women's Hospital, Boston, MA, United States

Introduction: Measuring the diffusion properties of lipids in bone marrow or metabolically active intracellular lipids in muscle may prove useful for assessing fatty acid distributions linked to such diseases as cystic fibrosis, diabetes and coronary heart disease (1-3). Measuring diffusion coefficients of high molecular weight lipids requires high b-factors and pulse sequence approaches which are relatively immune to motion and susceptibility artifacts. Recently, Lehnert et al achieved such conditions using diffusion weighted single voxel spectroscopic STEAM methods and reported lipid diffusion coefficients in human bone marrow in vivo of approximately 12 nm^2/us (4). In this work we performed image based measurements of lipid diffusion coefficients by implementing a line scan diffusion imaging (LSDI) sequence (5) on a 4.7 T animal scanner capable of achieving b-factors of 30,000 s/mm^2 at an echo time of 42 ms. Studies of rat paws in vivo were performed yielding lipid diffusion coefficients approximately two order of magnitude less than typical tissue water diffusion coefficients.

Methods: Six anesthetized adult Sprague-Dawley rats were scanned on a 4.7 T Bruker Biospec using a volume coil for RF transmission and a surface coil taped to both paws for reception. The right hind paw of each rat had been treated with a toxin as part of a separate muscle edema study. We hypothesized that the muscle edema would have no effect on lipid diffusion within the bone marrow. An LSDI sequence was applied to image both paws in the axial plane. Diffusion sensitization was performed along the four tetrahedral directions, sampling 16 equally spaced b-factors from 2,000 to 30,000 s/mm^2. The effective repetition and echo time were 8 s and 42 ms, respectively, and the voxel dimensions were 1.5 x 0.5 x 0.5 mm^3. The studies were carried out with the approval of the hospital animal care and use committee.

Results: Figure 1 shows in vivo images of rat paws acquired at b-factors of 2,000 and 30,000 s/mm^2 and typical diffusion decay curves from bone marrow. Muscle edema is evident in the right paw in the lower b-factor image while in the highest b-factor image the only signal remaining from either paw arises from bone marrow lipids in the digits. Signal decay curves were monoexponential (Figure 1) over the range of b-factors examined. Trace values for the lipid diffusion coefficients were 19.8 ± 2.3 (right paws, N = 12 digits) and 19.2 ± 2.2 $nm^2/\mu s$ (left paws, N = 12 digits) with no statistical differences between the right and left paws ($p > 0.7$, paired t-test), justifying the assumption that the muscle edema played no role in the study. Off-diagonal terms of the diffusion tensor available from the tetrahedral diffusion encoding scheme were less than 1 % of the trace diffusion coefficients, indicating minimal diffusion anisotropy (Figure 1, right).

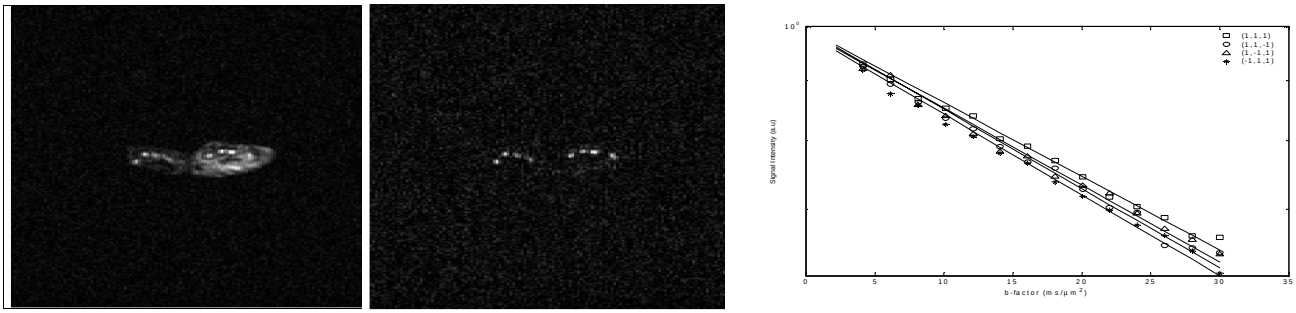

Figure 1: Axial images of rat paws acquired at b-factors of 2,000 s/mm^2 (left) and 30,000 s/mm^2 (middle) and typical diffusion decay curves from a marrow ROI for all four diffusion sensitization directions (right).

Discussion: Diffusion imaging of lipids in vivo is completely unexplored yet may have medical applications in assessing fatty acid distributions. Technical difficulties of performing lipid diffusion imaging were overcome in this work by using high b-factor LSDI sequences as implemented on a high performance animal scanner, allowing for measurements of lipid diffusion coefficients some 100 times smaller than typical water diffusion coefficients.

References:

1.Campbell IM, Crozier DN, Caton RB. Pediatrics 1976;57:480-486.
2. Boden G. Proc Assoc Am Physicians 1999;111:241-248.
3. Wood DA, Butler S, Riemersma RA, et al. Lancet 1984;2:117-121.
4. Lehnert A, Machann J, Helms G, Claussen CD, Schick F. Magn Reson Imag 2004;22:39-46.
5. Gudbjartsson H, Maier SE, Mulkern RV, et al. Magn Reson Med 1996;36:509-518.