Non-Gaussian Diffusion to investigate bone marrow

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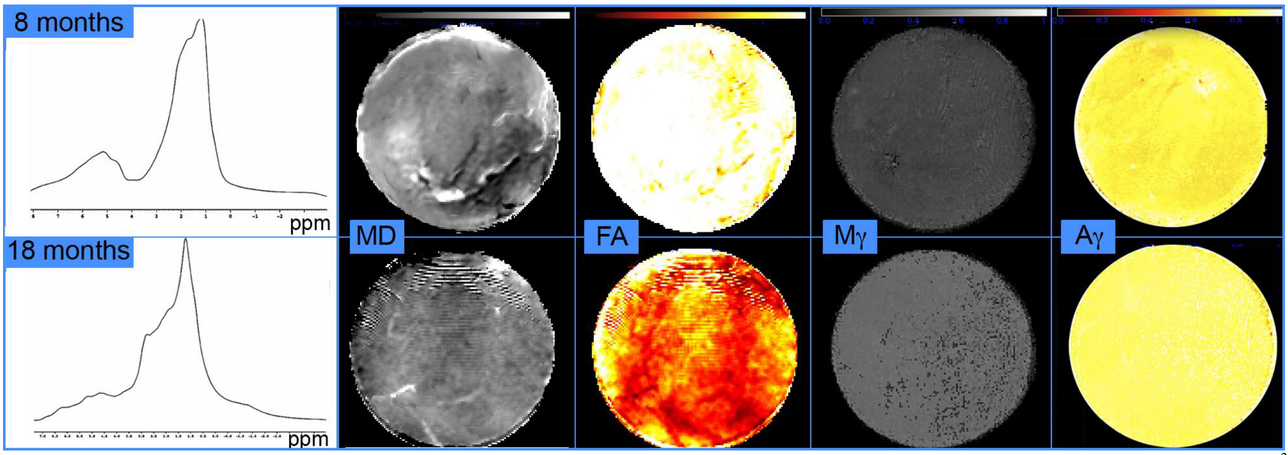
Introduction: Water diffusion in biological systems is often found to deviate from the conventional mono-exponential decay of Stejskal-Tanner equation S(b)=S(0)exp(-bD). As a consequence the behaviour of the signal decay can be interpreted as arising from a non gaussian propagator. As stated by the Continuous Time Random Walk (CTRW) theory, the gaussian approximation fails when the environment in which the spins diffuse is able to trap them, letting the waiting time distribution between two consecutive steps diverge [1]. The solution of the diffusion equation leads to a non linear dependence of the mean squared displacement to the diffusion time $\left\langle r^2(t)\right\rangle \propto t^{\gamma}$ and to a stretched exponential form for the signal decay: $S(b)=S(0)\exp(-Ab^{\gamma})$. By varying the b-value, it is possible to obtain by means of a fitting procedure, the so called anomalous exponent γ, which categorizes the deviation from the ideal conditions of Gaussian diffusion and the complexity of the diffusing spins excursions. Parametric maps based on the mean anomalous exponent γ and on its anisotropy may offer complementary information compared to conventional Mean Diffusivity (MD) and Fractional Anisotropy (FA) maps [2]. Some authors demonstrated, on animal model, that the stretching parameter γ used to assess sample water compartmentalization complexity showed a high sensitivity in detecting early pathological changes in tumor tissues [3]. Other authors obtained interesting result on human brain [2]. Bone marrow is affected by several benign and malignant pathologies. Recently it has been underlined that one of the the main features of osteoporosis is an altered quality of the bone marrow [4]. Bone marrow is composed by different kinds of fat and water. This complex system is located both in diaphysis, where it is free, and in the spongy bone, where it is constrained inside the pores of a solid-bone matrix. The relative content of lipids and water in bone marrow, is site- and age dependent. Moreover water diffusion behaviour, in bone marrow, strongly depends on water to lipid fraction. These findings are relevant in investigating the potential role of non–gaussian diffusion methods to evaluate bone marrow quality . Aims of the present work were: 1) to create a software to perform γ parametric maps from the diffusion weighted images at different b-values and 2) to characterize the effect of the environments on the diffusing water spins in calf bone marrow by means of the anomalous exponent γ at different lipid to water ratios

Methods and Materials: bone marrow was removed from the femur diaphysis of calf and bovine samples. Bovines of 8, 12-18 and 30 months were considered and their water/fat ratio was assessed from bone marrow spectra obtained by ^{1}H-MRS. For each sample, diffusion weighted images were acquired at 9.4 T using a



Pulse Gradient Stimulated Echo (PGSTE) sequence along 7 non collinear directions. Eight b-values (0 2500 5000 10000 15000 25000 35000 45000 s/mm^2) were used, TE/TR=18.1/3000ms, matrix 128x128, FOV 6mm . A matlab software was realized to filter the images with a 2x2 pixels Gaussian filter, to create a threshold mask and to perform a linear fit for every pixels: $\ln\left|\ln S(b)/S(0)\right| = \gamma \ln b + A$ in order to obtain the anomalous exponent value γ. Then its mean value Mγ and its anisotropy: $A\gamma = \sqrt{N\sum_{i=1}^{N}\left(\gamma_i - \langle\gamma\rangle\right)^2 \Big/ (N-1)\sum_{i=1}^{N}(\gamma_i)^2}$ was calculated and parametric maps were obtained. All the diffusion weighted images were also used to obtain conventional MD and FA parametric maps.

Results: Bone-marrow water/fat ratio decreases with bovine age. The image contrast between γ maps and the conventional DTI maps is different. Specifically, the image contrast in MD and FA maps seems to be more affected by susceptibility and chemical shift artifacts than that in the Mγ and Aγ maps. Mean γ value is lower in 8 months bone marrow sample compared to 18 months samples. Aγ in 8 months bone marrow is slightly lower compared to Aγ in 18 months sample. Conversely mean value of FA in 8 months bone marrow is strongly higher compared to FA in 18 months sample. In Figure, from left side to right side, proton spectra, MD, FA, Mγ and Aγ were reported for both 8 and 18 months bone marrow samples.

Discussion and Conclusion

Bone Marrow is a system characterized by strong magnetic susceptibility differences between water and fat, and by a 3.5ppm chemical shift difference between the two intense water and fat peaks. As a consequence, MD and FA values, in this particular system, depend not only on the water diffusion behavior but also on other factors due to the interaction of the system with the magnetic field. Conversely Mγ and Aγ maps seem to depend only on the peculiar diffusion behavior of water in bone marrow. The peculiar water diffusion modality detected by Mγ in 8 months bone marrow sample shows a strong deviation from Gaussian diffusion. This could be due to a more complex water compartmentalization in 8 months bone marrow sample compared to samples characterized by a lower water/fat ratio.

Preliminary results reported here, demonstrate that non-gaussian diffusion methods may provide complementary useful information about diffusion behaviour of water to improve bone-marrow pathologies diagnosis.

References [1] Metzler R Phys. Rep. 2000;339:1-77**.** [2] Hall MG, Barrick TR., MRM 2008;59: 447-455**.** [3] Bennett KM et al. MRM 2004;52:994-1004**.**
[4] Yeung DKW, JMRI 2005;22:279-285.