Magnetic susceptibility local variations affect γ-weighted maps contrast in brain

S. De Santis[1,2], A. Gabrielli[3], E. Macaluso[4], M. Bozzali[4], and S. Capuani[2,5]
[1]CUBRIC, School of Psychology, CARDIFF, South Glamorgan, United Kingdom, [2]Physics department, Sapienza University, Rome, Italy, [3]via dei Taurini 19, ISC-CNR, Rome, Italy, [4]Neuroimaging Laboratory Santa Lucia Foundation, Rome, Italy, [5]IPCF UOS Roma, Sapienza University, Rome, Italy

Introduction: Conventional DTI methods are based on the Stejskal-Tanner analysis which predicts a mono-exponential decay for water signal as a function of b-values, namely S(b)=S(0)exp(-Db). Non-monoexponential trends have already been largely reported in the brain tissue of both animal models and humans [1,2]. The stretched-exponential model, namely $S(b)=S(0)\exp(-Db^{\gamma})$, was recently proposed [3,4] to account for this deviation. Scalar invariant indices based on the exponent γ [5] allowed the characterisation of different brain structures, demonstrating that stretched exponential analysis provides additional information which is complementary to that offered by conventional DTI. Although some Authors have demonstrated an exquisite ability of γ parameter to discriminate between brain structures characterized by different microstructural features but with similar mean diffusivity values [3,4,5], the contrast obtained from γ-weighted maps has not been fully motivated yet. We have recently observed a dependence of γ on internal gradient generated by magnetic susceptibility difference between water and bone in spongy bone specimens [6] and a dependence of γ on internal gradient generated at the interface between water and packed polysterene microbeads samples [7].
The goal of the present work was to investigate the correlation between the mean stretching exponential parameter (Mγ) as described in [5], and the magnetic susceptibility difference at tissue interface, i.e. local variations in magnetic susceptibility between diffusing water and tissues which obstacle water molecules diffusion. Susceptibility, as well as diffusion, can be described as a tensor, whose orientation strongly depends on the interfaces geometry and, as a consequence, can provide relevant pieces of microstructural information. Stretching exponent γ and T2* measurements were obtained in a group of healthy subjects at 3T, aiming to characterise the influence of magnetic susceptibility local variations on anomalous diffusion of water in the brain tissue.

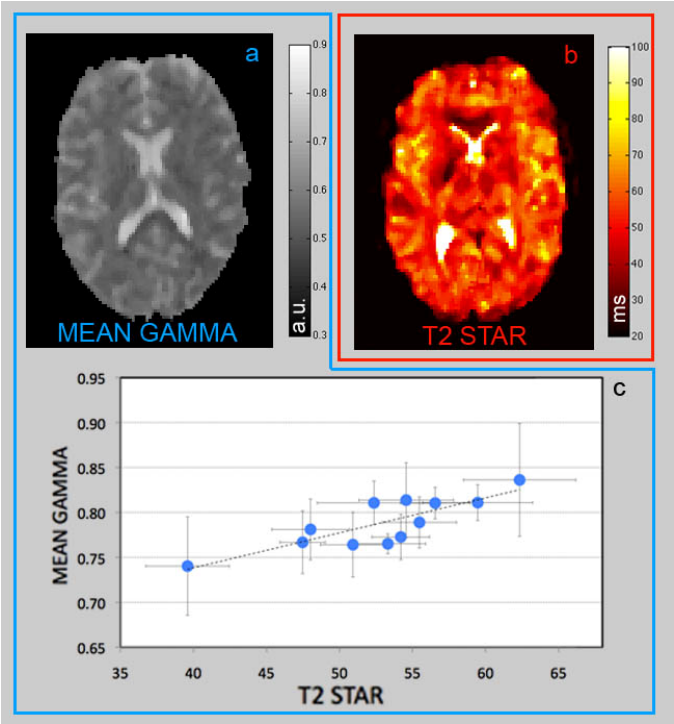

Fig. 1 Examples of Mγ (1a) and T2* (1b) maps obtained from a single subject. Panel C shows the strong correlation between Mean γ and T2* values (in milliseconds) derived from the investigated ROIs in all studied subjects . Please note a well defined linear correlation (R=0.83, p<0.001) between Mγ and T2* values.

Methods: Eight young healthy subjects (mean age 25 ± 2 years) underwent a MRI examination on a 3T scanner (Siemens Allegra), including gradient-echo (TR=5000ms,TE=10,20,35,65ms) and DTI acquisitions using diffusion weighted SE EPI (TR=6400ms,TE=107ms, bandwidth 1860 Hz/px, slice thickness 3mm, in plane resolution 1.8mm^2) acquired in 20 non collinear directions at 14 different b-values (0,100,200,300,400,500,700,800,1000,2000,2400,3000,4000,5000) s/mm^2. Thirty-two contiguous axial slices were collected with NS=2. An algorithm implemented in Matlab was used to perform a multidimensional fit of the diffusion signal decay in each pixel across the applied gradient directions. The fit generates as output the average of the three main exponents [4]. Diffusion-weighted acquisition at different b-values were combined with T2* multiecho relaxometry. Four consecutive T2*-weighted gradient echo were acquired using a segmented echo planar imaging sequence at different TEs: 6, 20, 35, 80 ms (TR=5s, in plane resolution 1.8mm^2). Parametric maps representative of the Mγ values and maps of T2* values were then obtained. Regions of interest (ROIs) were drawn based on anatomical landmarks in selected WM (Thalamus, Pericallosal areas and Corpus Callosum) and GM (Putamen and Head of the Caudate Nucleus) regions, and the correspondent values were averaged across all subjects.
Results and Discussion: In Fig.1, examples of Mγ (1a) and T2* (1b) maps are displayed, while in Fig. 1c, Mγ is plotted against the mean T2* for twelve different ROIs in the brain. The bars indicate the SD obtained from all studied subjects. Graph c shows the direct correlation between Mγ and T2* values (R=0.83; p<0.001).
Please note that the lower the T2* value, the lower the Mγ value, i.e. the strongest the deviation from mono-exponential behavior. It is well known that T2* strongly depends on the local magnetic susceptibility variations, which affect the spin phase, thus causing a faster loss of coherence and shorter T2*. Here, we reported for the first time that the amount of deviation from the mono-exponential behavior, quantified by γ, is correlated with the magnetic susceptibility difference strength. These results suggest an innovative explanation for the non-monoexponential patterns reported in previous literature [3,4,5]. Diffusion sequences are based on the encoding of the spin phase by means of magnetic field gradients. When internal gradients due to local variations in magnetic susceptibility are present, their overlap with the encoding gradients may affect the shape of recorded signals. We speculate that these results open a new scenario in the analysis of diffusion-weighted data. If confirmed, the peculiar combination of diffusion and susceptibility can be used to characterize cerebral structures in an innovative fashion.
Conclusion: Experimental results reported here show that local variations in magnetic susceptibility are correlated with the amount of deviation from mono-exponential behavior observed in diffusive decay of water in human brains. These results offer an innovative interpretation of water diffusion decay, and suggest that the peculiar contrast obtained from γ (arising from stretched exponential model) can be further explored and correlated to specific local microstructures.

References: [1] Mulkern RV et al. NMR Biomed 1999;12:51 [2] Alexander DC et al. Magn. Res. Med. 2002,48:331 [3] Bennet KM et al. MRM 2006;56:235-240. [4] Hall MG and Barrick TR.. MRM 2008; 59: 447-455. [5] De Santis S et al. MRM 2010 (in press). [6] De Santis S and Capuani S, Proc Intl Soc Mag Reson Med 2010 n.6294 [7] Palombo M et al. (submitted abstract)