Effects of water exchange: A high b-value diffusion study of ischemic stroke lesions in the human brain

J. Lätt[1], M. Nilsson[1], D. van Westen[2], R. Wirestam[1], F. Örtendahl[2], F. Ståhlberg[1,2], S. Holtås[2], and S. Brockstedt[1,2]

[1]Department of Medical Radiation Physics, Clinical Sciences Lund University, Lund, Sweden, [2]Department of Diagnostic Radiology, Clinical Sciences Lund University, Lund, Sweden

Introduction

Diffusion weighted imaging (DWI) can be used to visualise and differentiate ischemic stroke lesions in the acute phase [1, 2]. In acute ischemic stroke, cell swelling occurs due to cytotoxic oedema, although the specific origin of the contrast phenomenon visible in DWI is uncertain. To gain further understanding of the DWI contrast of ischemic lesions, i.e. the signal-versus-*b* curve differences between healthy and pathological tissue, and to improve the delineation of the infarcted area, high *b*-values have previously been employed [3]. However, repeated measurements with varied diffusion times (T_d:s) may improve the understanding of the origin of the contrast, as the hypothesis of restricted diffusion and exchange between diffusion components can be tested [4]. In this pilot study, we have studied the signal-versus-*b* curve in a stroke patient using high *b*-values and two different diffusion times.

Method

Measurements were performed at a Siemens 3T Allegra head scanner, on a 34 years old male ischemic stroke patient, four days after onset of the stroke. A diffusion tensor imaging (DTI) protocol, based on a stimulated echo pulse sequence, was performed with diffusion encoding in six directions. The signal attenuation curves were acquired for two T_d:s, i.e. 60 and 260 ms, by varying the mixing time (TM). The duration of the pulsed diffusion gradients were δ = 27 ms and TR/TE was 2000 ms/105 ms. For each T_d, 16 *b*-values was sampled with b_{max} = 7500 s/mm^2. Two regions of interest (ROIs) were used for analysis, one placed in the lesion (cerebellum right side) and one reference ROI in the contralateral healthy tissue. A two-component modified Kärger model, incorporating exchange between two freely diffusing components was fitted to the obtained data [4].

Results

In Figure 1, the ischemic lesion (indicated with a black ROI) is visible both in the T2-weighted image and in the S_0 image. In Figure 2, the signal-versus-*b* curves obtained from the two regions show that the normalized signal intensity of the stroke lesion decreased faster for the long diffusion time, while no such phenomenon is observed in the contralateral healthy tissue. The parameters obtained from the fitting to the data are presented in Table 1.

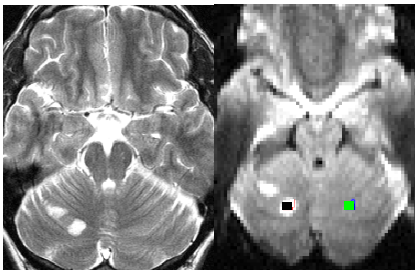

Figure 1. A T2W image (left) and a S_0 image (right) showing the ischemic stroke lesion in the sub-acute phase (indicated with a black ROI) and the control area (green ROI).

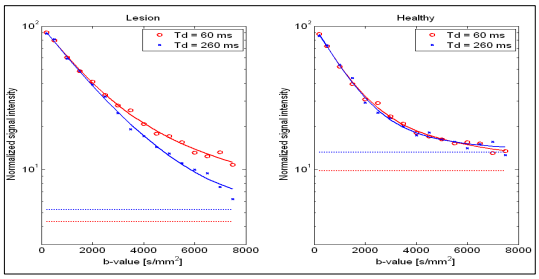

Figure 2. Geometrically averaged signal values for the two Td:s of 60 ms (red rings) and 260 ms (blue crosses), for the lesion (left) and the healthy tissue (right). The solid lines correspond to the fitted model. Dashed lines indicate the noise floor.

RoI	S_0	*T1* [ms]	ADC_{fast}/ ADC_{slow} $\times 10^{-9}$[m^2/s]	p_{slow} [%]	τ [ms]
Lesion	211	1116	0.64 / 0.08	24	341
Control	94	705	0.87 / 0.09	22	1038

Table1. The parameters obtained from the fitting of the two-component modified Kärger model. From left: S_0 (i.e. signal intensity for b=0), T1, ADC fast and slow, fraction of the slow component (p_{slow}) and the exchange time (τ). A decrease in ADC_{fast} was observed, as well as an increased T1 and a much shorter τ in the lesion.

Discussion

Effects of restricted diffusion have previously been reported from *in vitro* studies performed using NMR spectrometers [5]. However, for clinical MRI units, no alterations of the diffusion signal for varying T_d:s have been reported [6]. In this preliminary study, effects of a varied T_d were observed on the signal-versus-*b* curve for an ischemic stroke lesion, but not in the corresponding healthy control tissue. When the signal-versus-*b* curves were analyzed with a modified Kärger model of two freely diffusing and exchanging components, the findings in this sub-acute stroke indicate that exchange between two different water components occurs, while the longer τ = 1038 ms in the control tissue indicates that essentially no exchange occurred between the two components [7]. The brain ischemic edema with subsequent cell death is likely to affect the cellular compartment sizes in such a way that it is possible to observe the exchange mechanisms with a clinical MRI scanner operating with lower gradient performance than NMR spectrometers. Possibly, the exchange time can become a clinically relevant parameter used to characterise stroke lesions. Another possible interpretation of the observed phenomenon is a variation of T1 between the two components, but additional measurements with varying T1 are required to investigate this hypothesis.

References

[1] Moseley *et al*. MRM, 1990:14:330-346
[2] Lövblad *et al*. Eur Radiol, 2006:16:1253-1269
[3] Toyoda *et al*. Eur Radiol, 2007:12:1212-1220
[4] Kärger *et al*. Adv. Magn. Reson, 1988:12:1-89
[5] Assaf *et al*. MRM, 2000:44:713-722
[6] Clark and Le Bihan MRM, 2000:44:852-859
[7] Le Bihan Phys Med Biol, 2007:52:R57