# Visualisation of displacement-distribution parameters in q-space imaging

J. Lätt[1], S. Brockstedt[2], R. Wirestam[1], E. Larsson[2], F. Ståhlberg[1]

[1]Department of Radiation Physics, Lund University, Lund, Sweden, [2]Department of Radiology, Lund University Hospital, Lund, Sweden

## Synopsis

Structural information of the confining geometry of water molecules can be revealed by q-space analysis of highly diffusion encoded images. An advantage of q-space analysis based on high b-values is that data contain information about different compartments; extra- and intracellular water. Calculations of the mean displacement and the probability of zero displacement, from the average propagator, obviously reveal information on diffusion in different areas of the brain. In this study, we propose that the shape of the displacement distribution curve should be taken into considerations, and therefore the kurtosis, a measure of the deviation from a Gaussian distribution, was assessed.

## Introduction

High b-value diffusion imaging in combination with diffusion tensor analysis allows extraction of information about fast and slow diffusion in brain tissue, probably corresponding to the extra- and intracellular water, and differences between white and grey matter are evident [1]. As an alternative, q-space analysis of diffusion data may give similar information in terms of different displacements for water in different compartments [2]. The aim of this study was to obtain additional understanding of the compartmentalisation of brain matter by means of q-space analysis.

## Subjects and Methods

Throughout the study, a 3.0 T Siemens Magnetom Allegra head scanner was used (gradient 40mT/m @ 0.1 ms). A SE-based EPI pulse sequence was modified to allow for diffusion encoding in six directions (xz, -xz, yz, y-z, xy and -xy) with 32 equally spaced q-values, and a maximum q value of 450 $cm^{-1}$ (max b value 6600 $s/mm^2$). The diffusion encoding parameters are defined as: $q = (2\pi)^{-1}\gamma\delta g$, where $\gamma$ is the gyro magnetic ratio, $\delta$ is the duration of the gradient pulse and g the gradient amplitude, and $b= \gamma^2\delta^2g^2(\Delta-\delta/3)$, where $\Delta$ is the time duration between the leading edges of the diffusion gradients. Other scanning parameters were TE/TR = 135/4000 ms, $\delta/\Delta$ = 20/88 ms, $G_{max}$ = 38 mT/m, 10 slices with thickness 5 mm, FOV = 215 mm, matrix size = 100x128. This pilot study was based on five healthy volunteers (NEX = 2) and two patients (MS and tumour) (NEX = 1). Image post-processing was carried out using an IDL-base diffusion analysis program developed within the research group (Interactive Data Language, Research Systems, Inc.). Linear fits were made for two separate intervals of the assumed bi-exponential signal vs. b-value curve, and apparent diffusion coefficients (ADCs) were determined using b-value ranges of 0-1200 $s/mm^2$ and 2200-6600 $s/mm^2$, for determination of $ADC_{fast}$ and $ADC_{slow}$, respectively The inverse Fourier transform of the signal vs. q-value curve gives the average propagator which is a distribution that describes the probability of finding a molecule at a certain position, after the diffusion time $T_d=(\Delta-\delta/3)$. From the displacement, parametric maps of the mean displacement (FWHM), the width at 10% of distribution height (FWTM), the probability of map for zero displacement and the kurtosis were generated.

## Results

Maps pf ADC fast and ADC slow, FWHM, FWTM, probability of zero displacement and kurtosis are shown for a healthy volunteer in Fig 1 and in Fig 3 shows the corresponding images of an MS patient. Values form region of interests (ROI) in different brain tissues are given in Table 1 and the corresponding signal decays and displacement distributions are shown in Fig 2.

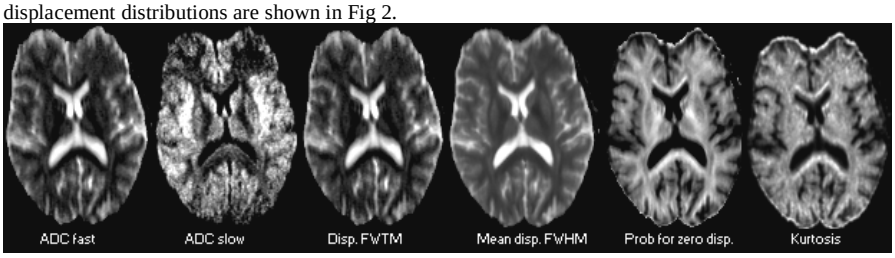


**Fig 1** Images calculated from one of the volunteers demonstrating various brain compartments by ADC maps and q-space analysis. The kurtosis image is calculated from the displacement distribution (*i.e.* the frequency function) using Fisher kurtosis.

| | GM | WM | CSF | MS | Control |
|---|---|---|---|---|---|
| ADC fast * | 0.86±0.04 | 0.70±0.04 | 3.09±0.22 | 1.42 | 0.71±0.05 |
| ADC slow * | 0.25±0.02 | 0.20±0.04 | 0.07±0.02 | 0.16 | 0.20±0.01 |
| $R^2$ -ADC fast/slow | 0.991/0.883 | 0.994/0.949 | 0.994/0.760 | 0.998/0.711 | 0.9940.949 |
| FWHM [μm] | 22±1 | 19±2 | 48±2 | 31 | 18±1 |
| FWTM [μm] | 88±2 | 73±3 | 163±10 | 113 | 72±4 |
| Zero prob [a.u] | 1.25±0.02 | 1.45±0.04 | 0.72±0.03 | 1.02 | 1.47±0.05 |
| Kurtosis | 2.68±0.09 | 3.16±0.17 | 1.41±0.16 | 2.16 | 3.16±0.12 |

**Table 1**. Mean values and standard deviations obtained from average values in the five volunteers for grey matter (GM), white matter (WM) and cerebrospinal fluid (CSF). The MS and control values refer to measurements in the MS plaque and in the control group (n=5) at similar positions. (* = $\times 10^{-9}$ [$m^2/s$])

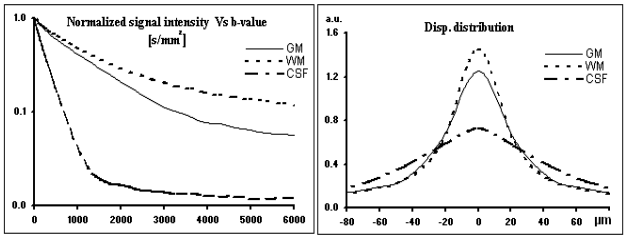


**Fig 2** Signal decay curves and the corresponding displacement distributions from ROIs in GM, WM and CSF.

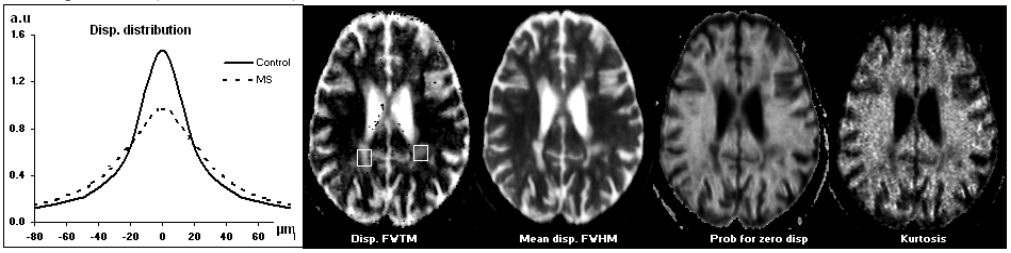


**Fig 3** The displacement distributions from MS lesions and from data in corresponding regions in healthy volunteers (control) are given in the graph to the left and the corresponding q-space images obtained from the MS patient are shown to the right. Corresponding ROI data are given in Table 1. The distribution in MS lesions is more platykurtic than the distribution of the control group.

## Discussion

The greyscale of the kurtosis image reflects the deviation from the normal distribution, possibly indicating the degree of compartmentalisation of different tissues (this is supported by the observation of kurtosis values close to zero in CSF). In areas of an MS plaque, the kurtosis is lower than in corresponding normal brain matter but not as low as for CSF, consistent with a degeneration of white matter fibres and loss of anisotropy. Data consistent with this hypothesis were obtained also for the tumour case. The findings are interesting and merit further inspection as they might provide a tool for investigations of extra- and intracellular water compartments in brain tissue. We hypothesize that the kurtosis of the displacement distribution can contribute further to the understanding of brain matter structures.

**References** 1. Clark, C.A. et al [2002] MRM 47:623-628 2. Assaf, Y. et al [2002] MRM 47:115-126