Efficient multi-dimensional diffusion measurements at 3 Tesla

L. G. Hanson[1], H. Lund[1], E. Rostrup[1]

[1]Danish Research Centre for Magnetic Resonance, Copenhagen University Hospital, Hvidovre, Copenhagen, Denmark

Introduction

q-Space imaging providing displacement probability maps is very time consuming especially when multiple diffusion times and directions are needed. To characterize the anisotropic water diffusion in the brain, we demonstrate a sequence, which efficiently probes the multi-dimensional parameter space. The sequence adopts the traditional multi-slice stimulated echo (STEAM) FLASH EPI technique, which is superior to spin echo at long diffusion times, as T2-losses can be kept small [1]. Additional loops for more b-values and directions as well as a loop for a slice re-ordering, ensure signal measurement in all slices for all chosen diffusion times. For example, with 12 diffusion gradient directions, 6 b-values and 12 diffusion times the signal attenuation from 3 slices can be measured in 3 minutes (see fig. 1).

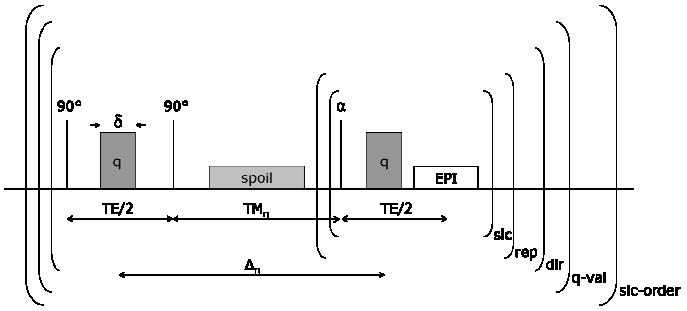

Fig. 1 Stimulated echo with excitation initiated by two non-selective 90° r.f. pulses. α is a slice selective r.f. pulse. δ and *g* are the duration and strength of the diffusion gradients separated by Δ. The two inner loops allow repeated data acquisition of each selected slice for the chosen direction of diffusion gradient and *q*-value. By separately changing the slice order (outer loop), the echo attenuation is measured in each slice for all chosen Δ, *q*-values and directions.

Methods

Scans were performed on a 3.0 Tesla whole-body scanner (Trio, Siemens, Erlangen, Germany), gradients 40 mT/m, 8-channel head coil. Data from two separate experiments are reported to illustrate the versatility of the sequence. Shared parameters: Spatial resolution 3.4x3.4 mm with slice thickness 8 mm, field of view 220x220 mm. Parameters for individual experiments: I) whole-brain volume, seven diffusion times (Δ) ranging from 21 to 362 ms, repetition time (TR) 1737 ms, diffusion gradient duration (δ) 8.8 ms, b-values 70 to 1718 s/mm^2, TM_{min} 11 ms, echo time (TE) 19 ms, 12 gradient directions. II) three slices centered on corpus callosum, six q-values ranging from 10 to 450 cm^{-1}, nine diffusion times (Δ) ranging from 52 to 819 ms, TR 921 ms, δ 37 ms, TM_{min} 11 ms, TE 74 ms, 12 gradient directions.

Results

I) The apparent diffusion coefficients (ADC) were calculated for each diffusion time using all b-values. Fig. 2 shows that the measured ADC is lower for higher diffusion times. Data shown are median values from white matter areas selected from a whole-brain data acquisition.

II) The signal attenuation as a function of *q* is illustrated in fig. 3.

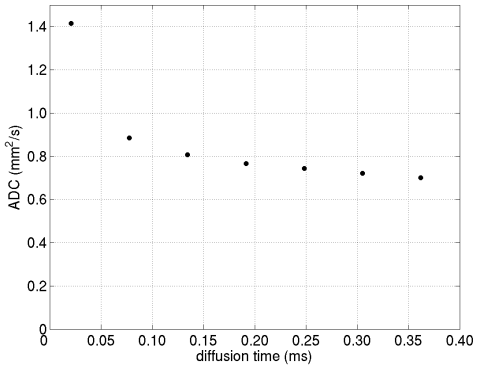

Fig. 2. Experiment I ADC plotted against diffusion time.

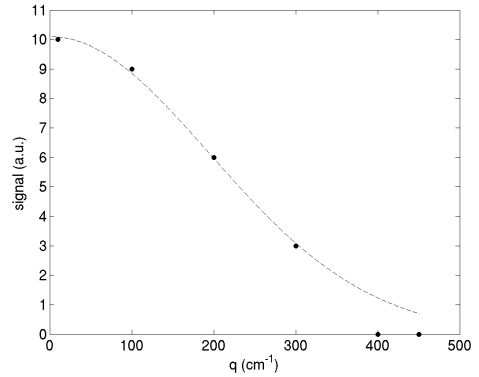

Fig. 3. Experiment II Signal plotted against *q*. The signal attenuation follows the dotted gaussian line.

Discussion

To avoid saturating the signal within the inner loop, refocusing flip angles must be held rather low (e.g., α=20°).

The calculated ADC-values in experiment I are in good agreement with previously reported data [2]. Lower ADC for higher diffusion times is expected from tissue barriers hindering the free diffusion of water.

The gaussian nature of the signal attenuation as a function of *q* is suggested by the dotted line in fig. 3. This correlation is exploited in q-space analysis of diffusion data.

We have demonstrated that the sequence efficiently samples data for traditional ADC calculations as well as q-space analysis. Though not demonstrated here, the sequence also provides multi-point T1 relaxation curves when *q* is chosen so small that the diffusion weighting is negligible.

References

[1] Hahn, E.L. (1950). *Phys. Rev.* **80**, 580

[2] Clark, C.A. and Le Bihan, D. (2000). *Magn. Reson. Med.* **44**, 852.