An Eddy-Current-Compensated Diffusion-Weighting Preparation Based on a Single Spin Echo

J. Finsterbusch[1,2]

[1]Department of Systems Neuroscience, University Medical Center Hamburg-Eppendorf, Hamburg, Germany, [2]Neuroimage Nord, Hamburg-Kiel-Lübeck, Germany

A double-spin-echo preparation [1] is widely used today for diffusion-weighted MR because the durations of the four gradients involved can be chosen to null eddy currents with a specific time constant and thereby minimize related artifacts, e.g. geometric distortions in echo-planar imagjng. However, in particular at higher magnetic field strengths, the signal inhomogeneiety introduced by the two refocusing RF pulses is considerable and hampers the applicability of the preparation. In the present work, an extension of the single-spin-echo approach of Stejskal and Tanner [2] is presented that uses three diffusion-weighting gradients. For appropriate gradient durations, the reduction of eddy-current-related distortions is comparable to the double-spin-echo preparation while a higher signal-to-noise ratio can be achieved in the presence of RF inhomogeneieties.

Methods

Figure 1a shows the standard Stejskal-Tanner diffusion-weighting experiment [2] with a single de- and rephasing gradient prior to and after the RF refocusing pulse, respectively. The double-spin-echo preparation [1] sketched in Fig. 1b involves four gradients with both polarities that can be set up to null eddy currents, generated with each of the gradient ramps, for a particular decay constant. The proposed extension of the Stejskal-Tanner sequence is shown in Fig. 1c and is obtained by splitting the rephasing gradient into two of durations δ_1 and $\delta_2=\delta-\delta_1$ and applying the first one with inverted polarity prior to the refocusing RF.

Parts of the analytical calculations and numerical simulations were performed with Maple (version 9.5.2, Waterloo Maple Inc., Waterloo, Ontario, Canada). Measurements were performed on a 3T whole-body MR system (Siemens Magnetom Trio) using a standard twelve-channel head coil and a doped water phantom. Single-shot spin-echo EPI images were acquire with a spatial resolution of 2x2x5 mm^3 and a field-of-view of 192x256 mm^2. The diffusion-weighting scheme applied involved one image without diffusion-weighting and six with a b-value of 1000 s/mm^2 in non-collinear direction. As a measure of the geometric distortions caused by the diffusion-weighting gradients, the standard deviation of the six diffusion-weighted images was calculated on a pixel-by-pixel basis using a self-written algorithm in IDL (Research Systems Inc., Boulder, Colorado, USA).

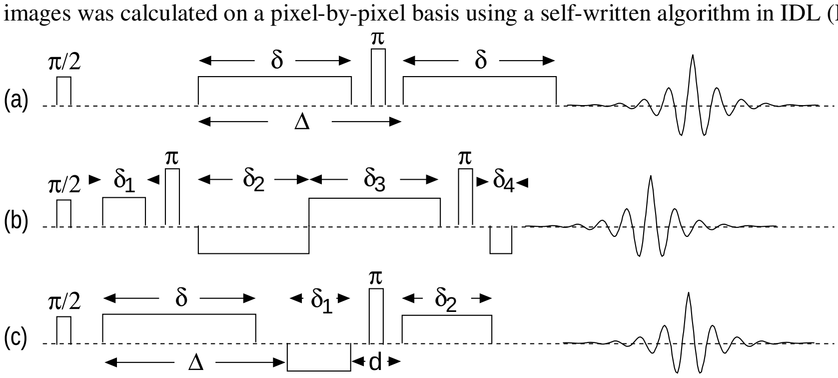

Figure 1: Basic pulse sequences for (a) the Stejskal-Tanner, (b) the double-spin-echo, and (c) the extended single-spin-echo preparation.

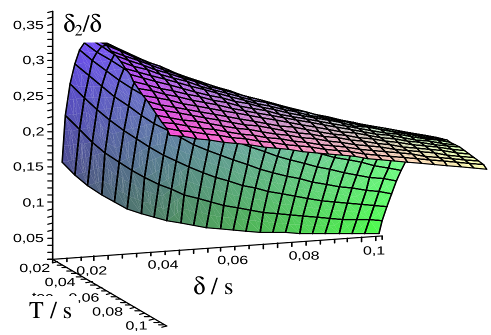

Figure 2: δ_2/δ vs. δ and T for compensation of eddy currents of time constant T (Δ = 100 ms, d = 12 ms)

Results

Assuming an exponential decay with a time constant T for the eddy currents induced by each gradient ramp, the proposed extension (Fig. 1c) nulls the eddy currents completely for $\delta_2 = T \ln \frac{\exp((\delta+\Delta)/T)(1+\exp(d/T))}{\exp(\delta/T)+\exp(\Delta/T)+\exp((\delta+\Delta+d)/T)-1}$,which is in]0,δ[for any positive d and δ and $\Delta>\delta$.

Typical values for δ_2 relative to δ are shown in Fig. 2 and are between 10% and 30% of δ. Figure 3 shows a single diffusion-weighted image and maps of the standard deviation of the six diffusion-weighted images obtained with the three preparation sequences. The signal inhomogeneiety due to dielectric resonances is obvious and more pronounced for the double-spin-echo preparation (echo time 87 ms) yielding only about 80% of the signal achieved with the other preparations in the centre of the phantom although a longer echo time is required for the proposed extension (94 ms). The standard deviation of the extension is lower than that of the Stejskal-Tanner preparation and comparable to that of the double-spin-echo preparation (Fig. 3b). Thus, the proposed extension may help to overcome limitations of the double-spin-echo preparation in the presence of RF inhomogeneities.

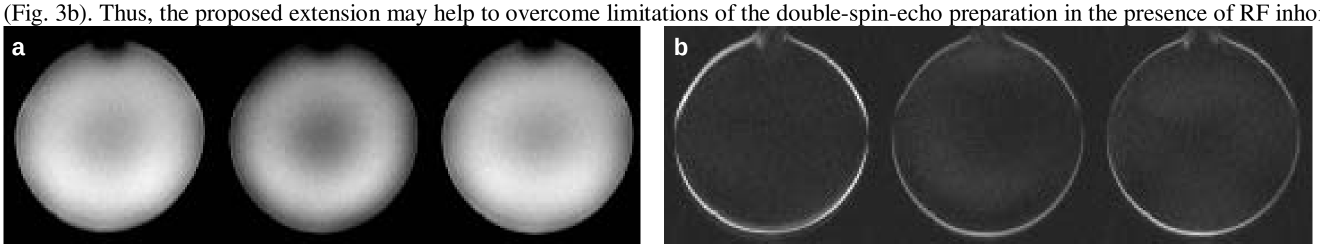

Figure 3: (a) Diffusion-weighted MR image and (b) maps of the standard deviation of the six diffusion-weighted images obtained with the Stejskal-Tanner, the double-spin-echo, and the proposed extension of the single-spin-echo preparation (from left to right)

References

[1] Reese TG et al., Magn Reson Med 49, 177-182 (2003)

[2] Stejskal EO et al., J Chem Phys 42, 288-292 (1965)