First results for diffusion-weighted imaging with a 4th channel gradient insert

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Introduction: Diffusion weighted imaging (DWI) provides contrast that can be a useful for various applications, such as the segmentation of carotid artery plaque [1]. However, DWI can be highly motion sensitive and time consuming, especially for the signal-to-noise-ratios (SNR) required plaque segmentation. Signal in DWI can be described by the following equations:

$$M_+ = M_o e^{\frac{-t}{T_2}} e^{-bD} \qquad b = \gamma^2 G^2 \delta^2 \left| \Delta - \frac{\delta}{3} \right|$$

D is the apparent diffusion coefficient of the tissue, G is the applied gradient, δ is the duration of the diffusion pulse, and Δ is the time between the diffusion pulses [2]. In order to minimize T2 signal loss, the required b-value should be obtained as quickly as possible. This means pulsing the gradients as strongly as possible.

In DWI the gradient coils serve two purposes. Linear gradients are used for image acquisition, and strong gradients are pulsed to apply and remove position-dependant phase, in order to encode for diffusion. If a strong, localized, fourth gradient were inserted into the bore during imaging, it could be used to apply the diffusion-weighting to the region of interest. The image acquisition could then be performed by standard whole-body gradients.

This abstract investigates driving a fourth gradient axis to provide the diffusion-weighting during DWI.

Method: A butterfly coil (Figure 1) was potted and inserted into the bore of a 1.5T scanner and powered during a T2-weighted pulse sequence as shown in Figure 2. The magnetic field profile was determined for the insert gradient by pulsing it in the bore and quantifying the signal loss in a homogenous phantom.

Two sets of diffusion-weighted images were obtained for a gelatin/water phantom. The first used both the native DWI pulse sequence at b= 100, 200, 500 s/mm^2 (TE = 49.8, 55.2, 64.8 ms). The second utilized the insert gradient for diffusion-weighting and the whole body gradients for image acquisition. The insert gradients were pulsed twice for 7 ms, with pulses separated by 14.7 ms and driven with I = 20 A, 40A, and 90A. A map of the apparent diffusion coefficients (ADC) over the phantom was calculated by combining the T2-weighted and diffusion-weighted images.

Discussion: Figure 3 illustrates imaging using the fourth channel-driven insert diffusion gradient. The images are combined with the T2 weighted imaging using the timing TE = 49.8 ms. They produce an ADC map with a high b-value in the centre and reduced b-values towards the edge of the image, corresponding to the drop-off in magnetic field. The calculated ADCs are shown in Table 1. The ADCs obtained using the insert at higher b-values match the ADCs obtained using conventional DWI. Using the insert coil, b-values up to 1000 s/mm^2 were produced with a timing of 49.8 ms. Using the whole-body gradient, a TE of 86.5 ms would be required for the comparable pulse-sequence. More accurate timing of the insert pulse sequence should allow for improvement of the process and higher received signals, as even a slight mis-match in the pulsed diffusion lobes will result in significant signal loss. However, we have demonstrated that accurate diffusion-weighting can be done using a fourth gradient insert. The butterfly coil can induce b-values of 1300 s/mm^2 much more rapidly than the whole body and that may be translated to higher overall signal for the received diffusion-weighted image.

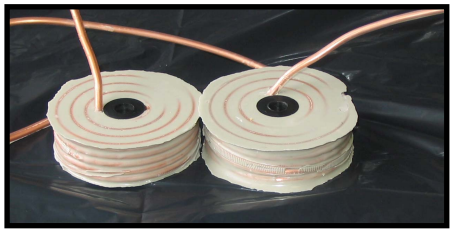

Figure 1: Butterfly coil prior to potting and electrical connections. 15 cm long, 2 cm thick.

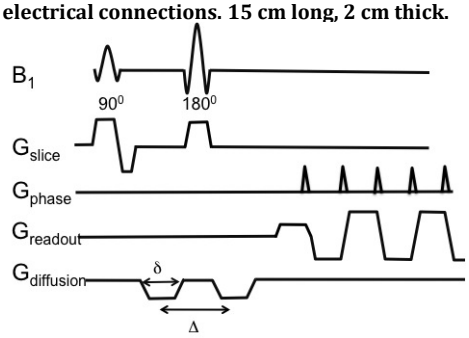

Figure 2: Butterfly coil prior to potting and electrical connections. 15 cm long, 2 cm thick.

Gradient	b-value(s) [s/mm^2]	Water ADC ± SD (SE) [X10^{-4} mm^2/s]	Gelatin ADC ± SD (SE) [X10^{-4} mm^2/s]
Whole-body Only	100	22.9±5.5(0.30)	11±19(1.1)
	200	21.3±3.3(0.18)	15±13(0.73)
	500	20.4±2.2(0.12)	11.6±5.5(0.3)
Butterfly Insert	52-99	23.6±10(0.55)	20.9 ± (1.9)
	145-307	25.1±(0.44)	13.6±(0.65)
	581-1332	21.8±5.2(0.29)	10.5±(0.34)

Table 1: Apparent diffusion coefficient calculated from the T2 and diffusion-weighted images

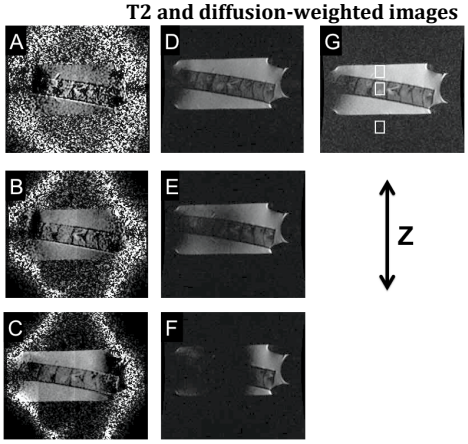

Figure 3: (A-C) ADC map of water-gelatin phantom for (A) b= 52-99 (B) 145-307 (C) 581-1332. (D-F) Diffusion weighted image using the insert for (D) b = 52-99 (E) b = 145-307 (F) b = 581-1332. (G) T2 weighted image for all sequences.

References:

[1] Clarke, et. al. Magn Reson Med 50:1199-1208 (2003)
[2] Haacke, et.al. Magnetic Resonance Imaging. (1999)