Design of Localized Surface Gradient Coil for DWI of the Carotid Artery

R. E. Feldman[1], B. K. Rutt[1], B. A. Chronik[2]

[1]Medical Biophysics, University of Western Ontario, London, Ontario, Canada, [2]Physics and Astronomy, University of Western Ontario, London, Ontario, Canada

Introduction: Carotid artery plaque structure and composition are hypothesized to play a role in determining a lesions potential for rupture, and the patients potential for experiencing a stroke[1]. Plaque structure and composition can be determined using multi contrast MRI, and it has been shown that a combination of 3 pulse sequences (T1 weighted, proton density weighted, and diffusion-weighted contrast) may do the best job of classifying the plaque components [2]. Unfortunately, diffusion weighted imaging is particularly difficult to accomplish at high SNR because of the long echo times required in pulsed gradient spin echo pulse sequences. We propose to implement a fourth, dedicated, gradient axis to operate a surface coil placed over the neck in order to improve achievable SNR during in vivo diffusion weighted MR.

Theory: The magnetization for a constant gradient single echo spin echo experiment can be expressed as:

$$M_+ = M_o e^{\frac{-t}{T_2}} e^{-bD} \quad \text{where,} \quad b = \frac{\gamma^2 G^2 TE^3}{12}$$

γ is the gyromagnetic ratio, G is the gradient field applied, and TE is the echo time[3]. b is the spin echo amplitude attenuation. In terms of diffusion imaging, a high value for b will result in a strongly diffusion weighted image. In order to achieve high b values for a minimum TE we need a high gradient strength.

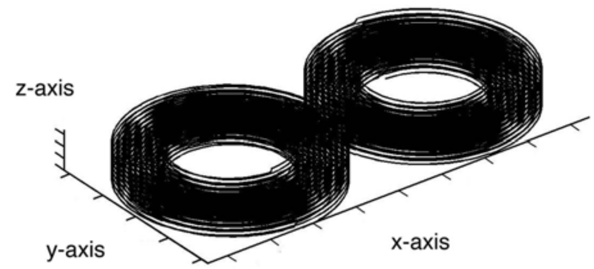

Figure 1: Illustration of butterfly coil wire pattern

Methods: The magnetic fields produced by 3 potential surface gradient coils were simulated and the resulting gradient efficiency and inductances were compared to a pre-existing body gradient coil, a head gradient coil, and a high powered gradient insert. Each of the 3 surface coils are butterfly coils, consisting of circular windings placed side by side along the x-axis. Figure 1 illustrates the butterfly coil configuration. Butterfly coils produce a highly focused magnetic field in the center. Therefore, on either side of the maximum field, there exists a region of high gradient. Each butterfly coil was simulated with an inner radius of 2.5 cm, and a wire diameter of 2.2 mm. The efficiency is quoted for 3 cm above the top surface of the coil.

Results and Discussion: Table 1 compares the efficiency, and inductance of the 3 simulated butterfly coils as well as a generic body gradient coil, a gradient insert, and a custom head gradient coil [4]. The efficiency, in terms of mT/m/A of the surface gradient coils can be made to be anywhere from 16 to 50 times stronger than the whole body gradient, with inductances that can be built to be between 200-3325 μH . A comparison of the b-values which can be acheived from the use of these coils in diffusion-weighted imaging can be seen in Figure 2. As the echo-time (TE) increases the b values increase, but the surface gradient coils always result in larger b-values. The butterfly coils can achieve b-values of over 1000 $s^{-1}mm^2$ in TE values of less than 9 ms. These small surface coils produce a region of about 10 cm^2 of gradient that is within 50% of the maximum 3 cm above the coil surface. This is fine for diffusion weighted imaging of a small area. Although these surface coils are producing large gradient fields, the actual magnitude of the magnetic field is small (because of the limited dimension of the coil). Thus, the resulting induced electric fields are lower than would be the case for a larger whole body or head gradient coil. As a result, the peripheral nerve stimulation threshold may be improved, in terms of maximum allowable gradient and slew rate for these coils, permitting more rapid execution of pulse sequences such as diffusion weighted SSFP, and better overall image SNR.

Coil Description	N Radial	N Axial	η [mT/m/A]	L [μH]	TE @ b=1000
Whole Body			0.178	1150	50.9 ms
Head Gradient			0.4	780	29.7 ms
Gradient Insert			1.0	800	16.1 ms
Butterfly 1	5	10	2.919	200	7.89 ms
Butterfly 2	10	20	8.828	3325	3.77 ms
Butterfly 3	5	20	3.877	575	6.53 ms

Table 1: Comparison of gradient coil efficiency and inductance

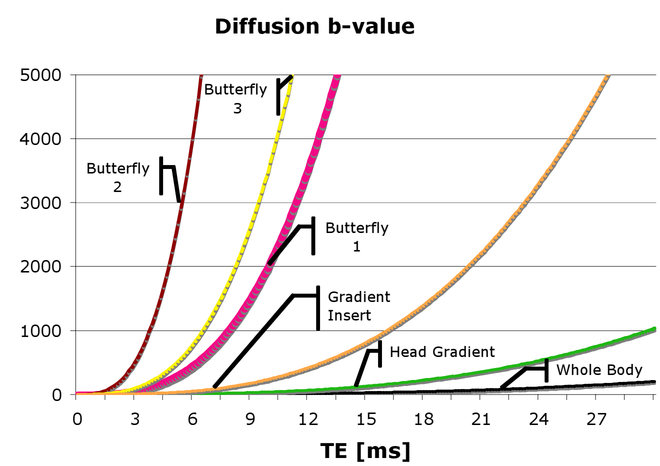

Figure 2: Comparison of TE vs. b-value for gradient

References:

[1] Libby, Ridker, Maseri. Circulation 105:1135-1143(2002)

[2] Clarke, Hammond, Mitchell, Rutt. Magn Reson Med 50:1199-1208 (2003)

[3] Haacke, Brown, Thompson, Venkatesan, Magnetic Resonance Imaging. (1999)

[4] B.A. Chronik, B.K. Rutt. MRM 46:386-394 (2001)