Optimization of insert gradient coils for highly localized diffusion-weighting

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Introduction: Localized gradient systems have demonstrated increased operational limits over traditional whole-body gradient coils. Fully functional cylindrical insert coils [1] and planar gradient systems [2] have both illustrated the advantages of a localized system for specialized applications. Insert coils have been shown to induce peripheral nerve stimulation at elevated thresholds when compared to a whole-body system [3]. Thus, the strength and slew-rate advantages of a localized system can be utilized on human subjects without causing undesired discomfort or sensation.

In DWI the gradient coils serve two purposes. Linear gradients are used for imaging, and strong gradients induce diffusion-related signal loss. A strong, localized, fourth gradient inserted into the bore during imaging, could be used to apply the diffusion-weighting to the region of interest, and the image acquisition could then be performed by standard whole-body gradients. This abstract investigates the optimization of highly-localized gradient designs intended to provide diffusion-weighting only.

Method: Five configurations (Figure 1) were examined, the z-gradients of a butterfly-coil, the z-gradient of a 3-loop coil (Z-flat), the x-gradients of a 4-loop coil (X-flat), the x-gradients of a curved 4-loop coil (Half), and the x-gradients of a cylindrical coil of reduced radius (Cyl). The gradients were optimized with respect to the inductive merit ($M=\eta/\sqrt{L}$) at the focus (F). The merit (M) is the gradient strength per unit current ($G/I = \eta$) divided by the square root of the inductance (L). The optimization algorithm searched the parameter space by varying the dimensions of the design relative to the focus: width in the x-direction ($\alpha = X/F$), height in the z-direction ($\beta = Z/F$) and thickness in the y-direction ($\gamma = Y/F$). For the Half and Cylinder designs, the radius of curvature was set to be the F. The optimized gradients were then simulated assuming a 10 cm focus and wound to approximately 800 μH assuming a minimum of 3 mm wire spacing, and maximum width and height of 60 cm. The gradient efficiency at 10 cm and 5 cm above the coil was calculated, as well as the area of the region of 30% and 50% gradient homogeneity at 10 cm. Finally, the minimum TE required to achieve a range of b-values (at 300 A) was calculated.

Discussion: As can be seen from Table 1 the butterfly magnet would produce the strongest gradient. The closed cylinder would provide the next strongest gradient. Figure 2 shows that the largest linear region in three-dimensions is produced by the cylindrical gradient. However, the closed cylinder's limited radius would prevent the cylinder's use for many applications and a larger cylindrical gradient would suffer from a reduced efficiency. Of the open designs, the planar geometry would produce the most linear gradient. All of these gradient designs produce magnets with efficiencies that far exceed the strength of a traditional whole body gradient (0.178 mT/m/A). The gradient efficiency made possible by the localized gradients can result in a reduced TE and increased received signal during DWI. A b-value of 1000 s/mm^2 could be achieved in less than 10 ms using an insert. The same diffusion weighting would take closer to 100 ms using a traditional system. The reduced TE can translate into a better SNR. Thus, gradient geometry needs to be application dependant. If the opportunity exists to completely enclose the region of interest with a small coil, a traditional cylindrical design may be the best solution. However, if the region of interest is small and sub-optimally positioned then an open planar design or a focused butterfly coil will provide significant advantages during DWI.

Figure 1: 5 designs. a) Butterfly, b) X-flat, c) Z-flat, d) Half, and e) Cylindrical

Design	Merit	η (10 cm) [mT/m/A]	η (5 cm) [mT/m/A]	R [mΩ]
Butterfly	133	3.855	5.388	74.46
Z-flat	28.9	0.808	1.328	20.60
X-flat	19.6	0.588	1.294	24.65
Half	43.7	1.076	4.264	182.5
Cyl	120	3.284	0.771	20.6

Table 1: Optimized design gradient properties

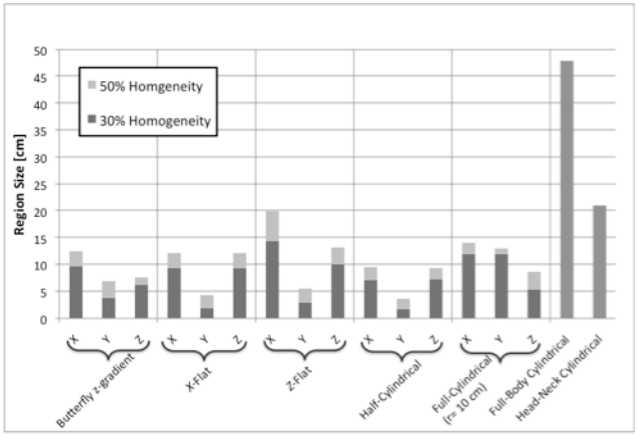

Figure 2: Gradient linear region

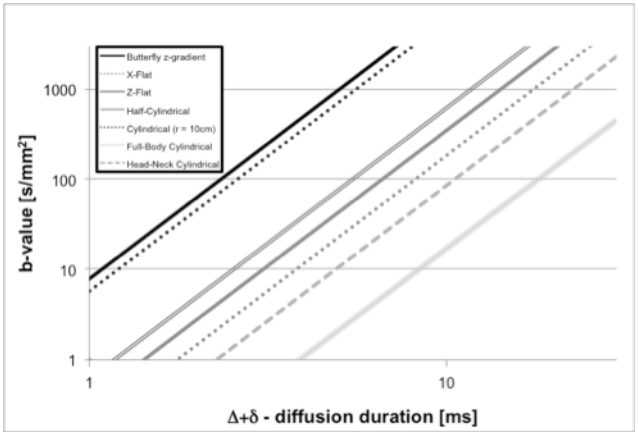

Figure 3: b-value vs diffusion duration

References:

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