Segmented Insert Gradient Coil for Bilateral Knee Imaging

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Introduction

MRI has become the noninvasive imaging modality of choice for evaluating the knee, because it is faster and avoids the invasive risks of arthroscopy. MRI provides unparalleled soft-tissue detail and contrast compared to other imaging modalities and offers high diagnostic accuracy. MRI of the knee can benefit from high spatial resolution and short echo times for both proton and sodium-23 imaging of cartilage. With higher gradient strength and slew rate, the local insert gradient coils can attain shorter echo times and higher spatial and temporal resolution than the body gradients.

Prior flat gradient system designs have achieved relatively small *homogeneous-gradient-volumes* (HGV) which are not quite wide enough for bilateral knee imaging. To address the challenge of bilateral knee MRI, we have developed a segmented two-region insert gradient system which has two wide HGVs, one for each knee, along the x-axis (left/right). This was achieved by adding an extra vertical plane for wire patterns in the middle of the x-gradient (i.e. in between the two knees) to create high gradient strength. In addition, the planar geometry has been transformed to the superelliptical geometry, which enlarges the HGV dramatically by spreading wire patterns around the imaging anatomy (i.e. both knees). The gradient linearity is improved by using a bi-planar, rather than uni-planar geometry. The transformation method provides an easy and fast optimization tool for bi-planar or superelliptical gradient coil design using a one dimensional stream function.

The proposed gradient coil set is designed to image both knees simultaneously, which is an improvement over coils in previous studies [1,2] that can only image one knee at a time, and suffer from cumbersome hardware for opening, closing, and securing the gradient assembly.

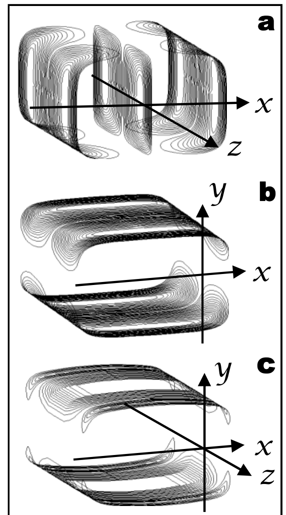

Figure 1. (a) x-, (b) y-, and (c) z-gradient wire patterns.

Methods

First, wire patterns were created on a cylindrical surface by using the stream function technique [3]. Next, these wire patterns were transformed onto a superellipse by using a cylinder-to-superellipse transformation [4]. Lastly, a vertical wire pattern is added as shown in Figure 1a to create two separate imaging regions for bilateral knee imaging. The proposed design has width (x, L/R) of 50cm (outer) and 44cm (inner), height (y, A/P) of 36cm (outer) and 30cm (inner), length (z, H/F) of 60cm. Magnetic fields were calculated using Biot-Savart law, and inductance values were obtained using the Neumann method.

Results

Figure 2 shows the resultant magnetic fields (top row), and gradient fieldmaps (bottom row) for each axis. Contours in the grayscale gradient fieldmaps are at 10% deviations of the field of the gradient from the desired field. The simulated results show that the HGVs are large enough for bilateral knee imaging. (see Table 1) Table 1 also shows detailed gradient performance measures.

	X - Coil	Y - Coil	Z - Coil
Efficiency (η, mT/m/A)	0.83	0.39	0.25
Inductance (μH)	370	285	358
HGV (10%, x/y/z-axis in cm)	Two regions of 19/30/18	35/29/20	26/28/25

Table 1. Simulated knee insert gradient coil performance measures.

Conclusion

The proposed gradient coil set is designed to image both knees simultaneously, and the simulated results show that the HGVs are large enough for clinical knee imaging. Even though the practical implementation and clinical testing of these coils have not been completed, the simulation results show that conventional planar gradient HGVs can be improved by conversion to the superellipse design. Also, the central x-gradient layer helps to create larger HGVs, facilitates two separate imaging regions, and increases x-gradient efficiency (up to 249 mT/m at 300A). Further applications of this work might include, bilateral imaging of the ankle, feet, wrists, and small animals.

References

[1] Crozier S et al., JMR; 139:81-89, 1999. [2] Petropoulos LS et al., US Patent 6,788,057, 2004. [3] Tomasi D, MRM; 45:505-512, 2001. [4] Moon SM et al., MRM, 2009. (in review)

Acknowledgments

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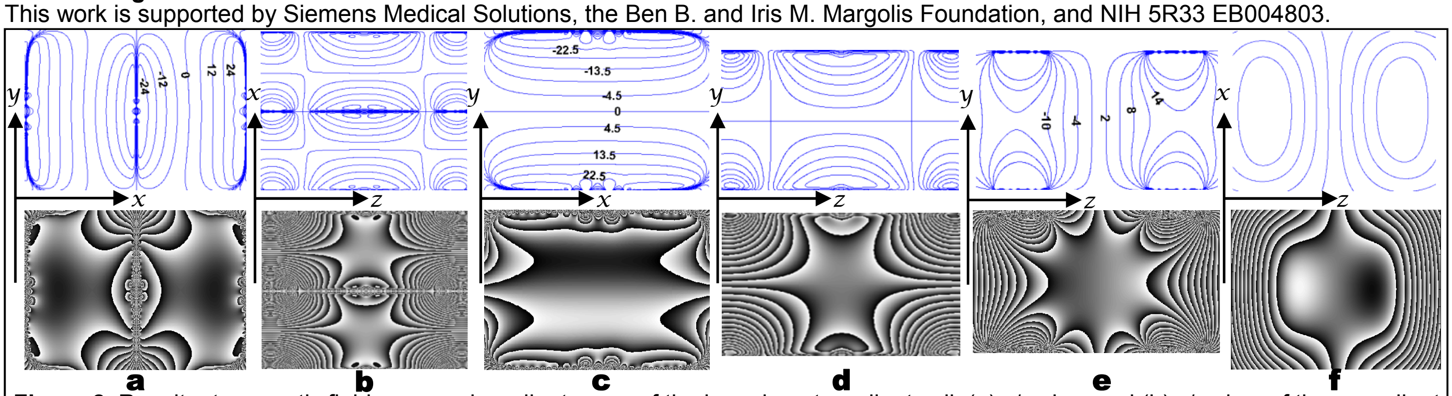

Figure 2. Resultant magnetic fieldmaps and gradient maps of the knee insert gradient coil. (a) x/y-view and (b) x/z-view of the x-gradient coil. (c) x/y-view and (d) y/z-view of the y-gradient coil. (e) y/z-view and (f) x/z-view of the z-gradient coil.