A Theoretical Comparative Study of the Induced Fields generated by Symmetric and Asymmetric Whole-Body Transverse Gradient Coils

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Synopsis
We have recently introduced the concept of whole-body asymmetric MRI systems [1]. In this theoretical study, we investigate the PNS characteristics of whole-body asymmetric gradient systems as compared to conventional symmetric systems. Recent experimental evidence [2] supports the hypothesis of transverse gradients being the largest contributor of PNS due to induced electric currents. Asymmetric head gradient coils have demonstrated benefits in the past [3, 4]. The numerical results based on an anatomically-accurate 2mm-human voxel-phantom NORMAN [6], show that asymmetric y-gradient is superior, in terms of reduced field induction, to its symmetric counterpart for typical patient orientations within the coil.

Methods
In order to closely mimic the realistic gradient coils, a previously developed simulated annealing optimization scheme [5] is used to generate the symmetric and asymmetric *actively-shielded* gradient y-coils operating at 1 kHz with identical field strengths of 35mT/m along the corresponding DSVs (42cm and 45cm in length, respectively). According to ICRP 66 (1994) guidelines for a reference man, the voxel phantom NORMAN (1.75m, 73kg) is used for the purposes of this study [6]. The conductivity values of all 38 body-identified tissue types were frequency scaled and kept constant at 1 kHz. In terms of imaging the heart or head region of the human body, there are four possible orientations within the asymmetric and two within symmetric coil. At a frequency as low as 1 kHz in this case, the vector magnetic potential due to the source, can be accurately evaluated using the Biot-Savart's Law without the consideration of the human body. With a previously developed, efficient quasi-static finite-difference scheme, we compute the electric field inside the body particularly in skin and fat (where most peripheral nerves are) via $E = -\partial A / \partial t - \nabla \phi$ .The method was verified against analytic solutions for a low frequency problem [7].

Results
The computational requirements on dual-3GHz-processor PC (3-GB RAM, Windows XP Professional) were quite intensive both in terms of time (approx. 13.5h for vector potential and 5h for scalar potential calculation) and memory (approx. 810MB RAM for vector potential and 1.75 GB RAM for scalar potential calculation). Figure 1 shows a sagittal view of magnetic field gradient dBz/dy and the voxel phantom positioned for head imaging inside both asymmetric and symmetric gradient y-coil. Figure 2 illustrates expected dissimilarities between normalized vector magnetic potentials induced by the two coils. Figure 3 shows the coronal and sagittal view of normalized eddy current distribution induced by asymmetric and symmetric gradient y-coils. As expected, the regions with large magnetic field amplitudes imply high electric fields and hence eddy currents in human tissue, particularly near the coil ends.

Discussion
Figure 2 shows that asymmetric gradient y-coil generates about three times less electrical current than its symmetric counterpart [8] when the human body is aligned in the typical orientation for head imaging. The *high-resolution* numerical results are in a good agreement with experimental human response data [2] in terms of frequently reported PNS for different body orientations within the symmetric y-coil system. Further investigations into different body orientations of both male and female subjects as well as a more detailed analysis of eddy currents inside skin and fat (peripheral nervous system) are under way. However, most importantly our further research will focus on reducing PNS by designing more-optimized whole-body asymmetric gradient coils for typical MRI applications.

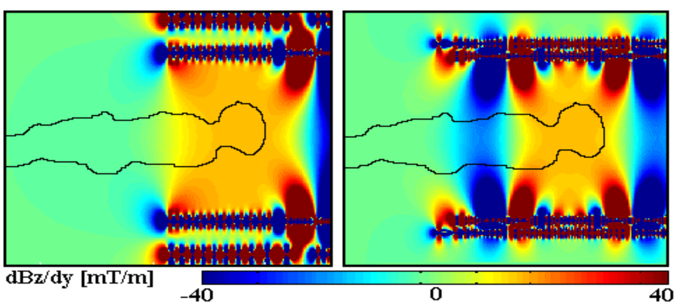

Figure 1: Sagittal view of magnetic field gradient with the patient oriented for head imaging inside asymmetric (left) and symmetric (right) gradient y-coil.

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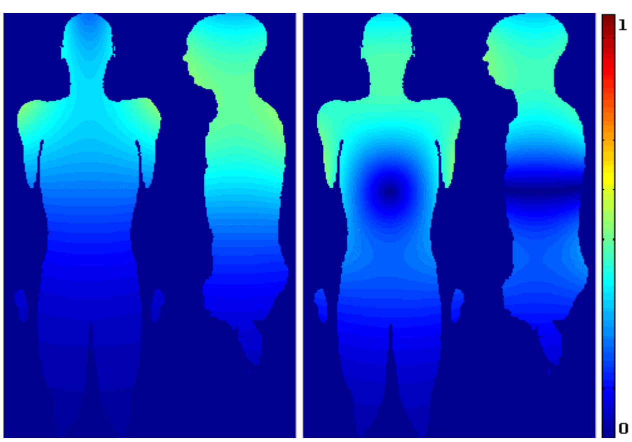

Figure 2: Coronal and sagittal view of normalized vector magnetic potential due to asymmetric (left) and symmetric (right) gradient y-coil.

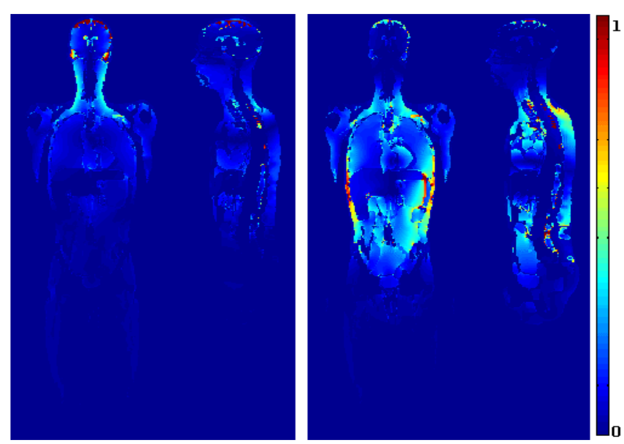

Figure 3: Coronal and sagittal view of normalized eddy current due to asymmetric (left) and symmetric (right) gradient y-coil.