A Numerical Analysis of Conservative and Magnetically-induced Electric Field For Low-frequency Human Imaging

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INTRODUCTION: In MRI, a distinction is often made between conservative and magnetically-induced electrical fields (E-fields). Conservative E-fields (E_c) are created by the electrical potential on conductors, and give rise to a portion of sample loss sometimes called "dielectric loss" (1). Magnetically-induced E-fields (E_i) are created by the fluctuating magnetic fields, give rise to a portion of sample loss sometimes called "inductive loss" (1). In some cases it seems possible to reduce losses due to conservative fields without changing the current distribution or magnetic field distribution, and thus maintain the desired sensitivity and field-of view while reducing heating of the sample and/or noise received from the sample. Regarding the birdcage coil (BC) for human use at frequencies used in MRI today, although it is generally believed that almost all of the sample loss is magnetically-induced, there have been some suggestions that conservative E-fields may play a significant role, including suggestions that low-pass (LP) and high-pass (HP) BCs have significantly different E-field distributions (2) (and may couple to the human subject very differently) due to their differing capacitor placement. We have recently developed a method to separate numerically-calculated E-field distributions into conservative and magnetically-induced portions (3). Here we perform Full-Maxwell numerical calculations of the electromagnetic fields and related power loss within a LP and a HP BC using a human head model, and analyze the results to evaluate the contribution of the conservative ($\mathbf{E_c}$) and the magnetically induced E-field ($\mathbf{E_i}$) to the total power loss.

METHOD: We modeled a LP and a HP BC each having 12 rungs, a coil inner diameter of 290mm, a coil length of 300mm, an RF shield inner diameter of 330mm and an RF shield length of 300mm (Figure 1). All simulation work was performed using commercially available software (xFDTD; Remcom, Inc; State College, PA). Analysis of results was performed in Matlab (The MathWorks, Inc., Natick, MA). The calculation procedure to obtain $\mathbf{E_c}$ and $\mathbf{E_i}$ (3) consists of 1) calculating the total E-field and the current density using the full-Maxwell FDTD method; 2) calculating the magnetic vector potential (**A**) using the current density (**J**) in the coil and shield; 3) calculating $\mathbf{E}_i$ using **A**; 4) calculating $\mathbf{E}_c$ using the total E-field and $\mathbf{E}_i$ ($\mathbf{E}_c = \mathbf{E}_{total} - \mathbf{E}_i$); 5) normalizing all fields so that average $B_1^+ = 4\mu T$ within the brain volume (corresponding to a 1.5ms 90° pulse).

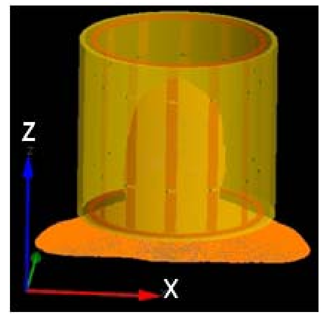

Figure 1 Geometry of LP BC and head model.

RESULTS AND DISCUSSION: In this case, the electrical field distributions and power loss of the LP and the HP BC were practically identical (Table 1 and Figure 2). Both E_c and E_i are seen to increase approximately linearly with frequency, as expected (Table 1). E_c was larger than we expected. E_c and E_i appear to oppose each other on average throughout the head, leading to an E_{total} smaller than either. This also makes sense from electromagnetic theory. Here we focused on relatively low frequencies because our method for calculating E_i and E_c from the full-Maxwell numerical solution relies on quasi-static assumptions. Our work with these methods has recently led to successful insights and demonstration of a method to reduce sample loss in microimaging without affecting the B1 fields, and we are hopeful that similar insights and success may be achieved for human imaging in the future.

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REFERENCES

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Coil	Freq [MHz]	Mean E_c [V/m]	Mean E_i [V/m]	Mean E_{total} [V/m]	Head Power Loss [W]
LP	4.258	7.3024	5.5258	4.4153	0.0178
HP	4.258	7.0434	5.2765	4.4307	0.0179
LP	12.774	21.6023	16.2909	13.1273	0.2145
HP	12.774	20.5503	15.3641	13.2189	0.2152
LP	64	-	-	66.3481	7.6908
HP	64	-	-	67.0476	7.5135

Table 1 Electromagnetic field properties of LP and HP BC at several different frequencies when loaded with a human head model.

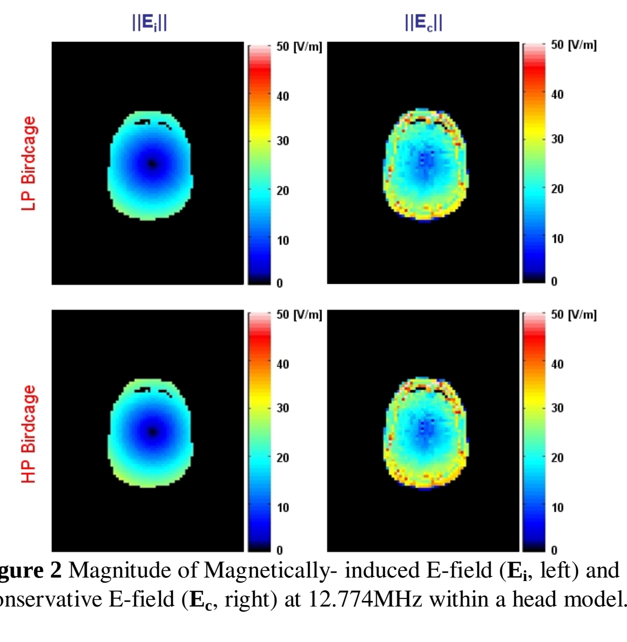

Figure 2 Magnitude of Magnetically- induced E-field ($\mathbf{E_i}$, left) and Conservative E-field ($\mathbf{E_c}$, right) at 12.774MHz within a head model.