Comparison of Peak Simulated Electric Fields with PNS Locations

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Introduction: Nerve stimulation has been reported to occur during MRI sequences where gradient coils are pushed to high gradient strength and slew rate. This nerve stimulation is thought to occur because the rapidly changing magnetic fields from the gradient coil induce an electric field which is experienced by the human subject inside the gradient coil. The electric fields cause action potentials in the sensory nerves, and these signals are interpreted as sensations of tingling, pinpricks, or pressure. Nerve stimulation represents a limit to the strength and rise time of gradient pulse sequences, and the electric fields experienced during MRI represent an important safety concern as the gradient coils improve in strength and efficiency. This abstract investigates the electric fields experienced in a human body during MRI. An algorithm was used to calculate the total electric field due to both the changing magnetic field and the resulting charge redistribution in the body. The effect of the charge accumulation on the air cavities in the body is examined and the locations of simulated maximum electric field are compared to the locations of actual stimulation reported.

Theory: Electric field may be approximated by applying quasi-static assumptions [1] to the electric field equation. The approximation neglects the effects of wavelength, skin depth, and tissue reactance. This permits the time dependant factor to be separated from E_o, the portion dependant on the fixed wire pattern, object shape and position:,

$$E(r,t) = (-\nabla\Phi_o(r) - A_o(r))\frac{dI}{dt} = E_o\frac{dI}{dt}$$

Where A is the vector potential and Φ is the scalar potential, and I is the current through the gradient coil. The vector potential is calculated directly from the wire pattern of the gradient coil. The scalar potential is determined by applying Laplace's equation, $\nabla^2\phi=0$, and the boundary conditions $d\phi/dn = n\cdot E_a$.[2]

Methods: An finite-difference algorithm was developed in C++ to iteratively converge on a solution for the distribution of scalar potential due to the vector potential induced by a head gradient coil [3], inside the human body defined by the Visible Man dataset [4]. The 3mm data set was used, and the data was truncated such that only the areas near to the head gradient coil, the head, neck, chest and trunk, were simulated.

The simulation was done with the model in two positions. One position located the neck in the imaging region at the end of the coil, and the other with the brain in that same region. The total electric field simulated in and around the conducting object was calculated, and the locations of maximum electric field were evaluated. The electric fields were analyzed both as an overall maximum, and within 6 selected areas of potential excitation: the crown, the side of the head, the nose, the lips, the neck, and the chest.

Results and Discussion: Figure 1 shows a sagittal slice of the magnitude electric fields experienced due to the gradient coil. Although places where the boundary of the object exhibits a short radius, such as the tip of the nose, demonstrate enhanced electric fields, the largest total magnitudes appear to be located in the sinus cavity, and an air cavity in the chest. These values were quantified and Figure 2 shows a graph of the maximum electric fields experienced in both Brain Mode and Neck Mode. In all cases, the electric field due to the vector potential was much smaller than the total electric field simulated in each of the areas. In both modes the nose area – which includes the sinus cavities, demonstrated the highest electric field. The next largest field was located in the chest cavity.

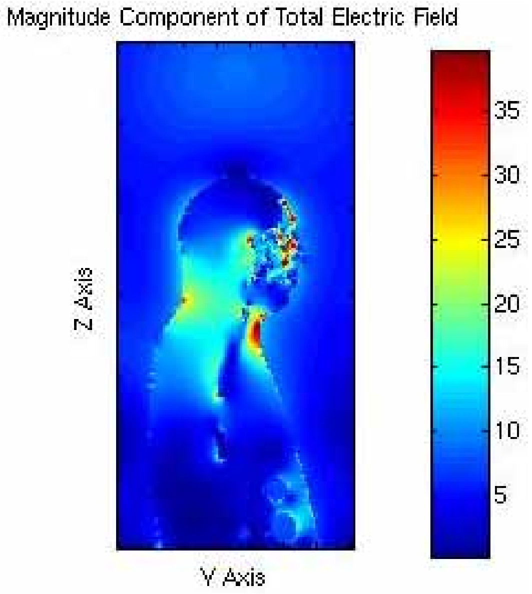

Figure 1: Magnitude [V/m] of total electric field simulated around the Visible Man data set

A ratio of the maximum total electric field to the maximum electric field due to vector potential was calculated, as a correction factor, for each area. The correction factor for the sinus area and the chest were similarly elevated.

Stimulation experiments using a physical prototype of the neck gradient coil simulated here have performed and were reported previously [5]. In these experiments stimulation was most frequently reported in the nose area, and less often on the lips, eyes and top or side of the head. Stimulation was never reported in the chest.

Depending on the geometry of the system, the body can experience electric fields more than an order of magnitude greater than the applied electric fields. For the head gradient coil the electric field in the sinus is simulated to be greater than anywhere else in the model and the predominance of the nose as the reported location of stimulation for this coil seems to follow logically from this. The absence of sensory stimulation in the chest, despite the high simulation values, probably highlights differences in the size and type of the nerves in the chest compared to those on the face and skin surface.

Other gradient coil configurations may produce fields whose distributions vary from the current pattern. However, internal cavities may remain favored as a location for charge accumulation. This result, combined with previous nerve stimulation experiments suggest that peak electric fields may not correlate to peripheral nerve stimulation.

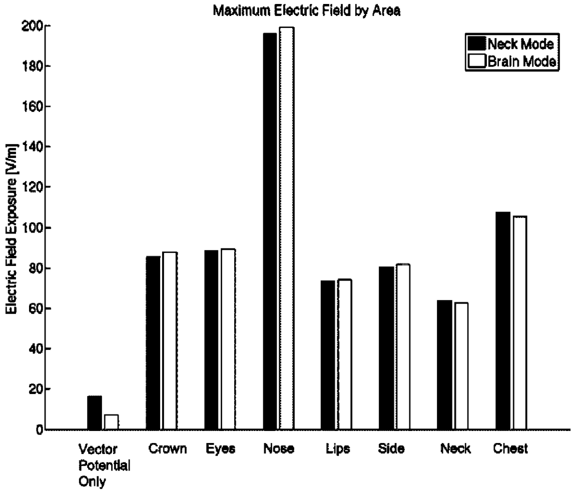

Figure 2:A comparison of the maximum electric field inside and outside the conducting material for different anatomical areas of simulation

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