Induced Magnetic Forces in the Human Head during MRI procedures: A group analysis

R. Wang[1], D. Tomasi[1], G-J. Wang[1], E. C. Caparelli[1], R. Z. Goldstein[1], N. D. Volkow[2], and J. S. Fowler[1]

[1]Medical Department, Brookhaven National Laboratory, Upton, New York, United States, [2]National Institute on Drug Abuse, National Institutes of Health, Bethesda, Maryland, United States

INTRODUCTION: Understanding the complex distribution of magnetic field gradients and the induced magnetic forces in human head during magnetic resonance imaging is an important safety issue, particularly for high filed MRI. The magnetic force acting on biological tissues that are exposed to an external magnetic field is proportional to tissue susceptibility and the spatial distribution of the static magnetic field. The aim of this work was to quantify the magnetic force acting on human heads placed in the homogeneous magnetic field of an MRI scanner for a group of healthy subjects.

METHODS: The magnetic field distribution in the human head was measured using two gradient-echo experiments with different echo times using the phase of the MR signal. The phase of the complex image ratio is proportional to the echo time difference, does not have the wrapping artifact (Fig 1) characteristic of phase images, and is proportional to the magnetic field offset. The relative phase was used to map the magnetic field distribution and calculate accurate maps of the induced magnetic field gradients and forces in the human head at 4-Tesla field as reported previously[1]. Seventy-six healthy subjects (male = 64, female = 12) with average 34.8 (21 - 51) year of age were studied under local IRB approved protocols. A FLASH pulse sequence with 1.56 mm in-plane resolution and 5-mm through-plane resolution covering the whole brain was used (acquisition time = 4 minutes). The gradient field and magnetic force maps for each individual were calculated using customized software written in IDL. These maps were normalized to the Talairach reference frame and spatially smoothed with an 8-mm Gaussian kernel using the SPM2 package software and Matlab. To make inferences about the population, group analyses of the induced gradient fields and magnetic forces in the head were conducted voxel-by-voxel in SPM2 using random effects analyses (one sample t-tests). A family-wise error (FWE) corrected threshold $p<0.05$ was used to assess the significance of the results.

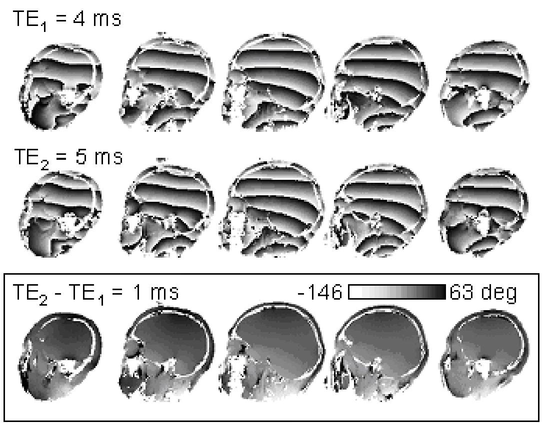

FIG.1: *Phase maps for two different echo-times showing the wrapping artifacts caused by magnetic field inhomogeneities produced by air/tissue interfaces in the human head. The relative phase image reflects the phase accumulation during the differential period TE_1 –TE_2 and does not have wrapping artifact*

RESULTS: The main finding of this study is that despite the gradient fields induced by the shape of the head are 50 times larger than those resulting from the highly uniform magnetic field of the MRI instrument, the associated magnetic force on brain tissues is 10^3 times smaller than the gravitational force (Fig 2). Taking into account that biological tissues are adapted to the gravitational pull, the results of this study suggest that the homogeneous static field of the MRI instrument cannot have a significant/measurable effect on biological tissues of the human head. Group analysis (Fig 2, top row) shows that the induced magnetic force density is maximal at the eyeballs (~10 $\mu N/cm^3$), the sinus cavity and the temporal bone. The induced force in these brain regions was highly significant across subjects, despite the shape of the head and its orientation in the magnetic field were different for each subject (Fig 2, bottom row).

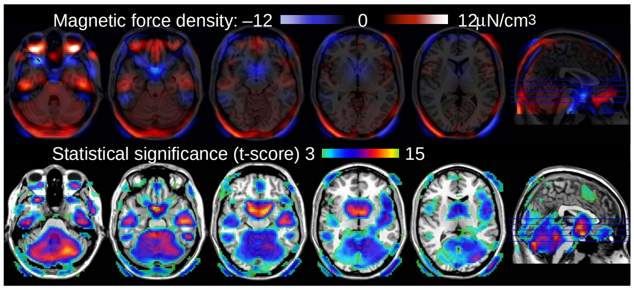

FIG.2 *Selected examples of sagital and axial maps of the magnetic gradient induced forces in the human head from the whole group of subjects (n=76; note the highest force in the eyes is in the level of 10 microNewton/cm^3 in this 4T MRI).*

CONCLUSIONS: The induced magnetic field gradients increase the magnetic force on biological tissues. However, even for tissue components with large magnetic susceptibility such as iron-containing proteins, this force is negligible compared with the gravitational force. The eyeball, midbrain, orbitofrontal and temporal cortices are the brain regions most susceptible to induced magnetic forces in humans. This study suggests that static and uniform magnetic fields employed by today's state-of-the-art MRI technology do not involve significant risk for biological tissues in the human head. However, since the magnetic force increases with the magnetic field strength of the MRI scanner, it is possible that the induced magnetic force would become a safety concern for MRI applications at extremely high magnetic fields in the future.

REFERENCES: 1-Tomasi and Wang (2007) JMRI **26**: 1340

ACKNOWLEDGEMENTS: DOE (OBER), NIH intramural and NCRR (GCRC 5-MO1-RR-10710).