Magnetic Field Homogeneity Improvement in the Lower Frontal Lobe by Combined Resistive and Passive Shims with a User-defined Mask

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INTRODUCTION: Regions such as the base of the brain have poor magnetic field uniformity because the tissue types in this area have a large range of susceptibility values. Water in tissue has a negative susceptibility value, while oxygen in the air in the frontal sinuses has a positive value. This creates magnetic field gradients at the base of the frontal lobe, and makes echo-planar imaging in this region difficult, since echo-planar imaging is particularly sensitive to magnetic field uniformity because of its long readout window and accumulation of phase errors.

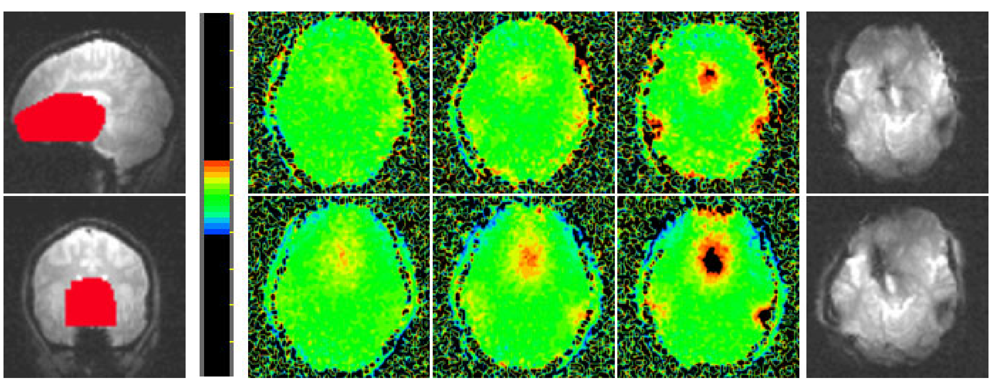
Various techniques have been proposed to compensate for the magnetic field gradients in this region, such as "Z-shim" compensation pulse sequences (1, 2) and using a mouth-piece composed of a high susceptibility material (3) to deal with these gradients in the lower frontal lobe. The technique presented here is based on the copier toner shim technique described by Jesmanowicz (4). A mask is used to select the region of interest to be shimmed.

METHODS: All experiments were conducted on a Bruker Biospec 3 Telsa scanner, using a local head gradient coil, an end-capped birdcage RF coil, with a single subject. First, an autoshimming protocol was performed. This protocol involved adjusting the currents in 14 resistive shim coils to optimize magnetic field uniformity over a 20 cm field of view. Then, a magnetic field map of the subject's brain was obtained using a dual-TE gradient-echo technique with the following parameters: TR = 1800 ms, TE = 15 ms, ΔTE = 1.024 ms, BW = 31.25 kHz, image matrix = 64 $\times$ 64, number of slices = 64, FOV = 192 mm, slice thickness/separation = 2.7/3 mm.

Using the AFNI software package, a mask was drawn over the area in the lower frontal lobe in which magnetic field gradients were present. Jesmanowicz's technique (4) was combined with this user-defined mask to create an insert that would fit on the curved inner surface of the local head gradient coil. The insert was made of spatially varying densities of copier toner, which compensated for magnetic field gradients in the masked region.

The subject was imaged again. The autoshimming procedure was performed, after which a magnetic field map was collected using the same parameters given above. In addition, echo-planar data was collected using the following parameters: TR = 3000 ms, TE = 27.2 ms, BW = 125 kHz, image matrix = 64 $\times$ 64, number of slices = 30, FOV = 192 mm, slice thickness/separation = 5/5 mm. All of these protocols, (i.e. autoshim, magnetic field mapping and echo-planar imaging) were performed with and without the copier toner insert. Geometric corrections were not performed on the echo-planar images.

RESULTS: The first pair of images shows the region of the brain used to compute the passive shims. The full range of the scale is approximately -3.8 to 3.8 ppm, and the colored region in the middle represents a range of -0.75 to 0.75 ppm. In the set of images to the right of the scale, the top row is acquired using both the resistive shims and copier toner insert, while the bottom row shows equivalent images obtained using only resistive shims. The first, second and third pairs of colored images are the magnetic field maps from the dual-TE gradient-echo pulse sequence. The greyscale-only images are echo-planar images.



The magnetic field maps show a closing of the "hole" at the base of the frontal lobe, reducing the area of magnetic field non-uniformity. This is borne out by the improvement in quality of the echo-planar images from the same region in the brain, which show less geometric distortion when passive and resistive shims are combined.

DISCUSSION: Resistive shims are limited in number and complexity. These factors make it difficult to utilize them to correct local magnetic field gradients. Using passive shims, it is possible to remove gradients which are both smaller and more complex in shape. This creates an opportunity to create customized correcting inserts for every subject, or even for regions within a subject. Resistive shims, combined with passive shims and a mask, should make it possible to obtain better quality echo-planar images from any region in the brain of interest to researchers.

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