SUSCEPTIBILITY MATCHING THE HEAD FIXING IMPLANT FOR ALERT ANIMAL HIGH FIELD fMRI.

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INTRODUCTION: fMRI of alert and anesthetized animals usually requires head fixation via head posts or padding and these materials can affect the magnetic field homogeneity. Echo planar imaging (EPI) is very sensitive to magnetic field homogeneity, and small perturbations result in large image distortions. Distortions have been observed in lower field imagers (1-3 Tesla) for ceramics, stainless steel, and other metal alloys when using EPI sequences. At high field even plastics cause detrimental effects (Figure 1). This is important since many alert animal fMRI studies are now conducted at higher magnetic fields and require rigid head fixation. The problem arises from susceptibility difference in air and water (or tissue) and the geometry of perturbing devices. Image distortions from plastic can be easily demonstrated with a spherical water sample with a 60 cm diameter and a flat sheet of Delrin (5mm thick) placed on top of the sphere. Figure 1 shows a 1 mm axial EPI slice 10 mm below the top of the sphere, the top image is without the sheet of Delrin. The bottom two images are with the Delrin sheet (1C) without an additional correction to the field homogeneity and (1D) with a correction calculated using a Bruker fastmap sequence. The magnetic field shimming is unable to correct the shape back to an expected round shape enough though the slice is 10 mm below the Delrin sheet. This simple demonstration leads to the question, can air or tissue susceptibility matched plastic be made to avoid distortion resulting from the fixing device? The goal of the current study was to develop methods for producing susceptibility matched materials that can be used for head fixation in alert animals.

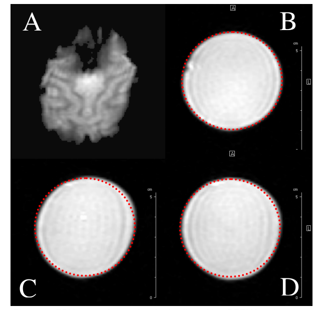

Figure 1: EPI image of a monkey brain slice with a PEEK head post (A), distortion in the front of the brain is due to the head post. EPI image of spherical phantom (B), EPI image with Delrin plane on top of sphere with no change of magnetic field shims (C) and EPI image with Delrin plane on top of sphere with a change of magnetic field shims (D).

METHODS: Eight dental acrylic samples (Bozworth Coralite Duz-All, Skokie, IL) doped with a paramagnetic compound (Sigma-Aldrich Neodymium (III) Oxide nanopowder, St. Louis, MO) and a blank were prepared by molding in a half-sphere with an inner diameter of 22 millimeters. This acrylic material was chosen since it is currently used to fix head posts to the skull in many laboratories. Samples where mixed by adding Neodymium(III) oxide to 3 gram of acrylic powder and adding 1.6 gram of methylmethacrylate, the sample concentration range of Nd_3O_2-acrylic powder was from 0 to 5%. For testing, the half spheres were attached to a rectangular bottle of water (7.5x7.5x12 cm) and 2mm gradient echo slices with two different echo times of 6 and 10 milliseconds (96x96 matrix, field of view 12.8 cm^2), were obtained through the center of the acrylic half spheres. Field maps were constructed in Matlab using SPM2 and the fieldmap toolbox. The water in the bottle was first shimmed without any acrylic samples and used as reference for the baseline magnetic field. The determined concentration which results in shifts comparable to a phantom bottle without the acrylic was used to produce a head post similar in dimensions to the PEEK headpost used in fixing alert macaques for fMRI imaging in our laboratory. EPI images (2 mm, 128x128, 12.8 cm^2) were acquired 1 cm below the head post at a 15 degree angle. All images were acquired on a Bruker 4.7T vertical scanner with a Siemens Allegra 40 mT/m gradient.

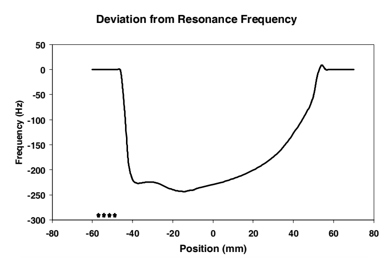

Figure 2: Profile from the field map along the axis bisecting the testing location for the acrylic sample on the phantom. Zero values are points outside the water in the bottle. **** Represents the position occupied by the acrylic samples during testing.

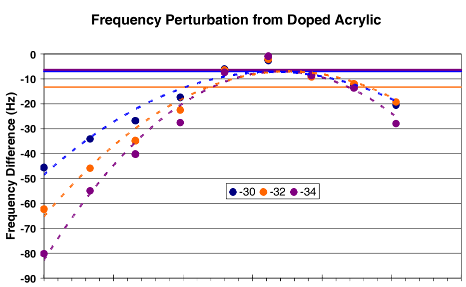

Figure 3: Plots for three locations in the phantom bottle with different acrylic samples attached to the bottle. Horizontal straight lines show the baseline value without acrylic spheres. The -30, -32, -34 values represent the positions relative to the center of the bottle in millimeters (corresponds to Figure 2 cordinates).

RESULTS: The optimal positions for frequency shift measurement were first determined from the frequency profile shown in Figure 2. Three positions sufficiently close to the acrylic sample and not on the steep gradient of the magnetic field at the edge of the water bottle (-30, -32, -34) were chosen. Figure 3 shows the frequency difference between the water phantom with and without the acrylic sample at specified positions at different concentrations of Nd_3O_2 in the acrylic. The optimal concentration for the doping was determined by the point of convergence of the three fitting curves (3.3% Nd_3O_2). EPI images show large artifacts associated with the PEEK head post (cf. Figure 1A) and no distortions from the acrylic head post (Figure 4).

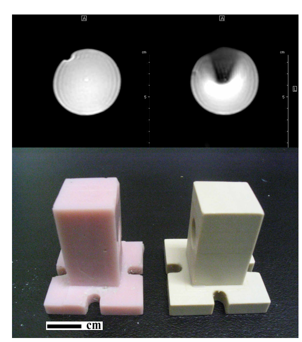

Figure 4: EPI image slices 1 cm below the headpost (TOP) and headpost (BOTTOM) photo. Right (PEEK), Left (Nd_2O_3-Acrylic)

CONCLUSION: We have shown that a currently used acrylic material can be modified by doping with a paramagnetic compound to achieve a magnetic susceptibility close to air. EPI imaging exemplifies the need to susceptibility match materials when even a small amount of PEEK can distort the image >1 cm away. We have demonstrated the possibility of matching to air, but it may be also very useful to match the susceptibility to tissue. This may allow for better imaging near the top of the head since there would be a smaller susceptibility gradient at the edge the imaging area, top of the brain, where tissue is displaced by the head fixing device. We are currently developing susceptibility matched headcap/headpost for implantation on a monkey.