Correcting Susceptibility Artifacts to Accurately Target Deep Brain Structures

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Introduction

Neurophysiology research in non-human primate subjects typically involves transdural targeting of brain structures by means of a chronically implanted plastic recording chamber. Such methods may include electrophysiology recording, microstimulation, tracer injection, and focal administration of pharmacological agents to transiently, or permanently, alter local brain function. High resolution and high contrast MRI anatomical images are valuable in planning these invasive procedures. The target structures can be readily identified on the images, and the desired point of entry, trajectory, and distance to target can be computed. In our facility, MDEFT images are routinely acquired on a 4.7T scanner to provide 0.5 mm isotropic 3D images with excellent gray/white matter contrast. While such scans are well-suited to plan precise, chamber-guided invasive procedures, magnetic field inhomogeneity, due to the susceptibility differences around the head and plastic implants, causes geometric distortion on the images [1]. This study demonstrates that geometric correction is both necessary and adequate for accurately targeting deep brain structures.

Methods

Anesthetized macaque monkeys were scanned in a 4.7 T vertical bore Bruker Biospec scanner. A plastic chamber had been implanted at the site of the craniotomy in preparation for the invasive procedure. A plastic guiding grid was inserted inside the chamber during the MRI scan in the same position as during a real procedure. The chamber and grid holes were filled with Gd-DTPA doped saline. Quick FLASH scans were first performed to determine the orientation of the head and the chamber grid. A coronal 3D slice package was carefully adjusted so that the images were in good alignment with the chamber and grid holes, with the read direction along the length of the grid holes. The 3D MDEFT sequence was then used to acquire high contrast and high resolution images (scan parameters: TR=11 ms, TE=3.75 ms, TI=2200 ms, flip angle=11 degree, FOV=96 x 96 x 90 mm^3, matrix size = 192x192x180). The 3D scan had 4 segments, took 33 minutes to acquire, and had an isotropic linear spatial resolution of 0.5 mm.

After the main acquisition, three quick 3D scans with the same slice package were performed to obtain the B_0 field maps, with TE of 3.75, 4.55, and 4.75 ms respectively. For speed, the MDEFT preparation was turned off, the phase encoding was accelerated by zero filling, and the number of slices was halved by doubling the slice thickness. Each of the three scans took 1 minute and 44 seconds. The field map was interpolated to the same spatial resolution as the MDEFT image and then used to correct the geometric distortion along the read direction according to a previously developed algorithm [2]. Following correction, the high-resolution images were used to identify target brain structures, locate the appropriate grid hole, and determine the required penetration distance. The effect of correction on targeting was computed, and compared to injections of MR-visible agents.

Results

The above scanning protocol has been successfully used in preparation of invasive procedures targeting hippocampus, pulvinar, perirhinal cortex, and temporal lobe. Figure 1 shows images for preparation of manganese tracer injection in the fundus of the posterior STS. The field map (A) shows large frequency shift in and around the plastic chamber. The frequency shift is as large as 950 Hz. The MDEFT images before (B) and after (C) geometric correction look almost identical, but their difference (D) reveals geometric distortion in and around the chamber. Analysis revealed that the correction procedure prevented targeting errors in excess of 2.5 mm, which primarily affected computed penetration depth. The scan after manganese injection (E) confirmed the accuracy of the measured penetration depth that was computed with the correct values.

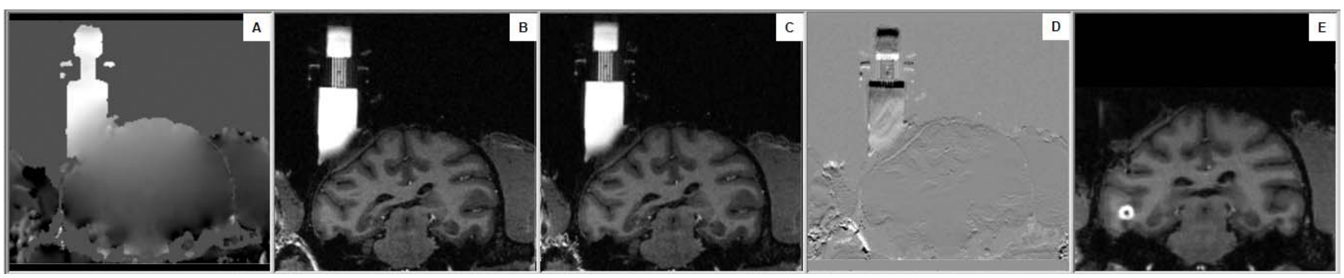

Fig. 1.

In similar routines with other deep targets, we observed maximum frequency shifts of roughly 900 Hz, and measurement error on the uncorrected images of between 2 to 4 mm. Following correction, the average obtainable accuracy was reliably less than 1 mm, and usually less than 0.5 mm, with the latter value representing the approximate precision of other limiting factors in the procedure.

Conclusions and Discussions

Image artifacts induced by magnetic susceptibility were studied in the early years of MRI [1], and field-map-based correction was successfully demonstrated [2]. Increased gradient strength and improved shimming has decreased the need to correct for geometric distortion on anatomical images. However, in animals with head implants at high field strength, geometric distortions are severe enough to throw off target planning that requires sub-millimeter accuracy. Since the cortical thickness of the monkey brain is less than 2 mm, relatively small errors in trajectory planning can easily lead to failed experiments. We have demonstrated here that by simply acquiring 3 additional images (total 5 minutes extra scan time), such distortions can be corrected and accurate geometric measurement is attainable. Alternatively, the geometric distortion can be reduced by using a much stronger read gradient along with a higher data sampling bandwidth, but that must come with a severe penalty in the signal-to-noise ratio.

References

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