

MRI Localization of Extracellular Electrodes using Metallic Deposition at 1.5T

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Introduction

Extracellular electrodes are widely used in neuroscience applications for electrophysiological recordings from cerebral cortex. Spatial localization of the exact recording site has traditionally relied on accurate stereotaxic positioning and histological confirmation of areas of gliosis at the end of the study. A novel technique described in rats by Fung *et al* (1) involves electrodeposition of a small amount of iron along the electrode tract, and subsequent localization with high-field MRI. We investigated the utility of a similar approach at conventional (1.5T) field strengths, potentially allowing neuroscience centers studying larger animal models, or without recourse to dedicated high field systems, to use more readily available conventional scanners, and thus avoid unnecessary histology.

Methods and Materials

Standard stainless steel recording electrodes (FHC, Brunswick, ME) were used throughout. Initial studies were done *in vitro* in unfixed bovine brain. A grid was marked out in the x - y plane and 17 electrode tracts made at 5mm spacing. Four lesions were made per tract in the z direction at 1mm intervals. Initial electrode impedance was $2M\Omega$ at 1kHz. Unipolar current of $1-4\mu A$ was applied cathodically to the electrode for durations of 5–160s.

Subsequent *in vivo* studies were done in a 10kg male macaque using the preliminary data from the *in vitro* work. A grid of 17 electrode tracts were marked out at 2mm spacing in frontal cortex (4 lesions per tract using $1-8\mu A$ for 5–40s). Six tracts were also made in parietal cortex, with 5 lesions per tract using 4 or $8\mu A$ for 20s). The animal was euthanized (for medical reasons unrelated to this study), and subsequent imaging was done *in vitro* on the fixed head.

All imaging was done on a conventional 1.5T Siemens VISION MR scanner equipped with 25mT/m gradients employing $300\mu s$ rise times. A 35×17 cm flexible surface coil closely applied to the sample was used. Lesion conspicuity was assessed using 3D FLASH ($T_R = 25$ ms, $T_E = 11$ ms, $\alpha = 20^\circ$, 0.4mm isotropic resolution), 3D MPRAGE ($T_R = 11.6$ ms, $T_E = 4.9$ ms, $T_I = 20$ ms, $T_D = 0$ ms, $\alpha = 8^\circ$, 0.8mm isotropic resolution), and 3D TSE ($T_R = 2200$ ms, $T_E = 105$ ms, $ETL = 21$, $0.6 \times 0.6 \times 0.7$ mm resolution). For fixed brain imaging, 3D FLASH was further optimized ($T_R = 25$ ms, $T_E = 11$ ms, $\alpha = 10^\circ$, 0.6mm isotropic resolution).

3D datasets were subsequently re-oriented to macaque stereotaxic coordinate axes using the standard Vision software package or MATLAB (Math Works, Inc.) in-house code, to allow accurate coordinate references for the observed electrode tracts.

Results

Electrode courses were readily visualized on 3D FLASH and 3D MPRAGE sequences as a series of punctate areas of low signal, measuring 0.6–1.0mm in diameter. Lesions were not readily seen with the 3D TSE sequence. Figure 1 shows lesions visible in the x - y (axial) plane using 3D FLASH, and Figure 2 in the y - z (sagittal) plane for bovine brain. Only 6 of the 17 lesions were visible corresponding to electrode currents of $4\mu A$ and times of 10–160s (currents below $4\mu A$ and lesions of less than 10s duration were not visualized). Table 1 summarizes the visible tracts.

Figure 3 shows electrode tracts in the lateral intraparietal cortex in macaque brain. Lesions less than $4\mu A$ and 20s duration were not visualized.

Conclusions

Electrode tracts from electrophysiological recordings can be reconstructed *in vivo* by applying unipolar currents of at least $4\mu A$ to stainless steel electrodes for at least 20s. Below these thresholds, either ferrous material is not deposited, or the amount deposited is insufficient to cause visible blooming at 1.5T. The failure to detect lesions with the TSE sequence implies that the lesions do come as a result of metallic deposition at the tip of the electrode (the point of maximum current density) rather than local gliosis, hemorrhage, or mechanical insult.

Electrode tracts were more conspicuous with 3D FLASH than with 3D MPRAGE, and higher resolution was also possible. 3D MPRAGE caused less susceptibility artifact and was more useful around areas of hemorrhage (e.g. at sites of previous surgery). Electrode tract visualization was difficult if susceptibility distortion was excessive, in which case the TSE images could be coregistered with the gradient echo images and viewed simultaneously to better define the anatomy.

This technique allows easy visualization and localization of the exact sites of electrophysiological recordings using a conventional MR scanner. Such precise spatial localization of recordings adds considerably to their value and accuracy.

References

1. Fung, SH, *et al*, *J. Neurosci. Methods* **80**(2):215–24, 1998.

Figure 1: axial view of bovine lesions

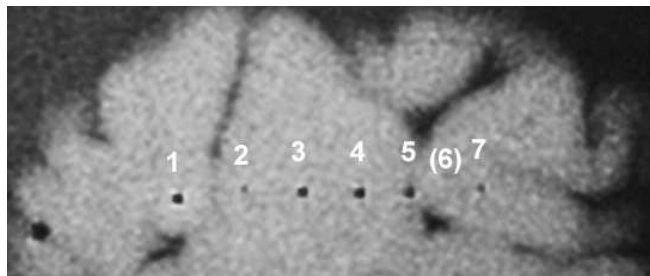


Figure 2: sagittal view of bovine lesions

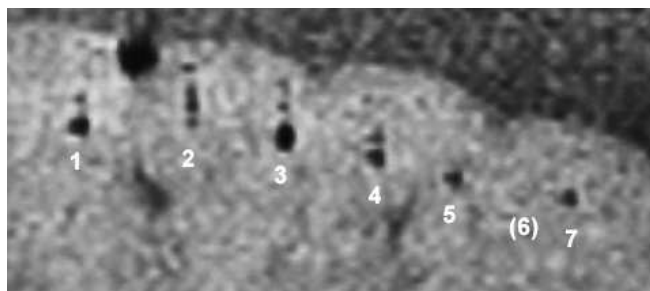


Table 1: parameters for bovine lesions

Tract	1	2	3	4	5	6	7
Current (μA)	4	4	4	4	4	4	4
Time (s)	160	80	40	20	10	5	10

Figure 3: coronal view of macaque lesions in LIP

