Simultaneous Wireless Fast Scan Cyclic Voltammetry and Amperometry with 3T MRI

K. Lee[1], J. Bledsoe[1], K. McGee[2], J. Huston[2], C. Kimble[3], F. Agnesi[4], K. Bennet[3], C. Blaha[5], and P. Garris[6]

[1]Department of Neurosurgery, Mayo Clinic, Rochester, MN, United States, [2]Department of Radiology, Mayo Clinic, Rochester, MN, United States, [3]Department of Engineering, Mayo Clinic, Rochester, MN, United States, [4]Mayo Clinic, [5]Department of Psychology, University of Memphis, [6]Biological Sciences, Illinois State University

Introduction: Recent developments in microsensor technology have revolutionized neuroscience research by permitting real-time concentration measurements of neurochemicals in brain extracellular fluid in awake and behaving animals. Great strides have also been made in advancing MRI and fMRI for anatomical and functional brain mapping in humans and experimental animals. Combining the exquisite temporal, spatial and chemical resolution afforded by real-time microsensor chemical monitoring with the global assessment capabilities of MRI and fMRI should thus provide a powerful new tool to advance brain study and diagnostics. Indeed, such an approach would support a broad range of investigations, including functional neuroanatomical studies to establish the neurochemical underpinnings of fMRI signals. We have recently developed instrumentation called wireless instantaneous neurotransmitter concentration system (WINCS) for neurochemical monitoring during functional neurosurgical procedures [1, 2]. A small, battery-operated device, WINCS performs electrochemical measurements at a brain-implanted microsensor and wirelessly transmits collected data to a home-base station using Bluetooth® telemetry. Two real-time electroanalytical techniques, fast-scan cyclic voltammetry (FSCV) and constant-potential amperometry (CPA), are supported. In the brain of laboratory animals, FSCV is used for measuring electroactive neurotransmitters at a carbon-fiber microelectrode (CFM), whereas CPA is typically used for measuring non-electroactive neurotransmitters at a biosensor. Here we investigate the feasibility of combining WINCS-based real-time chemical microsensor measurements with 3T MR imaging.

Materials and Methods: CPA and FSCV were performed using WINCS. Test measurements were collected at a CFM or an equivalent resistor/capacitor circuit ("dummy sensor"). A 3T MR scanner was used for all imaging, and WINCS ferromagnetic and heating tests. MR imaging used a fast spin echo (FSE) sequence (TE/TR = 7.7/4000 msec, average RF energy specific absorption rate = 2.4 Watts/kg, field-of-view = 24 cm, slice thickness = 3 mm, kx/ky/number of excitations =256/192/1, receiver bandwidth = 32 kHz, echo train length = 10, total imaging time = 4min, 25 sec) with a transmit-receive RF birdcage coil. A mineral salts (nickel chloride and sodium chloride)-doped water phantom was used for WINCS heating and image distortion tests. The head coil and phantom, along with WINCS, are shown in Figure 1.

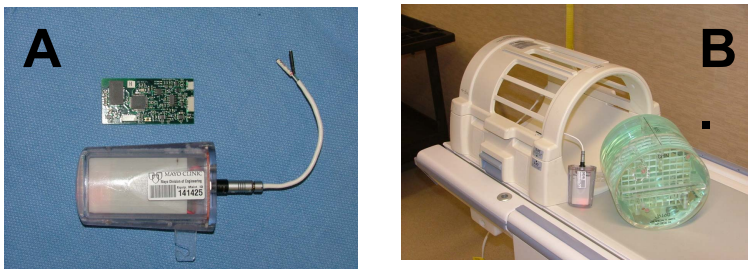

Figure 1. WINCS. A. Photograph of WINCS circuit board with polycarbonate sheath. The battery (not shown) and circuit board are encased in the sheath during usage. Leads are for connecting the reference electrode and carbon-fiber microelectrode. **B.** Photograph of the encased WINCS, head coil and phantom.

Results: The WINCS device was not subject to heating during image acquisition, and only a minimal attraction to the MR magnet was observed. The phantom image was minimally distorted when WINCS was placed outside of the head coil. With WINCS located in the bore of the scanner, RF pulsing induced noise spikes in dummy sensor measurements for CPA and FSCV during the FSE sequence. However, artifacts could be suppressed with median filtering, as shown in Figure 2. Under these same conditions, WINCS dynamically recorded dopamine electrochemical signatures with sub-second temporal resolution and with high fidelity when dopamine was injected into a beaker and measured by FSCV at a CFM. FSCV data are plotted without background subtraction, and current is shown in pseudo-color and as well as topographically (see Figure 2).

Conclusions: Using the digital-wireless device, WINCS, we demonstrate proof-of-concept for combining simultaneous real-time chemical microsensor measurements and 3T MR imaging. RF interference could be minimized by offline processing, but synchronizing MR scanning and neurochemical measurements may be required to achieve the necessary fidelity for monitoring more physiologically relevant signals. We submit that these combined measurements may usher in a new generation of functional neuroanatomical studies for assessing the neurochemical underpinnings of fMRI.

References: (1) Bledsoe et al., J Neurosurgery 2009. (2) Agnesi et al., J Neurosurgery 2009.

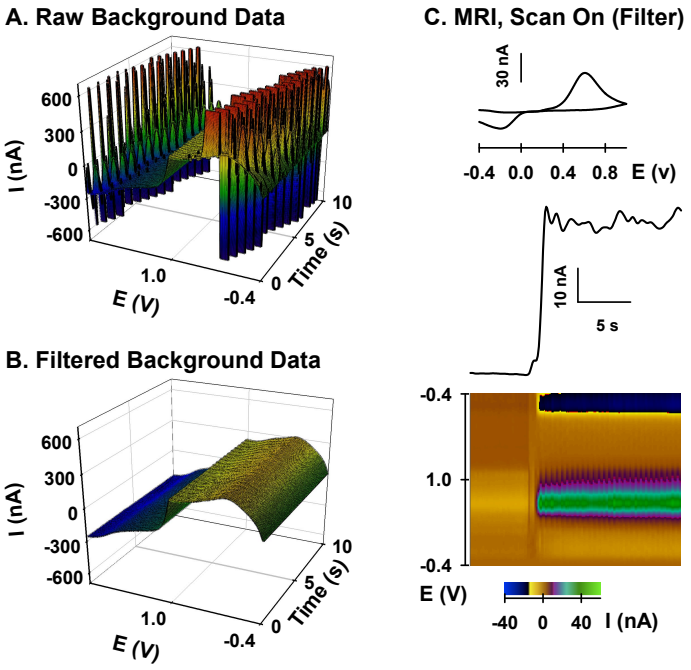

Figure 2. Filtering of FSCV at a CFM. A. Raw background current. **B.** Median filtering of trace recorded in **A. C.** Median filtering of the beaker dopamine recording.