Investigation of Gradient-Induced Artefacts in Simultaneous Graphene-Array Electrophysiology-fMRI in 7T Preclinical MRI

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Introduction: Concurrent electrophysiology (EP) and functional magnetic resonance imaging (fMRI) is a powerful technique for investigating brain activity, offering insights into both electrical and hemodynamic processes. However, a significant challenge in simultaneous EP-fMRI acquisitions is the contamination of electrophysiological data by artifacts, primarily the gradient artifact (GA), which is induced by the rapidly switching magnetic gradients of the MRI scanner. Traditional artifact correction methods, such as Average Artefact Subtraction (AAS), are commonly employed to mitigate these artefact [1]. New graphene-based electrophysiological recording technology, specifically Graphene Solution-Gated Field-Effect Transistors (gSGFETs) [2], offers distinct advantages over conventional electrodes, including a significantly reduced amount of metallic content that can interfere with MRI signals and the capability for high-fidelity DC-coupled brain signal recording [3]. Given these benefits, there is considerable interest in performing simultaneous MRI acquisitions in animals with implanted gSGFET probes. This pilot study aims to investigate the performance of these novel probes during concurrent MRI acquisition in rodents within the MRI environment, with the specific goal of understanding and effectively removing the gradient artifacts induced during MRI scanning.

Methods: Electrophysiology data were acquired using 16-channel graphene arrays of gSGFETs, identical to the Computer-Aided Design (CAD) model presented in Fig. 1A. Magnetic Resonance Imaging was performed on an Agilent 7-Tesla, 16 cm horizontal-bore magnet interfaced with a Bruker Biospec Avance III console. A custom-built 25 mm diameter loop surface coil was designed for both RF transmission and reception (Fig. 1B), specifically due to the unavailability of space to effectively accommodate the arrays and PCB in commercial volume RF coil. This RF coil was positioned above the rodent's head, with the graphene arrays cemented and their PCB located inside the loop coil. The arrays were connected via a long MRI-compatible cable to a recording amplifier, which was situated outside the MRI's safety line.

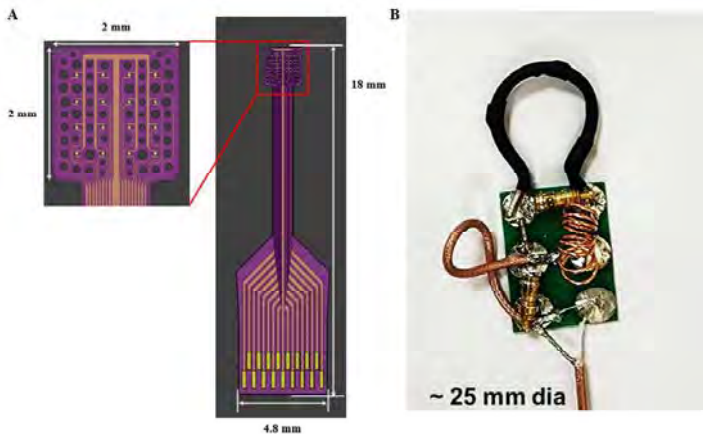

Fig. 1. *(A) Schematic CAD diagrams and dimensions of the epicortical probe (for a detailed description, see [4]); (B) Custom-built transmit–receive loop RF coil.*

Electrophysiological data were recorded on a healthy rodent at a sampling rate of 50 kHz using a 32-channel recorder system configured for 16-channel active recording (Multichannel Systems). The raw data were subsequently exported to the EDF for inspection and gradient artifact correction using either BrainVision Analyzer or EEGLAB software. Due to the absence of direct synchronization

between the MRI scanner clock and the MCS amplifier, automated artifact correction features within these tools were not effective. Consequently, manual marker detection was performed for each slice repetition time (TR) before applying the AAS correction algorithm to the raw electrophysiology data.

Results: Prior to data acquisition, the custom-built RF coil underwent rigorous tuning and matching procedures inside the MRI scanner, utilizing a uniform saline phantom loading. This process ensured optimal resonance at 300 MHz, as verified by a Vector Network Analyzer (VNA). Figure 2 illustrates the comprehensive workflow implemented for GA correction, alongside a representative single slice of the generated artifact template. Figure 3 visually shows the electrophysiological raw data following the crucial manual marker detection step, clearly demonstrating the substantial reduction in gradient artifacts after the application of the AAS correction algorithm.

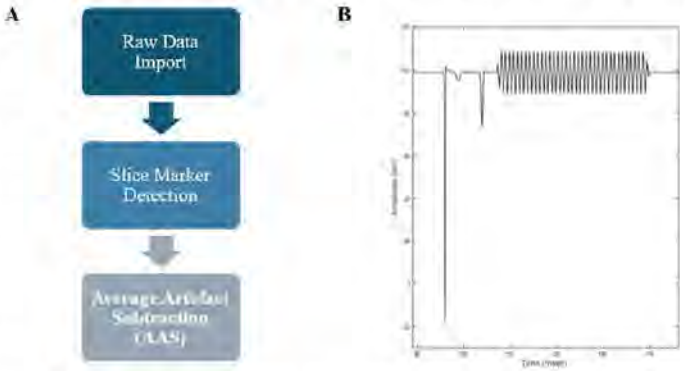

Fig. 2. *(A) Workflow for unmarked GA correction; (B) Single-slice artefact template.*

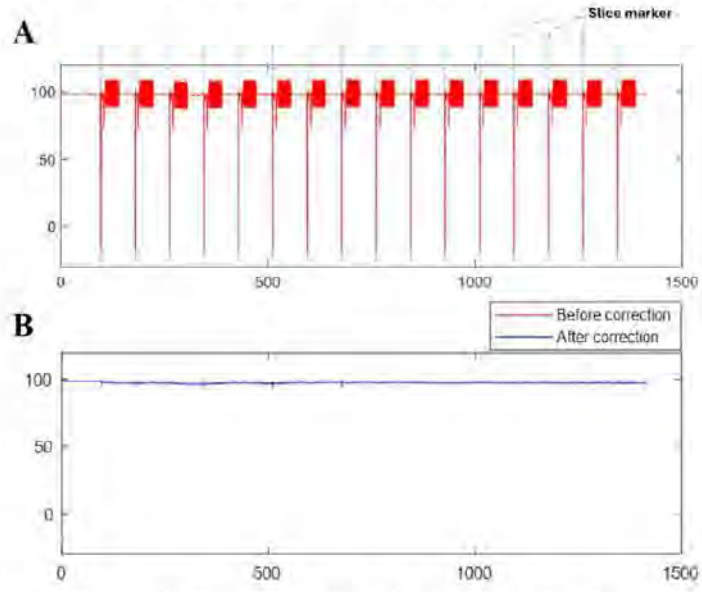

Fig. 2. *(A) Raw data after the marker detection; (B) Electrophysiology data after the GA correction.*

Discussion: This work shows an progressive effort in utilizing graphene-based technology for the acquisition of electrophysiology data in a healthy anesthetized rat during an active fMRI session. As anticipated, the simultaneously recorded electrophysiological data were significantly contaminated by MRI-induced events, particularly the gradient artifact. Our findings clearly demonstrate that while the AAS method effectively corrects a substantial portion of these artifacts, some residual artifacts persist in the corrected data. This highlights the efficacy of AAS as a primary correction strategy but also underscores the complexity of completely eliminating all MRI-related interference, suggesting avenues for further refinement in artifact removal techniques for future concurrent EP-fMRI studies with these novel probes.

Conclusions: This pilot study successfully demonstrated the feasibility of acquiring electrophysiology data using novel graphene-based probes concurrently with fMRI in a rodent model. The AAS method proved effective in substantially removing these artefacts. While some residual artifacts remain, this research validates the potential of gSGFET technology for simultaneous EP-fMRI. Future studies will focus on further optimizing artifact correction strategies, crucially involving the clock synchronization between the two modalities, and advancing studies on diseased animal models to unlock the full potential of these advanced probes for high-fidelity brain signal recording in the MRI environment.

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