Investigation of Electromagnetic Interaction Between RF Coil & Graphene-based Electrophysiology Probes at 7 Tesla Preclinical MRI

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Introduction

Introduction to Graphene-Based Recording Technology:

- New advancements in electrophysiological recording technology, specifically Graphene Solution-Gated Field-Effect Transistors (gSGFET) [1].
- gSGFETs offer several advantages over traditional electrodes, particularly in MRI settings.

Advantages of gSGFET:

- Reduced Metal Interference: Significantly lowers the amount of metal that can interfere with MRI scans.
- High-Fidelity Brain Signal Recording: Enables DC-coupled brain signal recording with high fidelity, specifically demonstrated in rodent models [2].

Importance of MRI Compatibility:

- Interest in performing MRI acquisitions on animals implanted with gSGFET probes.
- Ensuring MR compatibility and safety of these graphene-based EEG probes is crucial for research continuity and accuracy.

Study Objective:

- Computational Simulations: Conducted to assess the electromagnetic (EM) interaction and safety of animals implanted with these probes within an MRI environment.
- Goal: Achieving the highest possible level of MR compatibility for these advanced probes.

Methods

EM Simulation Analysis:

- Technique used: Finite-Difference Time-Domain (FDTD).
- Software: Sim4Life (V8.0, ZMT, Switzerland).
- Model: 3D rodent model comprising 68 tissues [3, 4].

RF Transmission Coil Setup and Specifications:

- Type: Quadrature highpass birdcage RF coil.
- Coil dimensions: Diameter: 72 mm, Length: 72 mm.
- Shield dimensions: Diameter: 90 mm, Length: 225 mm.
- Coil structure: 8 rungs, each 9.9 mm wide.
- Tuning capacitor: 14.2 pF placed on the end-rings, which are 11.5 mm wide. *See **figure 1***.

3D Modeling of EEG Probes:

- Generated from 2D drawings and exported to CAD format.

Simulation Setup:

- Excitation parameters: 300 MHz Gaussian excitation with a bandwidth of 650 MHz, excited in two-port, combined in circular-polarized mode.
- Sub-gridding feature: Utilized for localized mesh refinement, obtained from ZMT.

SAR Calculation:

- Specific Absorption Rate (SAR): Mean and peak SAR averaged over 0.01g, 0.1g, and 1g tissue-mass were calculated following IEC guidelines [5].

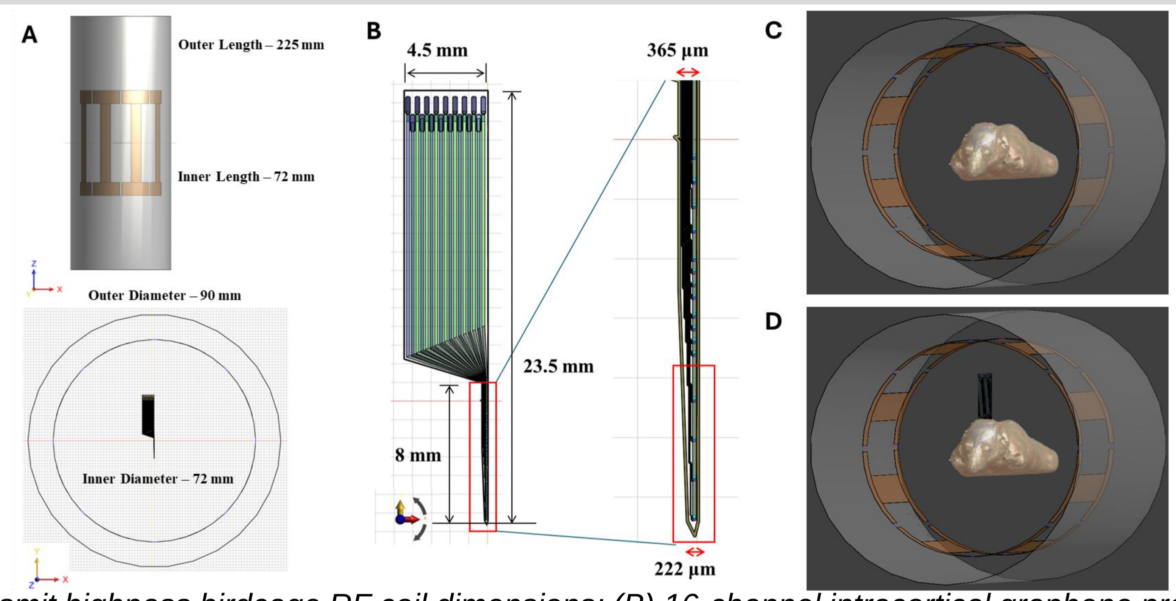

Fig. 1. *((A) Transmit highpass birdcage RF coil dimensions; (B) 16-channel intracortical graphene probe dimensions; (C) Configuration of rodent model placed in RF coil without, and (D) with graphene-based probe model as a brain implant.*

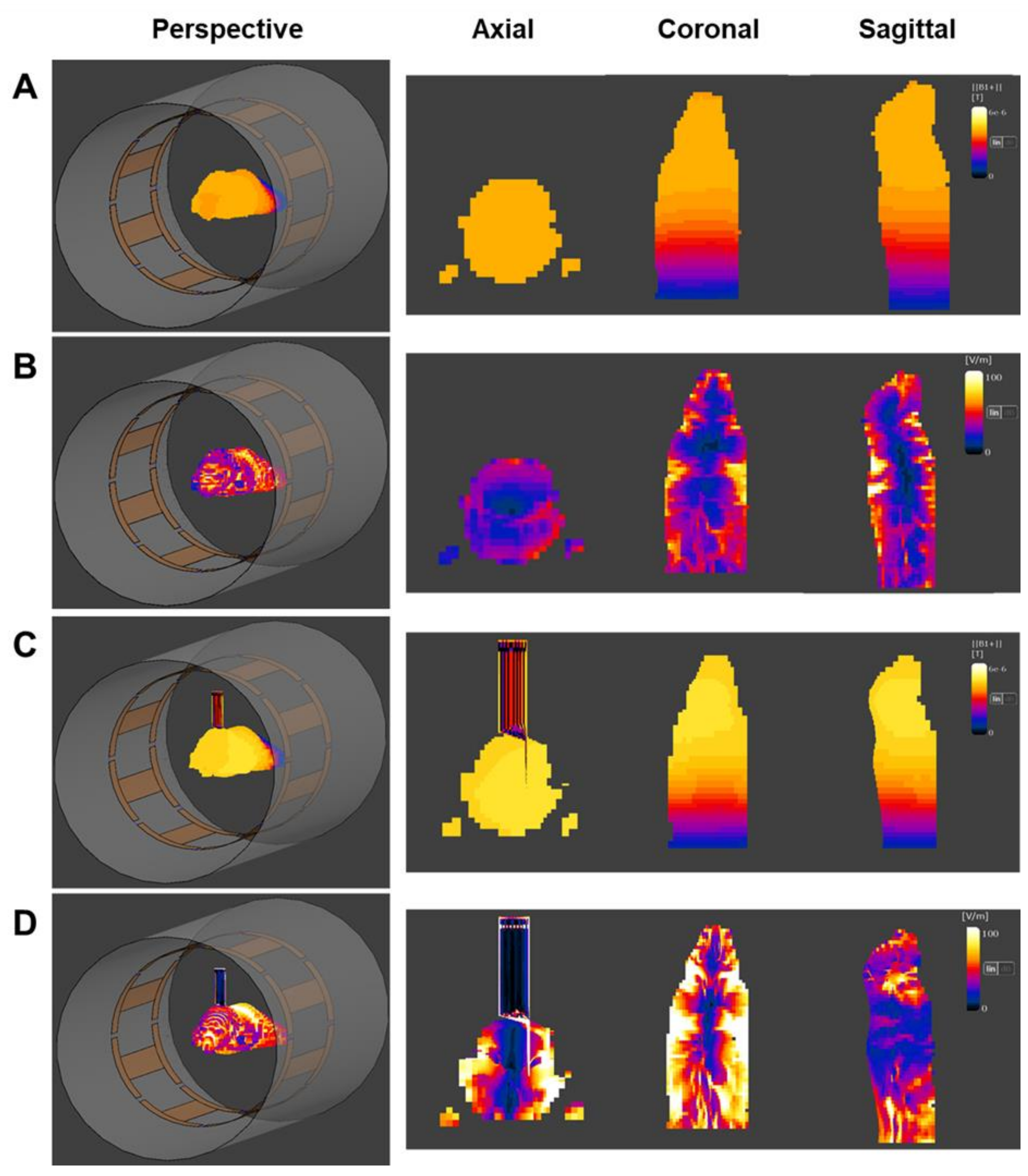

Fig. 2. *Simulated B_1^+-field distribution in rodent model (A) without, (C) with probe model; E-field distribution in rodent model (B) without, (D) with probe model.*

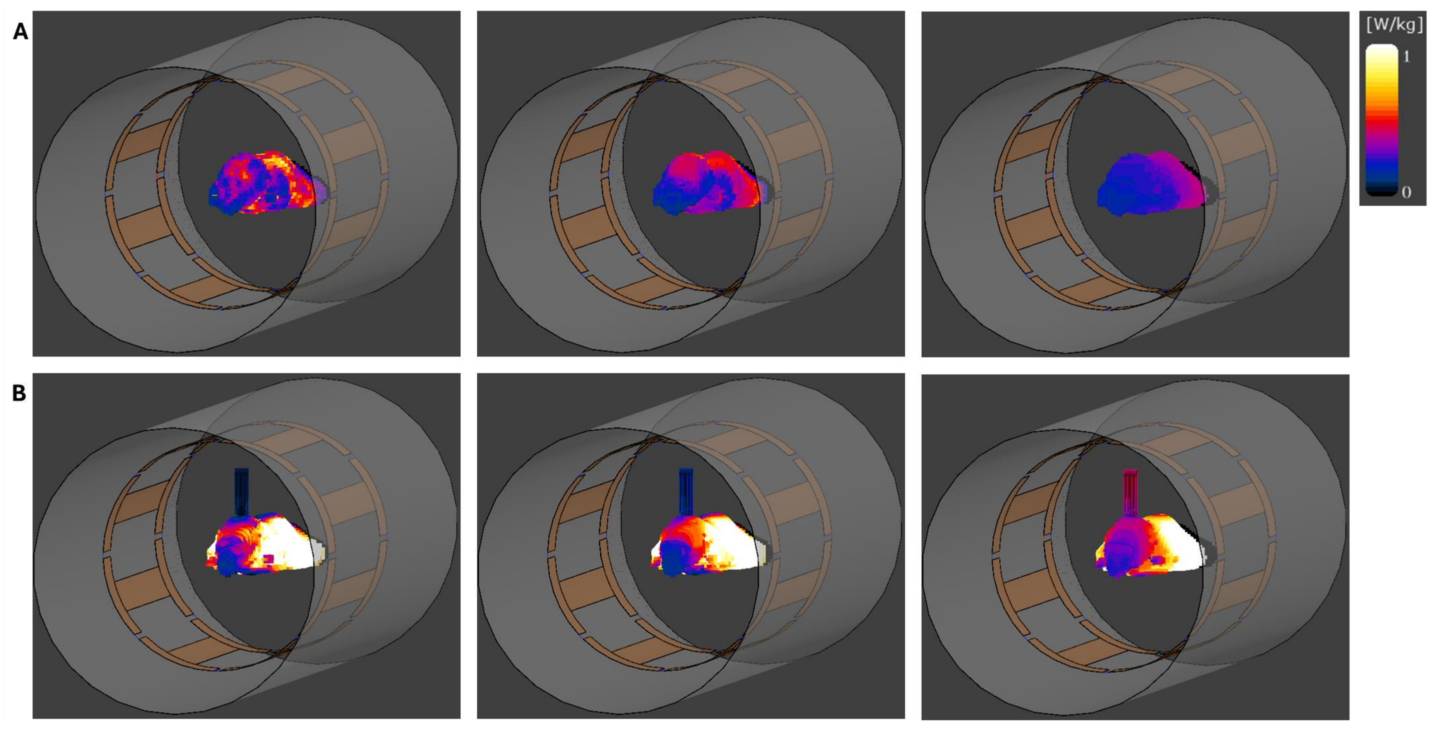

Fig. 3. *Simulated mass-avg SAR distribution in rodent model (A) without, (B) with EEG probe model for 0.01g (left), 0.1g (middle) and 1g (right) tissue mass.*

Results & Conclusions

Results

- **B_1^+-Field and E-Field Distributions:**
  - Increase in Magnitude: Graphene-based probes increase B1+ and E-field magnitudes by approximately 15-20% near the probes.
  - Cause: Induced current in the metal layers of the probes during transmission (see ***figure 2***).
- **SAR Distributions:**
  - Elevated SAR due to probes:
    - Mean Mass-Averaged SAR (W/kg): **Without probe**: 0.63; **With probe**: 0.83
    - Peak Mass-Averaged SAR (W/kg): **Without probe**: 0.01g: 2.5, 0.1g: 1.3, 1g: 0.8
      With probe: 0.01g: 5.9, 0.1g: 2.8, 1g: 1.6 (see ***figure 3***).
  - Localization: SAR peak localized in the skin.
- **Computational Time:**
  - **With probe**: Approximately 160 h / port; **Without probe**: Approximately 1.5 h / port.
  - Note: Computational power limitations on a single GPU require cluster GPU implementation.

Conclusions

- **EM Interaction:** Successfully demonstrated the electromagnetic interaction of graphene-based EEG probes in an MRI environment.
- **RF Transmission and SAR:** Graphene-based probes can affect RF transmission and increase SAR deposition while staying within permissible limits, ensuring MR compatibility and safety.
- **Future Work:**
  - Optimization: Further work needed to optimize computational efficiency using GPU clusters.
  - Experimental Verification: Necessary using phantom studies.
  - Concurrent Studies: EEG-fMRI studies in vivo in normal and chronically epileptic rodents.
  - Scaling: Potential scaling of these probes for human application.

References: [1] Bonaccini Calia, Andrea, et al. Nature Nanotechnology 17.3 (2022): 301-309. [2] Wykes, Rob C., et al. Clinical and Translational Medicine 12.7 (2022): 1-4. [3] Sim4Life, ZMT, <http://www.zurichmedtech.com>. [4] Kainz, Wolfgang, et al. Physics in Medicine & Biology 51.20 (2006): 5211. [5] International Electrotechnical Commission (IEC) (2022): IEC 60601-2-33.

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