Low-field MRI's Spark on Implant Safety: A Closer Look at Radiofrequency Heating

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Introduction

- 2008 Report – 90% of the world lacked access to magnetic resonance imaging (MRI) [1]
- Low-field MRI scanners (0.55 T and below) – reduced cost, ease of siting [2]
- Are they "implant-friendly"?
  - Metal artifacts and risk of device dislodgment due to magnetic forces are reduced at lower fields
  - SAR tends to be lower at lower field strengths
  - Antenna Effect – SAR can be extremely high in the presence of elongated implants such as leads [3]
- Lack of quantitative data to support "implant-friendly" claims – needed to prevent unintended injuries
- Comparative study of power deposition in a tissue-mimicking gel around tips of implanted wires of different length and geometry during RF exposure at 23 MHz (0.55 T) compared to 64 MHz (1.5 T)

Methods

Systematic Simulations with Wire Models

- 368 Electromagnetic simulations in ANSYS Electronic Desktop 2021 R1 (ANSYS, Canonsburg, PA)
- Models of two 16-rung, high-pass, birdcage body coils tuned to their resonant frequencies (23 MHz – 0.55 T, 63.6 MHz – 1.5 T) (Figure 1A)
- Models of insulated and non insulated wires with apparent lengths varying from 10 cm to 120 cm at 5 cm intervals (Figure 1B-C)
  - Four different geometries for each wire: Straight and three different helical pitches
  - Wires were placed 15 mm from the edge, centered on the center axial plane of cylindrical tissue-mimicking phantom
  - Wire - platinum-iridium compound ($\sigma = 4 \times 10^6$ S/m, $\varepsilon_r = 1$), Insulation – Urethane ($\sigma = 0$ S/m, $\varepsilon r = 3.5$)
- Maximum of 0.1g-averaged SAR (0.1g MaxSAR) around the tip of each lead, input power of both coils adjusted to mean B_1^+ of 2 µT on central plane passing through coil's iso-center (Figure 1D)

Simulations with Realistic Deep Brain Stimulation (DBS) Lead Trajectories

- 2 patient models with implanted DBS leads – trajectories from post-operative computed tomography scans after surgery (Figure 2AB)
  - Full DBS system: 40 cm lead + 60 cm extension + implantable pulse generator
  - Lead-only system: 40 cm lead only
- Similar materials and SAR calculation as systematic simulations used for realistic simulations (Figure 2C)

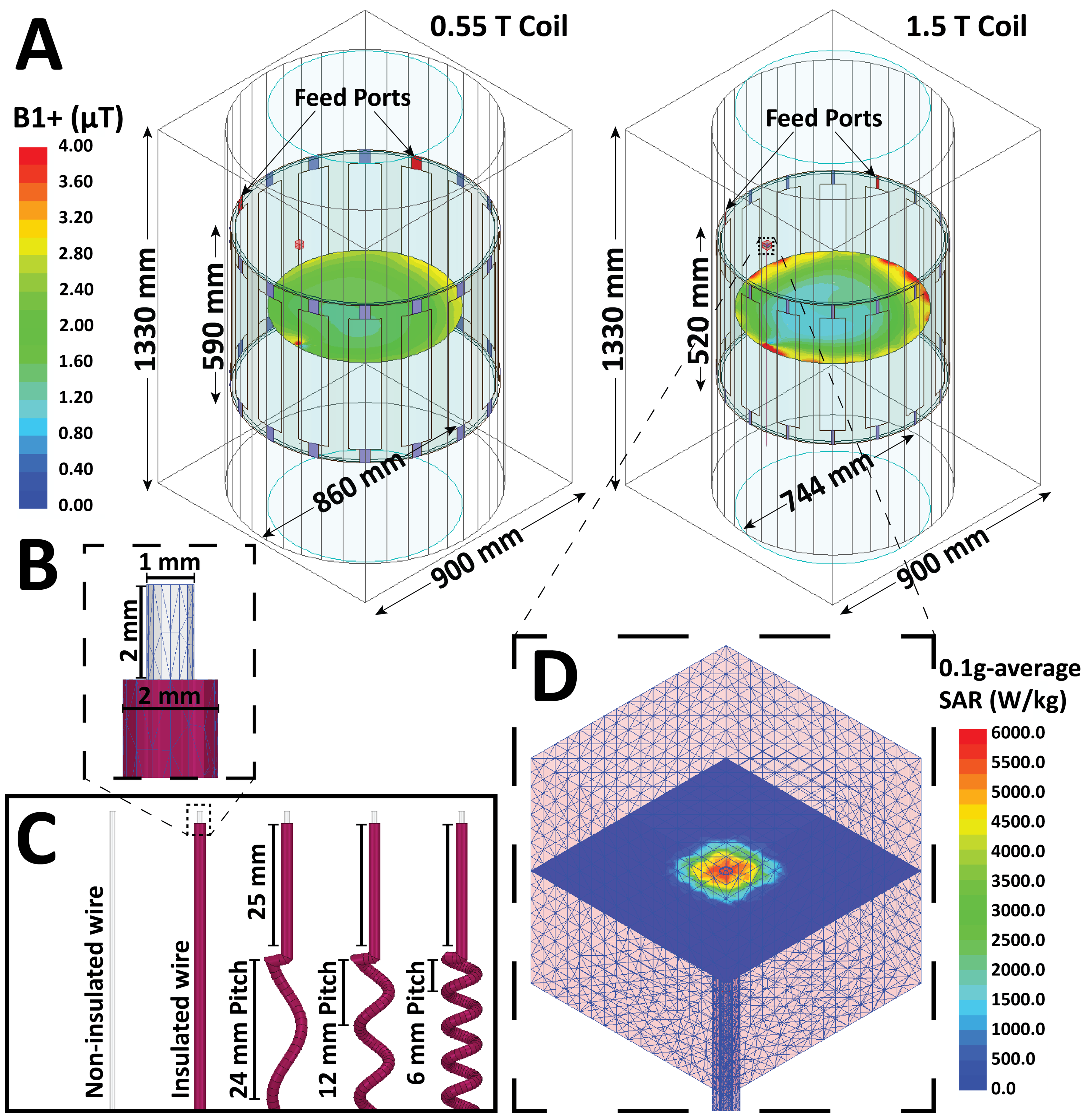

Figure 1. (A) Models of a 0.55 T and a 1.5 T birdcage coil loaded with a cylindrical phantom which contains a 75 cm straight insulated wire near the edge of the phantom. The input power of the coil is adjusted to generate B1+= 2 µT at the iso-center. (B) A close view of the high-mesh area surrounding the wire and tip, and the high gradient SAR field in the tissue near the tip. (C) Display of different wire pitches.

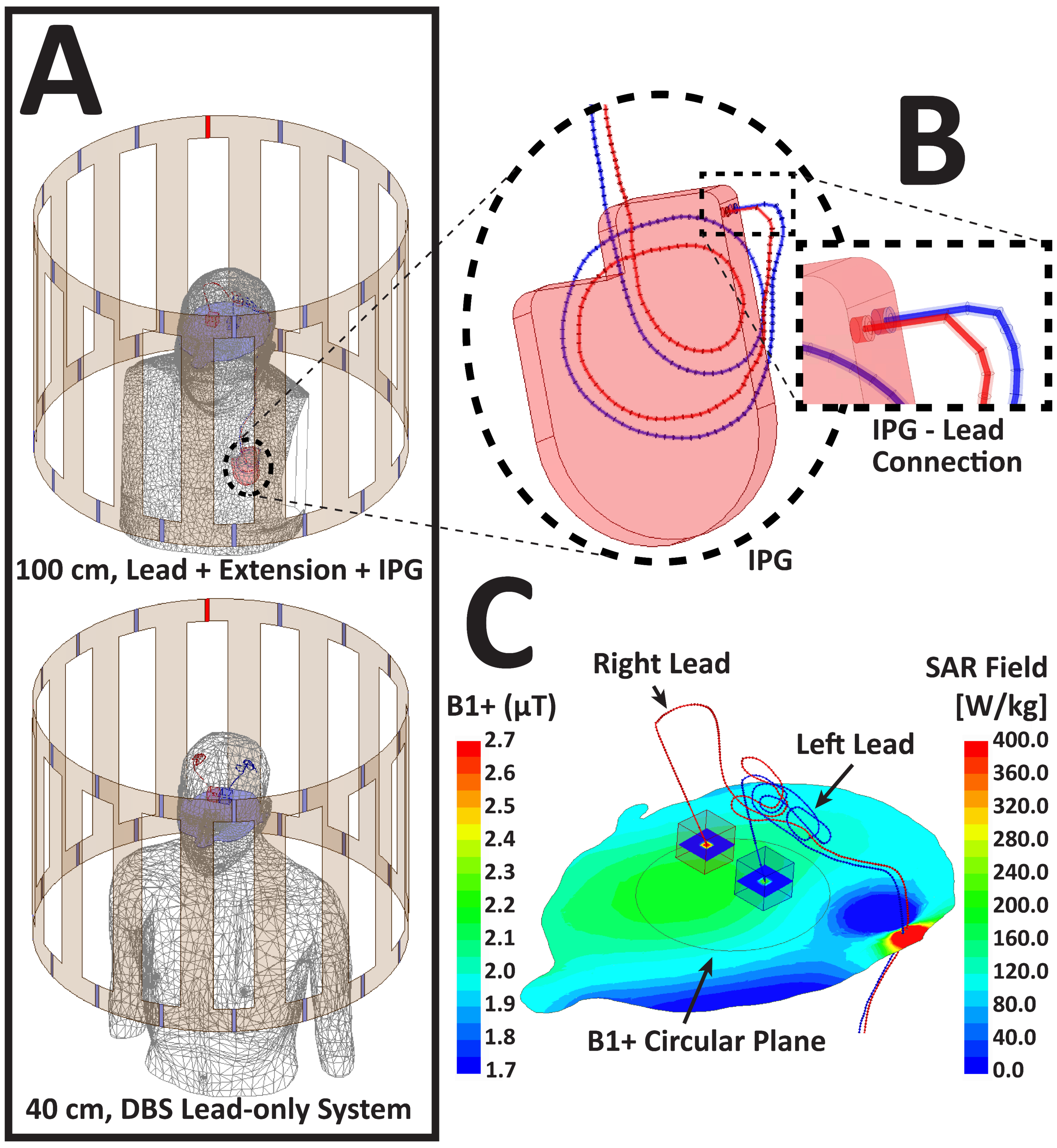

Figure 2. A) A DBS lead-only system with a 40 cm lead, and a full DBS system with a 40 cm lead connected to a 60 cm extension and a pulse generator (100 cm total length). B) Close view of the IPG-lead interface in the full system. C) Close up of the lead-only case the 1.5 T coil, showing the SAR fields near the tips of the leads and the B1+ field on an axial slice located in the center of the coil.

Results/Discussion

- Systematic Simulations – As the pitch decreases, apparent length where peak occurs gets shorter, and magnitude of peak 0.1g MaxSAR gets smaller (Figure 3A)
- DBS Simulations – 40 cm leads lower in 0.55 T than in 1.5, opposite for 100 cm (Figure 3B)
- Resonance effect – peaks occur when the length of the lead approaches the half-wavelength of RF wave in the medium [4]
- Serious ramifications in patients with long insulated leads, where the apparent length of the lead reaches 60+ cm, complicated internal geometries lead to even longer actual length
- 0.55 T scanners are not necessarily point-blank safer than 1.5 T scanners!

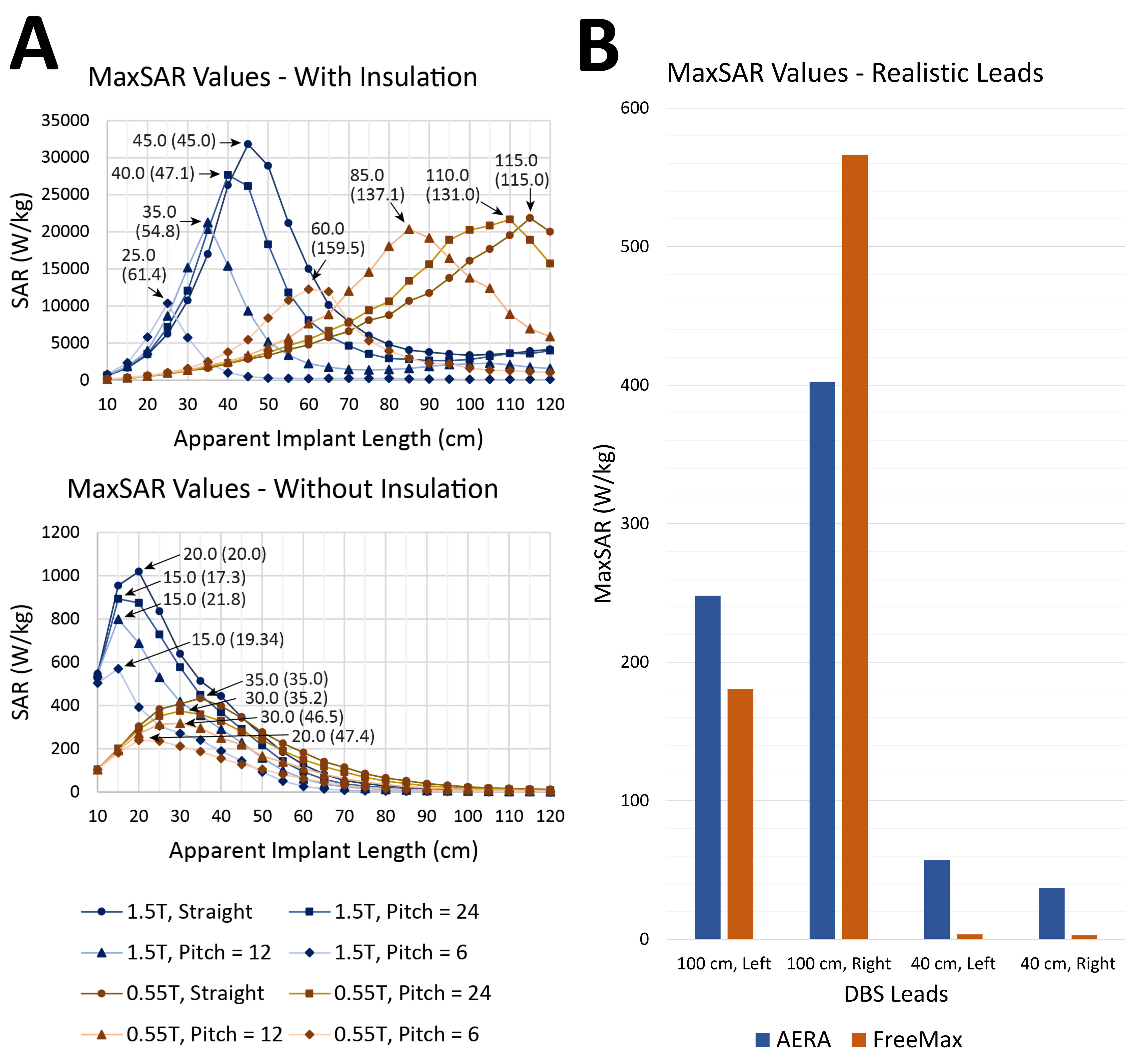

Figure 3. (A) 0.1g MaxSAR around tips of insulated and uninsulated wires in the 1.5 T and 0.55 T RF coils. For all simulations, the input power of the coil was adjusted to generate a mean B1+ = 2 µT on a central plane passing through the coil's iso-center. The apparent and actual lengths (in parentheses) at which the peak occurred are denoted on the graphs. (B) Results of Realistic DBS implant simulations.

References: [1] Geethanath S et al., J. Magn. Reson. Imaging, 49(7): e65-e77. [2] Sarracanie M et al., Front Phys. 2020; 8:172 [3] Golestanirad L et al., MRM 2019; 81(1):653-669. [4] Bhusal B et al., MRM 2018; 80(4):1676-1685.

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