A Monte Carlo Analysis of Guidewire Safety Comparing a Body and Local Coil

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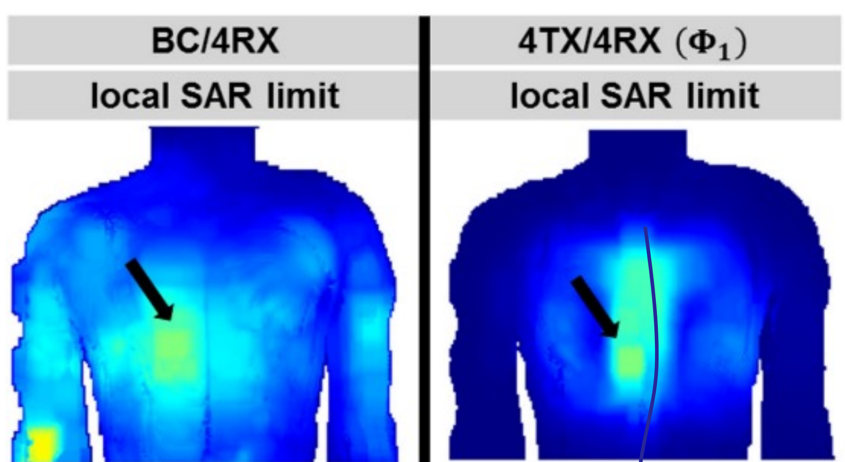
Introduction

In MRI, endovascular devices, such as guidewires, are unsafe due to heating caused by coupling to the transmit coils of the scanner. A novel solution is to design a transmit coil with a small electric field footprint, in comparison to a body coil which emits a larger electric field. Using simulation, the potential for heating at the device tip was evaluated by comparing a local coil array and a body coil.



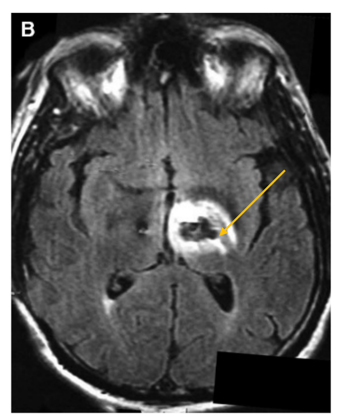
Whole body coil vs local coil SAR[1]

The simulated local SAR from electric field generated from a body coil and a local coil array. The Local coil produces a smaller electric footprint.

Guidewire

Heating Mechanism

- Resonant length of guidewire
- Tangential electric field (E-field) present with B_1^+
- Incident RF power

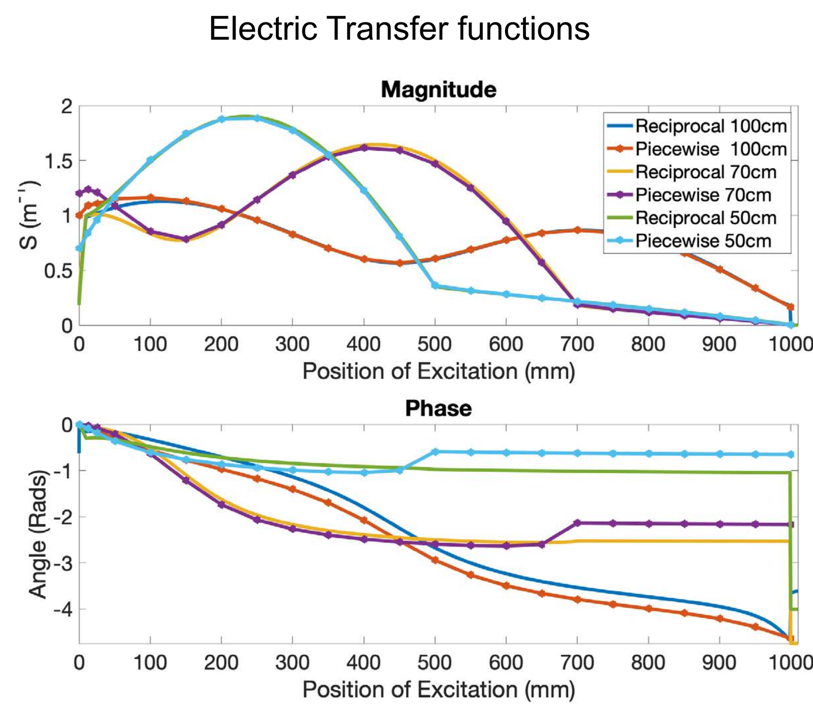


Burn lesion from deep brain stimulator[2]

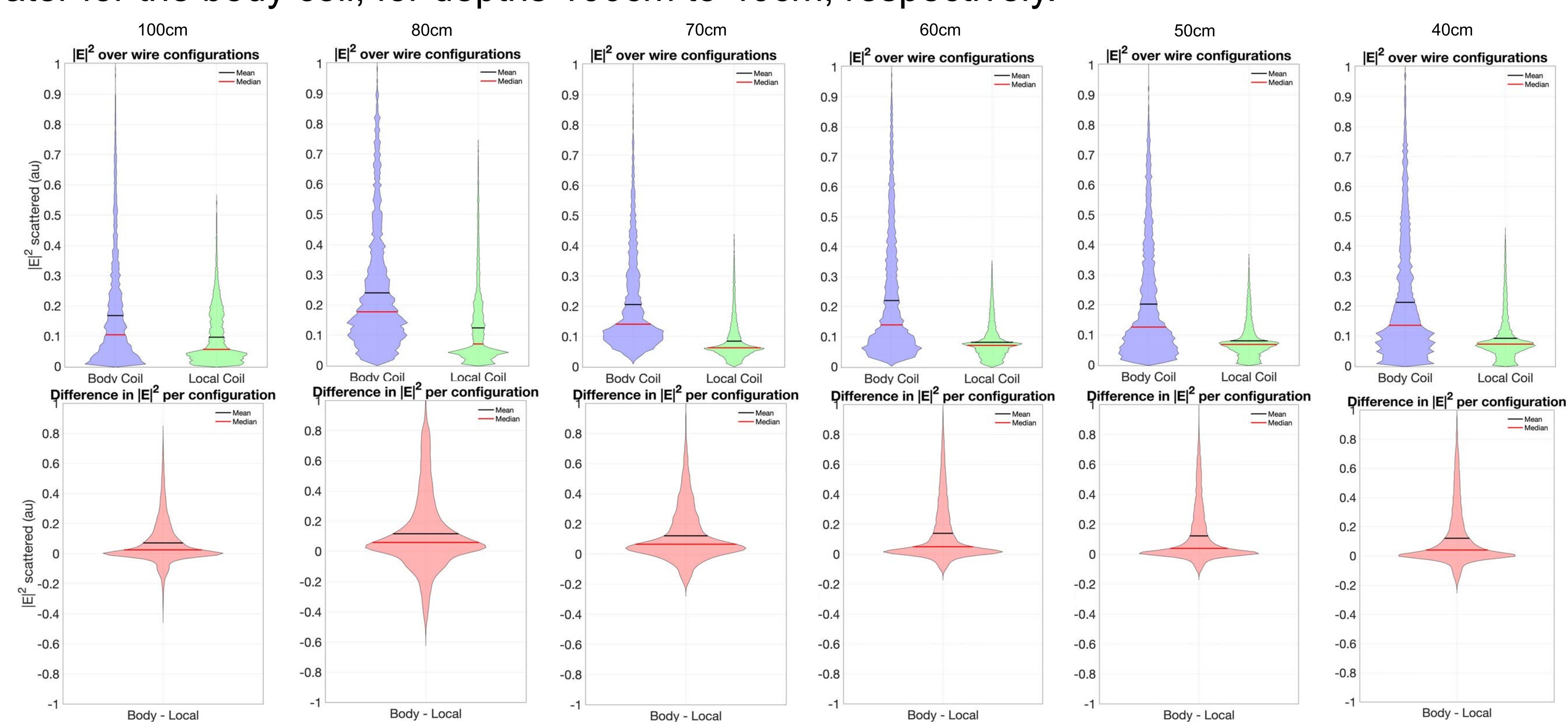
Burn in wood from copper wire at resonant length[3]

Results

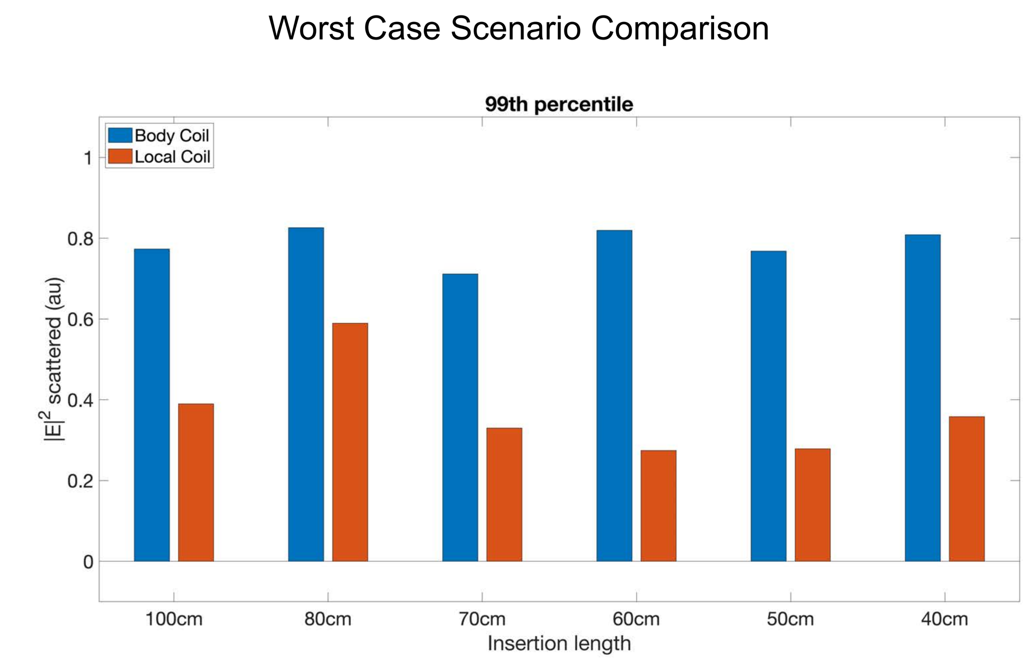
The body coil to local coil array ratios for the mean electric power at the tip were 1.7, 1.9, 2.4, 2.7, 2.5, and 2.3 for depths 100cm to 40cm, respectively. The 99th percentile electric power at the tip (close to worst case) was 98%, 40%, 115%, 198%, 175%, and 125% greater for the body coil, for depths 100cm to 40cm, respectively.



Magnitude and phase of transfer function for reciprocal and piecewise TF for 100cm, 70cm,50cm insertion lengths.



The violin plots of the electric power at the wire tip for each wire trajectory/geometry for the body coil and local coil, respectively (middle row). Violin plots of the difference in electric power between the body coil and local coil.

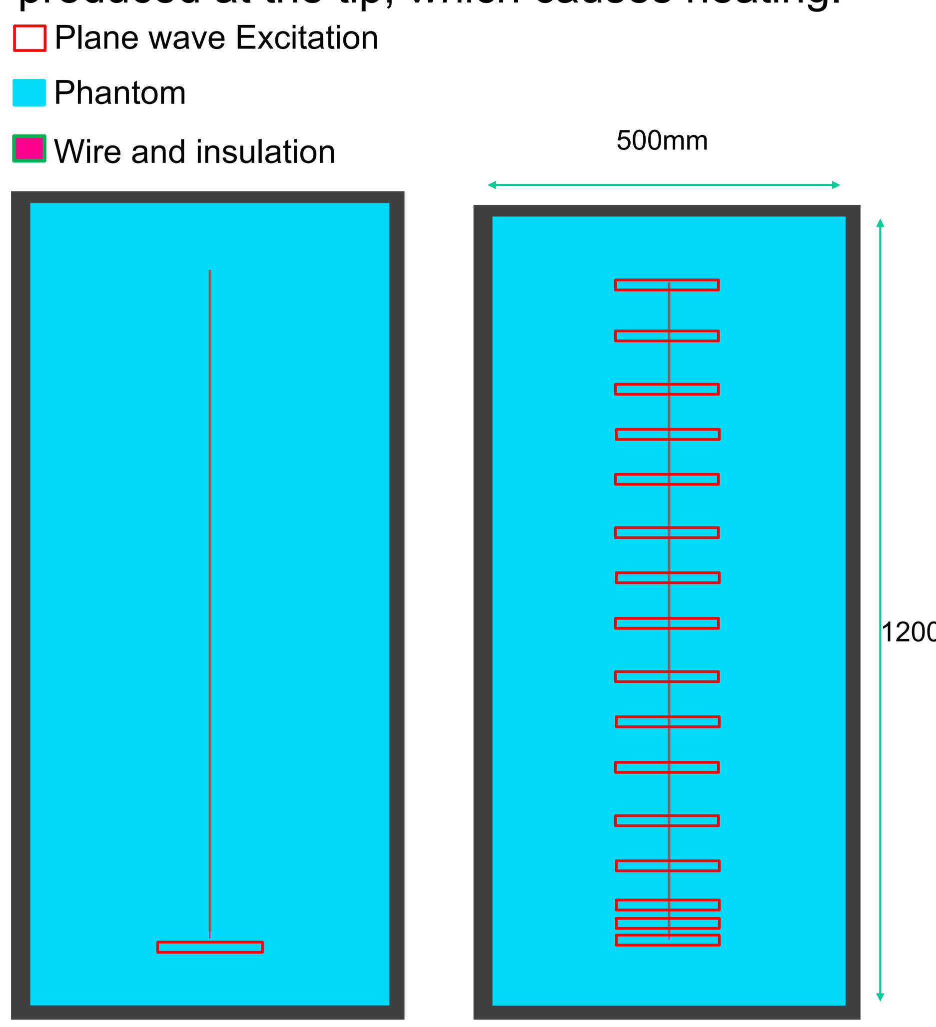


The 99[th] percentile (worst case scenario) comparing the body coil with local coil scattered electric field, for multiple insertion depths. The local coil was always less.

Methods

A. Electric Transfer Function (TF) Simulation

The transfer function relates the incident electric field on a wire to the scattered electric field produced at the tip, which causes heating.



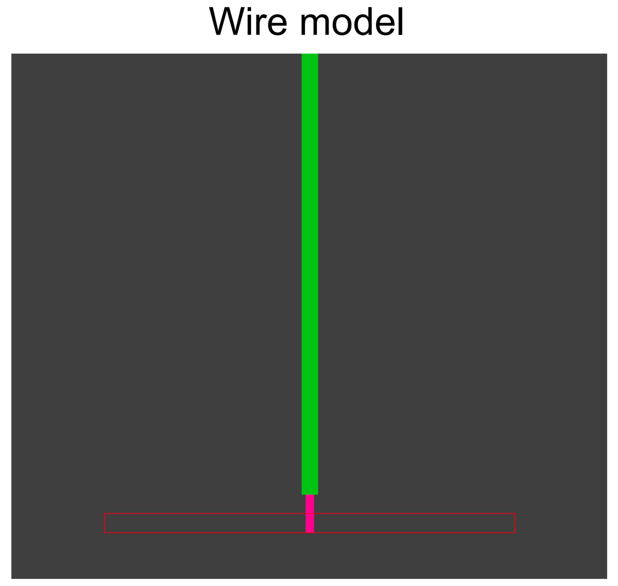
Reciprocal TF[6]   Piecewise TF[4,5]

Scattered electric field formula at the wire tip

$$E_s \approx \int S \cdot E_{tan}\, dz$$

S = transfer function
E_{tan} = Tangent electric field
E_s = Scattered electric field
Z = position on wire

Wire model

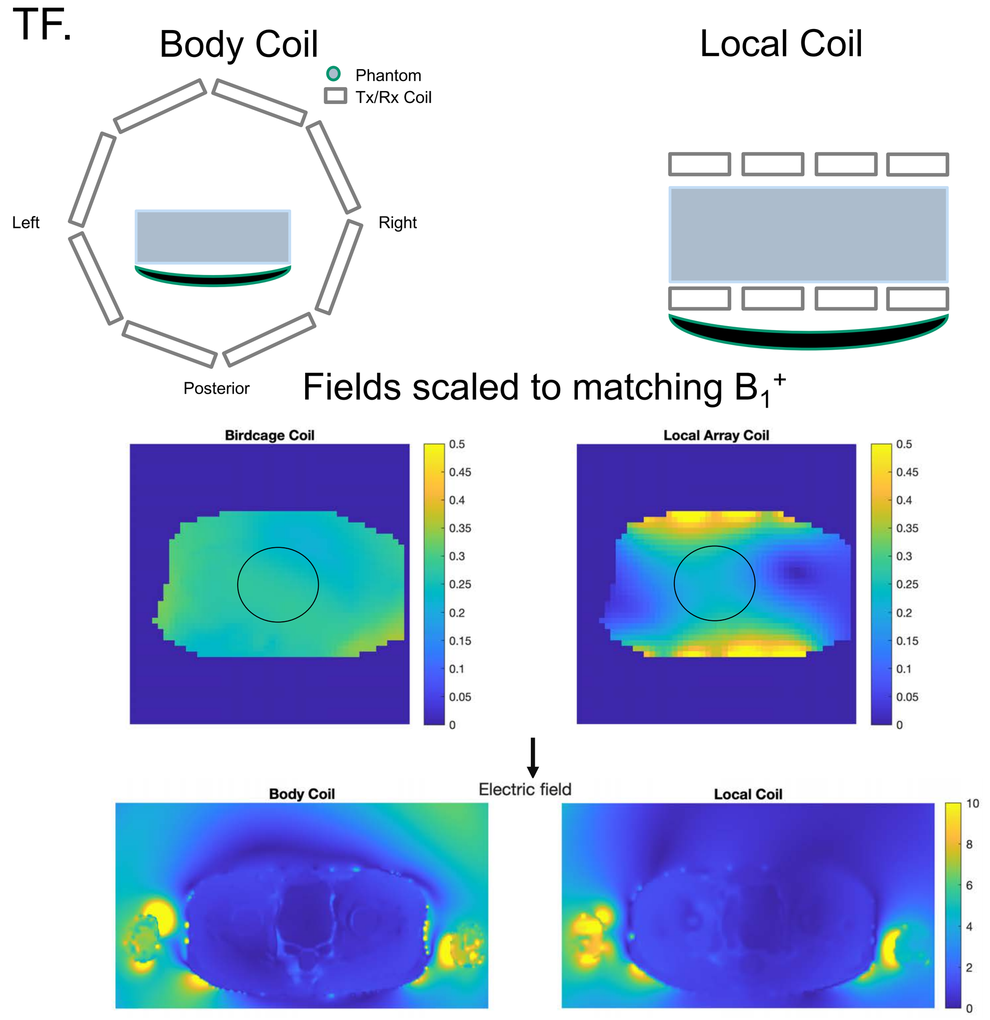


2mm diameter x 1000mm long wire, 1mm plastic insulation

- Sim4life V6.2 (Zurich Med Tech, Zurich, Switzerland)
- 10mm exposed tip
- 5mm thick plane wave excitation
- Insertion lengths: 100cm, 80cm, 70cm, 60cm, 50cm, 40cm

B. RF Electromagnetic Field Simulation

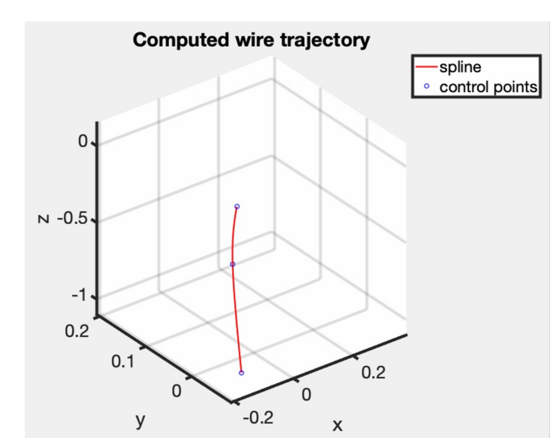
The incident electric field from a body or local coil array was simulated. The tangential component was extracted according to the wire trajectory to compute Es using the TF.



- Sim4life V6.2 (Zurich Med Tech, Zurich, Switzerland)
- Adult phantom (Duke)
- Body coil (Bird cage)
- Local coil (4 loops anterior, 4 loops posterior)

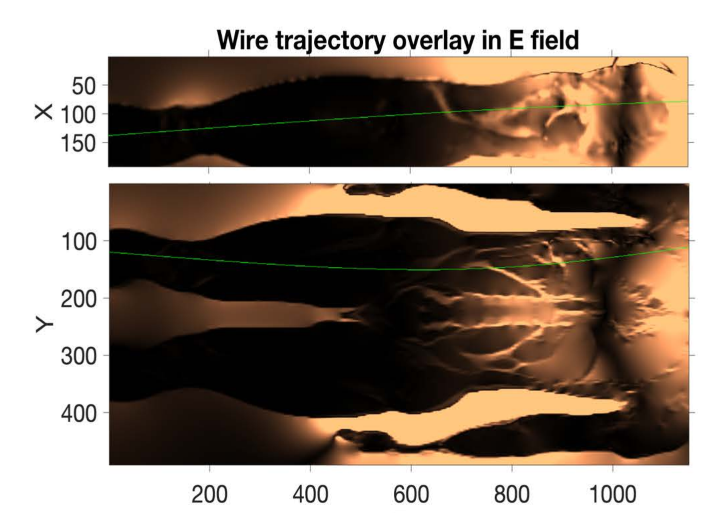
C. Random Wire Trajectory Generation

Wire trajectories were randomly generated to evaluate the influence of wire geometry and dielectric environment on the Es.



The calculated spline trajectory in MatLab. The trajectory was randomized by selecting random control points within the phantom

function: cscvn()



The overlay of the projection of the tangential component along the guidewire and the incident electric field is shown

- MatLab (Mathworks R2021a, MA, USA)
- 3 fixed points randomly selected
- Tangential electric field component extracted, E_{tan}
- 10,000 trajectories simulated

Conclusions/Further Study

Conclusion

- The local coil reduces heating at the guidewire tip for all insertion lengths
- The amount of reduction in heating is sensitive to a resonant insertion length
- Speculate that this advantage comes from a reduced E-field coverage
- The reciprocal TF is a good way to rapidly explore many guidewire geometries

Future work

- Further explore the use cases that meet the safe condition
- Build a dedicated local transmit coil tested in animals

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References

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