MRI SAFETY AND RETAINED EPICARDIAL LEADS

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Introduction

There is a concern on whether a patient with retained post-surgical epicardial leads can safely be scanned in an MRI device because the interaction of the magnetic field, RF and gradients with these leads are still not well defined. They may rise problems such as RF-induced heating, translational forces, and torques and induced currents. In previous graduate student thesis and research, these risks and issues were highlighted. [1, 2]. The thesis pointed out that over 50% of patients with cardiac implantable electronic devices (CIEDs) will require MRI in their lifetime [2]. Moreover, there is a lack of consensus across clinical guidelines that leaves physicians with the task to assess risks on a case-by-case basis.

Objective: To synthesize findings on MRI safety with epicardial leads, focusing on RF heating, magnetic forces, and torques, while identifying research gaps and proposing strategies for safer imaging.

Risks of MRI with Epicardial Leads

- **RF-Induced Heating:** Leads can act as antennas, they absorb RF energy and cause localized tissue heating, particularly at the lead tips [2].
- **Translational Forces:** The strong magnetic field can induce translational forces, pulling ferromagnetic materials toward the scanner's isocenter. These forces depend on lead material and length. [1].
- **Torque:** Leads experience twisting forces that align them with the magnetic field, this can cause discomfort or tissue damage if the lead length is significant [1].
- **Electrical Stimulation:** RF fields can induce currents in leads and stimulate cardiac tissue. This remains an underexplored area requiring further research [2].
- **Device Malfunction:** MRI fields may interfere with pacemaker settings, causing unintended pacing or disabling the device altogether [2].

Background

To answer whether safety concerns signify the outlined risk tissue-equivalent phantoms were designed, created and tested in previous research. Figure 1 shows the the phantom design and experimental setup used and table 1 compares the properties of the phantom materials to ASTM standards, confirming their clinical relevance.

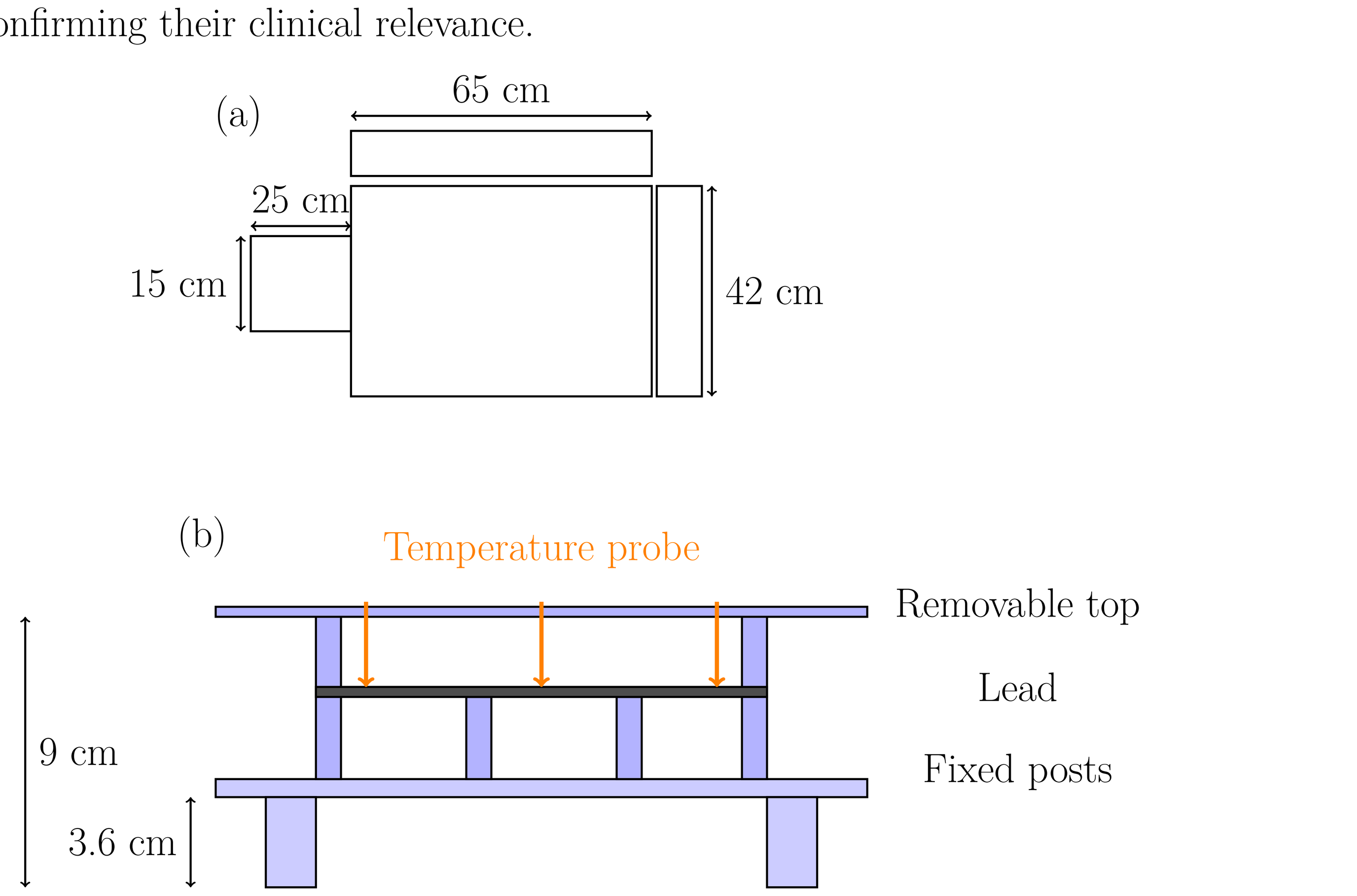

Figure 1: Phantom design with dimensions and setup components for RF-induced heating experiments. Adapted from Aboyewa, 2021.[2]

Phantom Properties	ASTM F2182-11a	Aboyewa (2021)
Dielectric Constant	80 ± 20	82.1 ± 1.4
Electrical Conductivity (S/m)	$0.47 \pm 10\%$	0.47 ± 0.04
Thermal Conductivity (W/mK)	0.54	0.850 ± 0.007
Density (kg/m^3)	1000	$1027 \pm 1\%$
Specific Heat Capacity (J/kg°C)		
New Gel (21°C / 37°C)	4150/4190	4129 ± 47 / 4118 ± 48
Old Gel (21°C / 37°C)		4207 ± 54 / 4166 ± 52
Water (21°C / 37°C)		4168 ± 42 / 4151 ± 42

Table 1: Results of phantom characterization as compared to ASTM standards [2].

- **Phantom Design:** Tissue-equivalent phantoms developed by Aboyewa in 2021 simulate clinical conditions, measuring RF heating under SAR values of ~2 W/kg and providing a well defined methodology for simulating patient conditions and measuring RF-induced heating [2].
- **Preliminary Results:** Findings indicate leads shorter than 13 cm exhibit minimal heating under 3T MRI conditions. Orientation significantly impacts RF heating [2].
- **Heating Studies:** Temperature rise increases with lead length as showed on figure 2, this finding establishes the expected threshold for classification of leads on MRI Safety.

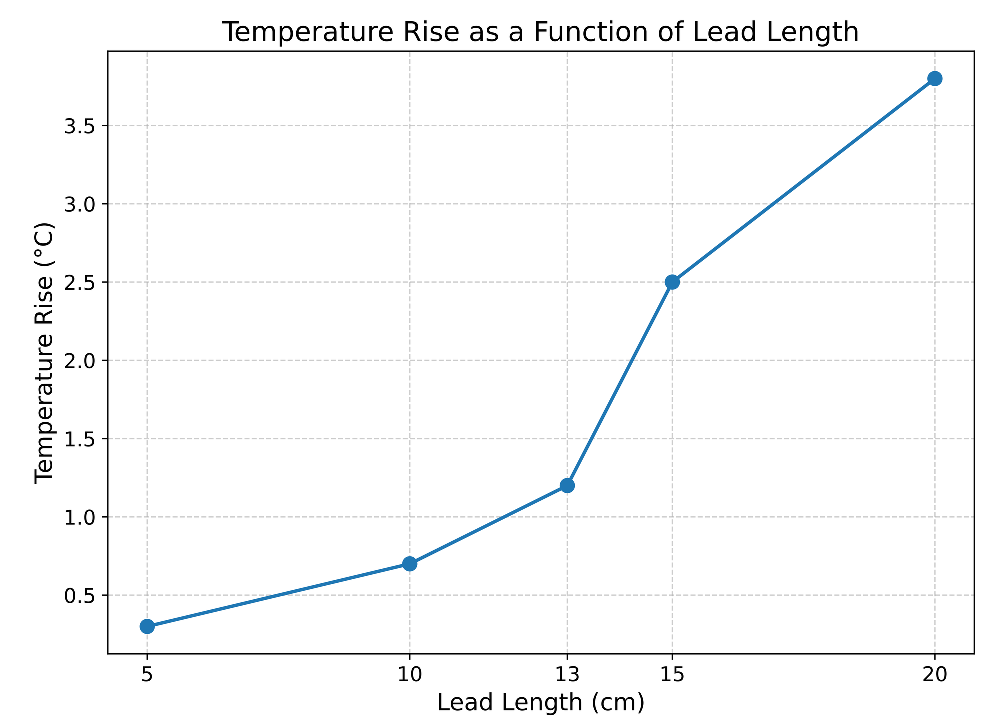

Figure 2: Temperature rise as a function of lead length under MRI. Adapted from Aboyewa, 2021.

Aboyewa further explored the effects of implant configuration on RF-induced heating. Figure 3 illustrates the influence of implant orientation, shape, and length on maximum temperature rise.

Implant Configuration and RF-Induced Heating: The straight configuration showed the highest temperature rise due to the antenna effect. Rotating the lead by 45° toward the right-side wall (TRS) or center (TC), as shown in Figure 3(b), reduced heating by more than half. An 8-fold reduction in heating was observed when the lead was bent into an arc, as shown in Figure 3(c). Although temperature rise increases with lead length [2], lead orientation and shape must also be considered to predict behavior in the MRI environment.

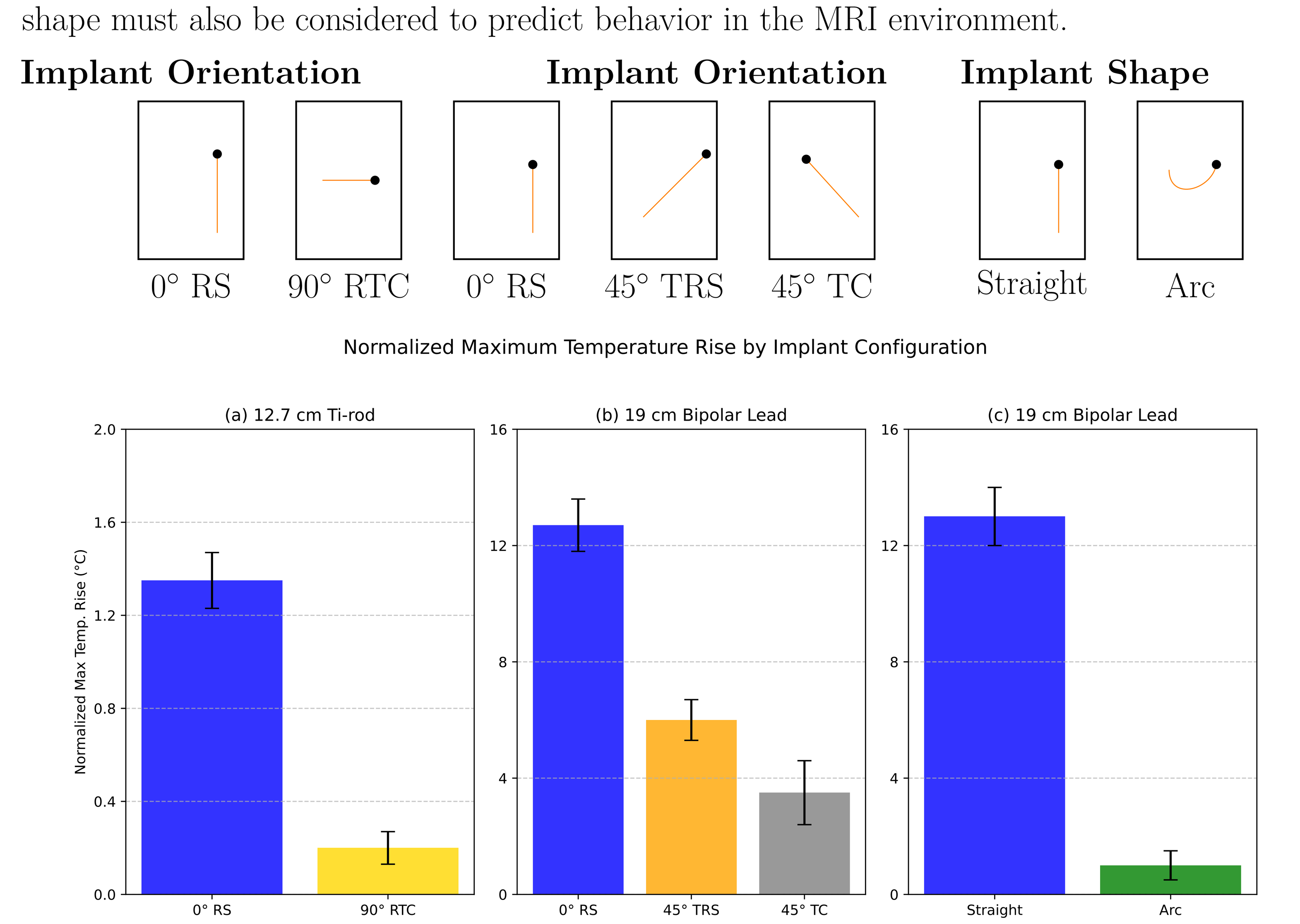

Figure 3: Effect of implant orientation on maximum temperature rise during MRI. (a) 12.7 cm Ti-rod, (b) 19 cm Bipolar Lead, (c) 19 cm Bipolar Lead. Adapted from Aboyewa, 2021.

Recent Advancements

- **Force and Torque Studies:** The Haddix proposal outlines experiments to measure translational forces and torques, with findings suggesting that forces are typically less than 10% of the lead's weight at the bore entrance [1].
- **Research Gaps:** Limited studies exist on the effects of RF-induced electrical stimulation in leads, requiring further exploration.
- **Safety Evidence:** Several recent studies have demonstrated the safety of MRI in patients with abandoned or epicardial leads when following specific protocols. Table 2 summarizes key findings from these studies.

Study Name	Population	Key Takeaway	MRI Outcome
JAMA Cardiol (2021) [3]	139 patients (200 MRIs)	Abandoned leads no longer absolute contraindication for MRI.	Safe
European Heart Journal (2021) [4]	16 patients (24 MRIs)	Functional epicardial leads pose minimal risk when leads are modern (post-2000).	Safe for modern devices
Magn Reson Med (2021) [5]	Simulation/Phantom	Abandoned leads demonstrate minimal RF heating at 1.5T/3T.	Safe
Europace Meta-analysis (2024) [6]	656 patients (21 studies)	Adverse events negligible under strict protocols, justifying cautious guideline revisions.	Safe

Table 2: Key findings from recent studies on MRI safety for patients with abandoned or epicardial leads.

Safety Strategies

- **Technological Advances:** Improvements in MRI-conditional devices and scanning protocols have minimized risks like RF heating and device malfunction.
- Limiting lead lengths to reduce RF heating risks [2] and developing MRI-specific lead configurations to minimize mechanical interactions [1].
- **Clinical Impact:** Updated guidelines now cautiously include patients with abandoned and epicardial leads, reducing delays in critical diagnostics.
- **MRI Workflow Recommendations:** In the College of cardiology an article outlines steps for preparation, monitoring, and post-scan follow-up, ensuring patient safety and device functionality for managing MRI safety protocols in patients with CIEDs depicted in Figure 4.

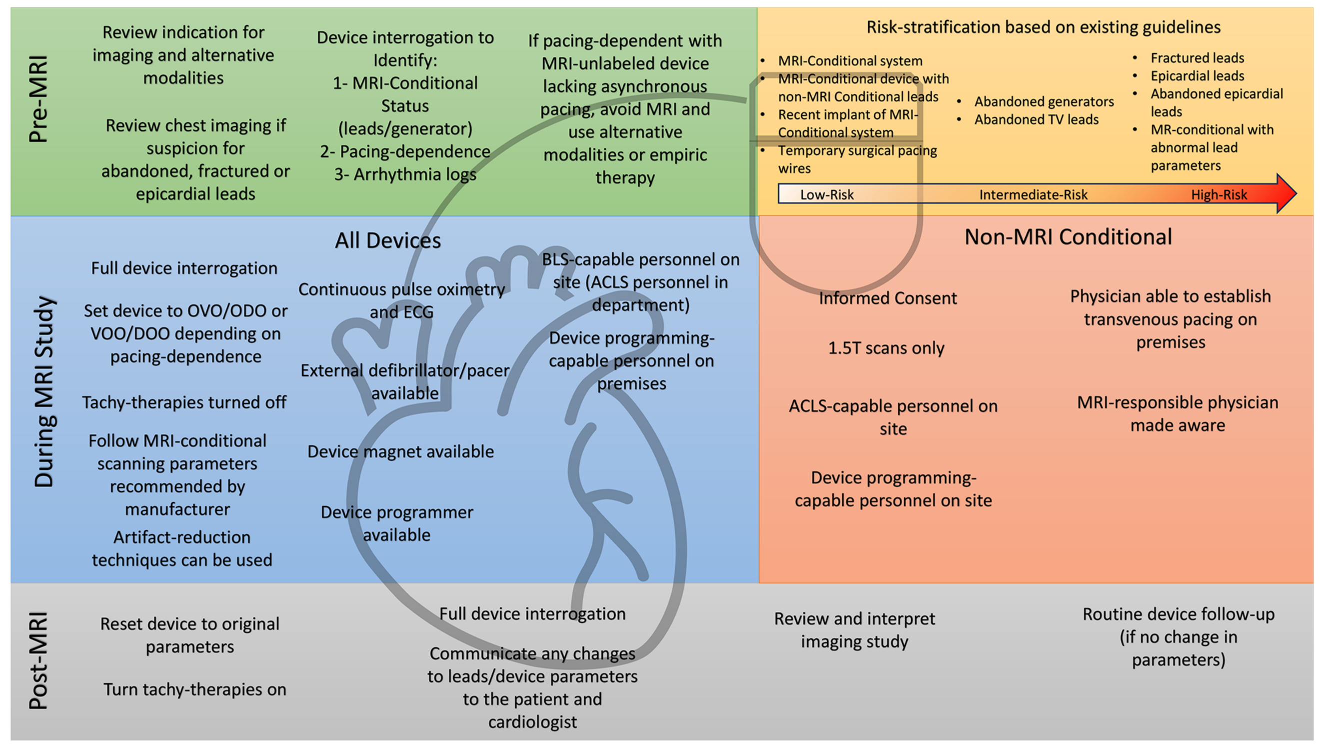

Figure 4: Comprehensive workflow for MRI safety protocols in patients with MRI-conditional and non–MRI-conditional CIEDs, covering pre-MRI preparation, during-MRI monitoring, and post-MRI follow-up.[7]

Acknowledgements

This work builds upon the foundational insights provided by Dr. Nichols's proposal and Oluyemi Aboyewa's thesis, which will serve as a basis for my forthcoming thesis research.

[1] Michael G. Nichols. Safety assessment of translational forces and torques on post-surgical epicardial leads during mri. Technical report, Creighton University, 2022. Fund Proposal Document.

[2] Oluyemi Aboyewa. Safety assessment of epicardial leads during mri. Master's thesis, Creighton University, 2021. Master's Thesis.

[3] Robert D. Schaller, Tamara Brunker, Michael P. Riley, Francis E. Marchlinski, Saman Nazarian, and Harold Litt. Magnetic resonance imaging in patients with cardiac implantable electronic devices with abandoned leads. *JAMA Cardiology*, 6(5):549–556, 2021.

[4] AM Vuorinen, R Paakkanen, J Karvonen, J Sinisalo, M Holmstrom, S Kivisto, J Peltonen, and T Kaasalainen. Mri safety with abandoned or functional epicardial pacing leads. *European Heart Journal - Cardiovascular Imaging*, 22(Supplement 2), 2021.

[5] Bach T. Nguyen, Bhumi Bhusal, Amir Ali Rahsepar, Kate Fawcett, Stella Lin, Daniel S. Marks, Rod Passman, Donny Nieto, Richard Niemzcura, and Laleh Golestanirad. Safety of mri in patients with retained cardiac leads. *Magnetic Resonance in Medicine*, 87(5):2464–2480, 2021.

[6] Claudia Meier, Carsten Israel, Michel Eisenblätter, Annika Hoyer, Ferdinand Valentin Stoye, Ali Yilmaz, and Stephan Gielen. Safety of magnetic resonance imaging in patients with cardiac implantable electronic devices and abandoned or epicardial leads: A systematic review and meta-analysis. *Europace*, 26(6):euae165, 2024.

[7] Tarek Zghaib and Saman Nazarian. Current state of mri with cardiac devices, May 2024. Published by the American College of Cardiology. Figure adapted with permission. Accessed on December 2, 2024.