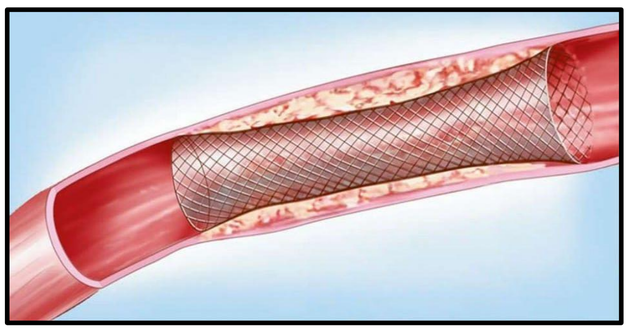
Development and Validation of a Tissue-Mimicking Phantom for MRI-Based Temperature Mapping in Implant Safety Studies

Daniel Franklin, Justyna Janus, Charlotte Bull, Alimul Chowdhury

University Hospitals of Leicester NHS Trust

1) Introduction

Magnetic Resonance Imaging (MRI) of patients with implanted medical devices carries a risk of heating from radiofrequency (RF) and switched gradient fields, which may exceed safe limits during prolonged scanning [1, 2, 3]. Implant manufacturers define scan duration limits, often 15 minutes for passive implants.



(https://www.vascularsurgeryassociates.net/contents/treatments/stenting)

There are a lack of validated, tissue-equivalent MRI phantoms for studying heating dynamics and test mitigation strategies [4]. Therefore, this study aimed to (i) develop a thermally and electrically representative tissue-mimicking phantom (TMP) embedded with implant or implant-like materials and (ii) validate its' ability to measure temperature changes using MRI-based proton resonance frequency (PRF) shift and T2* mapping techniques.

2) Methods

- TMPs were fabricated in-house based on published methods using readily available ingredients to replicate the MRI relaxation properties of muscle tissue [5].



Figure 1: Example of TMP test tubes. In this case the TMPs contain embedded wires.



Figure 2: Lab Equipment used to manufacture TMPs.

Stage 1

- The TMP test tubes were heated and placed in a transmit/receive knee coil. Each test tube had a paired temperature reference which was kept in the control room.
- An EPI based T2* mapping sequence was run as the temperature of the reference tube passed through set values.

Stage 2

- Lengths of wire with diameters ranging from 0.1mm to 0.8mm were embedded in the TMP tubes to replicate the presence of a implant. A control tube without an embedded wire was included for comparison.
- The T2* mapping sequence was run at baseline and after 15 minutes of a high SAR (~9W/kg) Fast Spin Echo (FSE) sequence to simulate a worst-case heating scenario.

- Image analysis was performed using ImageJ to draw ROIs and a python script to generate exponential decay fits and calculate T2*.

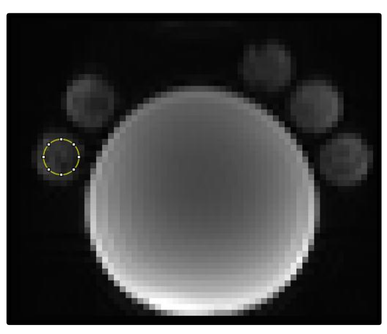


Figure 3: T2* weighted EPI image of TMPs surrounding a large fluid phantom.

3) Results

- The TMPs were successfully manufactured and demonstrated appropriate structural integrity and safety for use in the MR environment.
- The signal decay was fitted and T2* values obtained for each temperature datapoint (Figure 4)

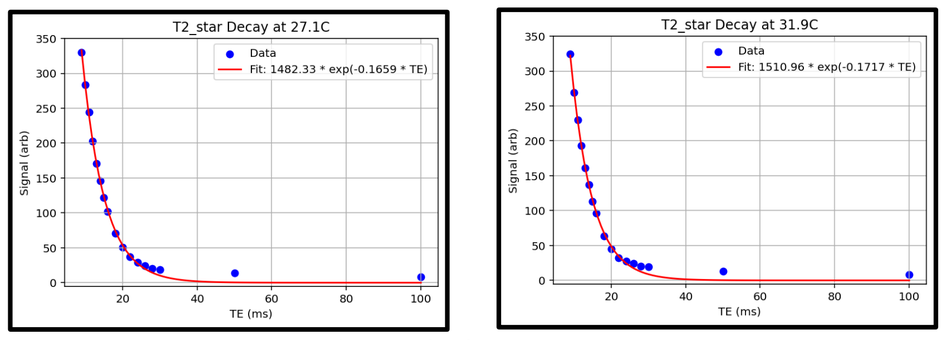


Figure 4: T2* decay fits for the same TMP test tube at 27.1C and 31.9C

- T2* decreased as temperature increased over a temperature range of 27C to 32C (Figure 5)
- The effect of the 15 minutes high SAR exposure on T2* is unclear. Some of the wire containing TMPs showed an increase in T2*, some a decrease and one remained approximately constant. The TMP without a wire showed an increase in T2* (Figure 6).

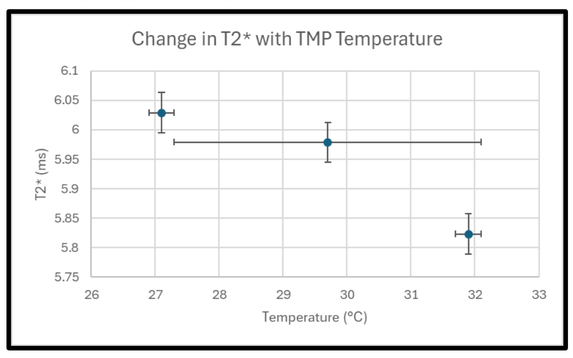


Figure 5: Relationship between T2* and TMP temperature.

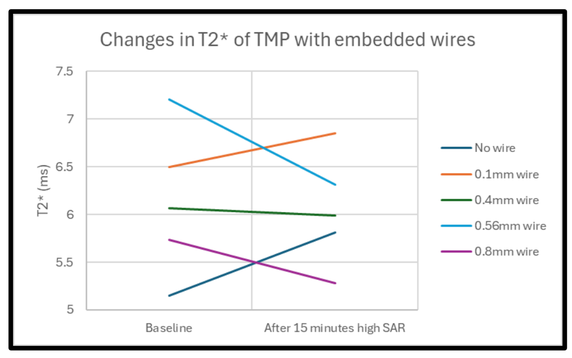


Figure 6: Change in T2* produced by high SAR exposure of a wire embedded in TMP.

4) Discussion

- Preliminary data suggests the T2* mapping technique is sensitive to changes to bulk temperature changes in the TMP. Generally, the T2* shortens as temperature increases. Further work is needed to determine whether the sensitivity of this method is sufficient to detect T2* changes produced by localised, rather than bulk, heating around implants.
- Limitations of this approach include the assumption that the rate of cooling is the same for the TMPs inside the scanner and the reference tubes in the control room. There may have been insufficient time for the temperature of the TMPs to equilibrate before carrying out the pre and post high SAR measurements. Additionally, the SAR spatial distribution within the coil may be non-uniform, especially close to the coil surface, leading to uneven heating conditions between samples. Mitigation strategies will be developed to address the existing limitations.
- Future work is planned to measure temperature change using MR spectroscopy. The placement of a single voxel close to the implant tip may be better suited to measure localised heating, as the T2* change in a slice produced by localised heating may be imperceptible.

5) Conclusions

We have manufactured TMPs for MRI thermometry and evaluated the feasibility of a T2* mapping method. These phantoms enable future assessment of scan pause strategies and supports ongoing work to improve MRI safety in patients with implants by characterising thermal responses under extended scanning conditions.

[1] ASTM F2182. Standard Test Method for Measurement of RF-Induced Heating Near Passive Implants
[2] Boston Scientific. MRI Safety for Boston Scientific Products. www.bostonscientific.com;
[3] Winter, L. et al. (2021). MRI-Related Heating of Implants and Devices: A Review. J Magn Reson Imaging, 53(6), 1646–1665
[4] Bonmassar, G. & Serano, P. (2020). MRI-Induced Heating of Coils for Microscopic Magnetic Stimulation at 1.5 Tesla: An Initial Study. Front. Hum. Neurosci. 14:53
[5] Barendsz, L. et al. (2024). Phantom Material with Biological Composition. EuCAP