Temperature-Enhanced Delineation of the Lethal Ablation Zone in Prostate Cryoablation Treatment using UTE Spiral VIBE MRI

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Introduction

- *Prostate cancer* is the #1 cancer diagnosis and the #2 cause of cancer-related mortality in men across the United States.
- Prostate focal cryoablation is a minimally invasive option for localized, low to medium risk procedures due to the following benefits: its ability to target specific areas and the visibility of frozen tissue below 0°C, known as the "iceball".
- **However**, recent studies have suggested that that temperatures ranging from -20°C to -40°C are required to achieve complete necrosis in cancerous tissue. Due to this, the volume of the iceball may not reflect the lethal ablation zone, leading to serious complications and/or local recurrence.

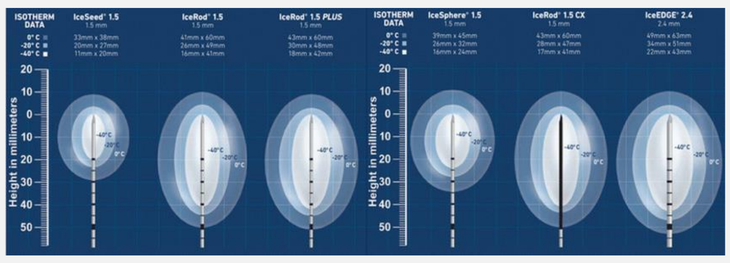


Figure 1: Example cryoprobes with 0 °C, -20 °C, and -40 °C boundaries marked (Yilmaz et al. 2016)

- Relied on the known temperature dependency of longitudinal (T1) relaxation time, which is a time constant measuring the rate at which excited protons realign with an external magnetic field.

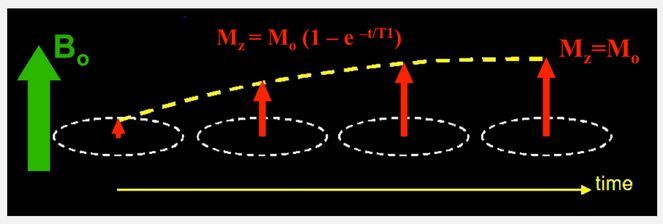
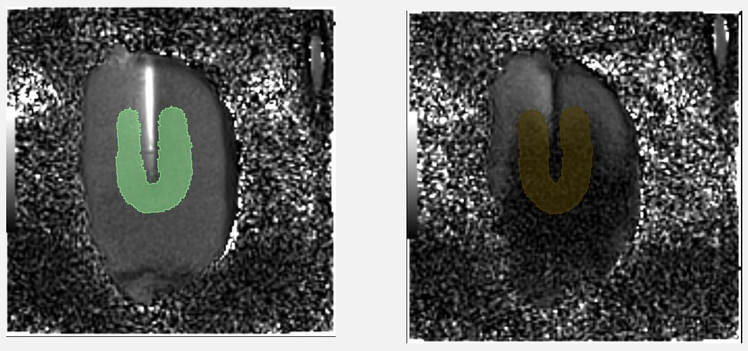


Figure 2: Visualization of T_1 relaxation time in relation to net magnetization (M) (T_1 relaxation n.d.)

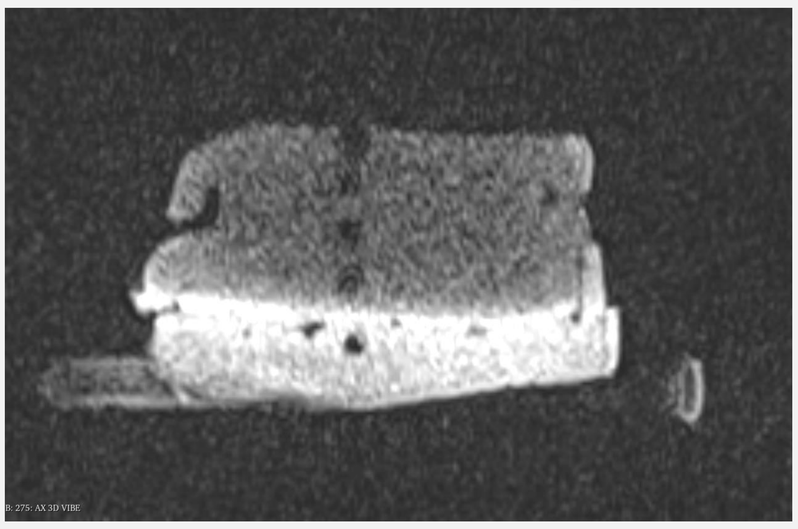
Objective: Evaluate the feasibility of frozen tissue thermometry based on quantitative T1 mapping with the UTE Spiral VIBE MRI sequence in delineating the lethal ablation zone. Additionally, evaluate hysteresis conditions in frozen tissue post-freeze.

Results

Coronal T_1 images with ROI



Axial VIBE Image



Temperature vs. T_1 time graph

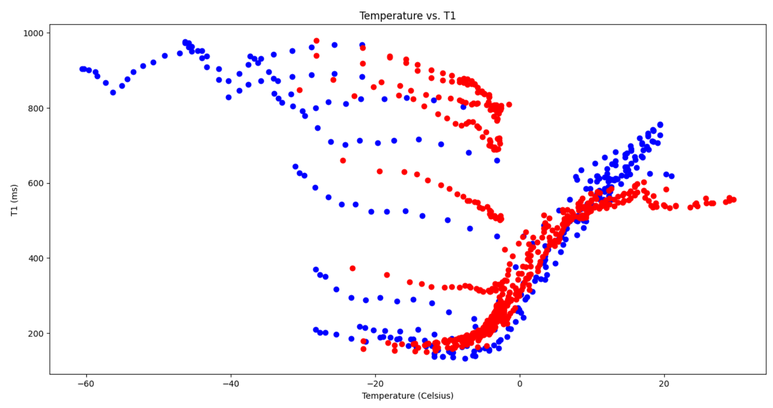
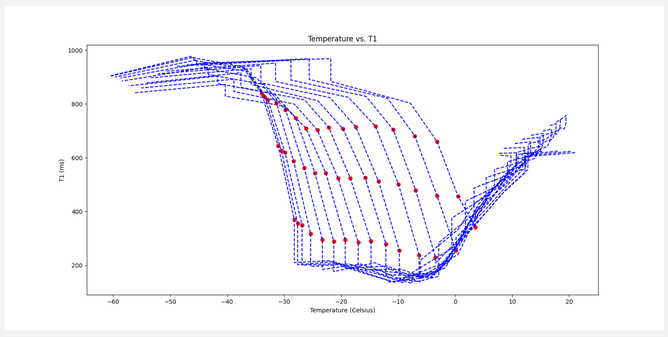


Figure 6. Freezing data graphed in blue and thawing/hysteresis data graphed in red for all slices.

Conclusion

- Tissue temperature has a strong correlation with T_1 time:
  - T_1 reached a minimum at approximately -30°C to -5°C, which is within the freezing range
  - T_1 showed a strong clustering from approximately -20 °C to 0 °C, indicating a relationship
- Slope of both the freezing and hysteresis graphs stayed relatively consistent throughout the primary freezing range
- Graph offset most likely caused by folding within the MRI, causing a sharp jump around slices 13, 14, and 15



- Signs of hysteresis indicated, but further validation will be needed due to end of hysteresis graph

Future Directions

- Collect more scans/temperature readings with the desired temperature gradient
- Conduct a T_1 validation test with agar phantoms to calibrate T_1 values
- Test UTE Spiral VIBE MRI sequence in a clinical case to confirm real-world applicability
- Test different methods of cooling to better simulate cryoablation treatment

Methodology

Logic Behind the Method: Known temperature-dependency of the T_1 relaxation time in frozen tissue – Can be seen with UTE Spiral VIBE

- Multi-flip-angle UTE Spiral VIBE sequence used to acquire T_1 images
- Evaluated in ex vivo bovine muscle
- Image intensity and tissue temperature, acquired via thermocouples, were correlated
- Mean pixel intensity calculated in ROI using 3D Slicer Segment Statistics module

MRI Settings

- Repetition Time (TR) = 20 ms
- Echo Time (TE) = 0.05 ms
- Matrix = 160 x 160
- Slice Thickness = 2 mm
- Number of Slices = 20

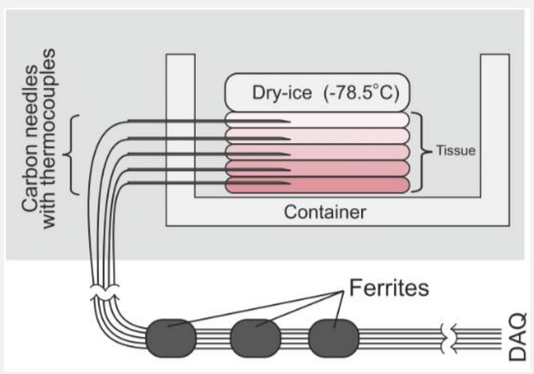
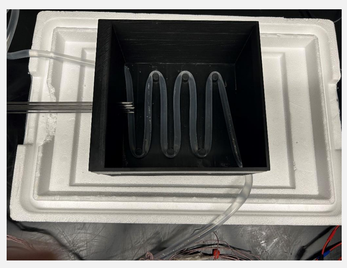


Figure 3. A diagram of the apparatus used during the ex vivo experiment. A dry ice slab was placed on top of 5 ex vivo swine muscle slices in a custom 3D-printed container. Five thermocouples embedded in carbon-fiber tubes were inserted roughly in the middle of each slice. The thermocouples were connected to a data acquisition device (DAQ) located outside the MRI room via cables with attached ferrites. The dry ice pack gradually cooled down the tissue sample from the top down while the circulating water heated the slices from the bottom up, forming a temperature gradient within the tissue. (Tokuda et al. 2020)

Experimental Setup

- 5 pork slices of ~1cm thickness
- Dry ice of ~3cm thickness placed on top + water at 37.5 °C circulating throughout → temperature gradient
- Multiple ferrites attached to wires to reduce MRI noise



Figures 4 & 5. Experimental apparatus setup without and with pork slices

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