MR thermometry of frozen tissue using signal intensity: a feasibility study at 11.7T

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Purpose MR-guided cryoablation is a promising minimally invasive therapy for localized prostate cancer[1,2]. As effective treatment relies on achieving a sufficiently cold end temperature of -40°C throughout a target lesion[3], temperature feedback during such procedures is essential. An effective non-invasive approach for this is still needed. Recent studies have been able to obtain measurable MR signal from frozen tissue using ultrashort echo time (UTE) imaging[4,5]. Our study investigates the relation between UTE MR signal intensity and tissue temperature and demonstrates the feasibility of a high-resolution MR temperature map of frozen tissue at 11.7T.

Methods An MR-compatible cryoneedle (IceRod, Galil Medical, Yokneam, Israel) was inserted into chicken breast at room temperature in a 11.7T pre-clinical MR system (BioSpec, Bruker, Ettlingen, Germany). Three fiberoptic temperature sensors (T1, Neoptix, Quebec, Canada) were placed at one side parallel to the cryoneedle at a lateral distance of respectively 0.5, 1.0 and 1.5cm. Two cycles of 10:3 min. freeze-thaw were applied. Continuous MR monitoring of iceball progression was performed using a single-slice axial UTE sequence (TR/TE = 30ms/286μs, voxel size = 0.47x0.47mm, slice thickness = 1.5mm, acq. time = 12s). For each temperature sensor, signal intensity (SI) values during the experiment were recorded for three different voxels at the same radial distance from the cryoneedle, to obtain representative SI values for the temperature sensor positions. SI was normalized to its baseline value before cooling and related to temperature. All data points in the subzero temperature range were fitted using a double exponential to best fit the data. Using the curve fit, SI values could be converted to temperatures to construct MR temperature maps of the frozen tissue.

Results Signal intensity increases when temperature decreases towards the freezing point but remains above 0°C (Fig. 1). When temperature drops into the freezing range, SI decreases exponentially. For each sensor position, in the thawing phase when temperature increases again, lower SI values were observed for the same temperature than in the freezing phase. This apparent hysteresis was most profound for the sensor at 0.5cm from the cryoneedle, as seen in the distinct subdivision of SI values for this sensor position between -20 and -40°C. For all subzero temperature data points, the signal decay is fitted by $SI = 0.47e^{0.04T} + 1.16e^{0.24T}$. When comparing each measured data point to its fitted equivalent, the curve fit had a mean temperature error of 3.9°C. UTE images as acquired at different time points during the experiment are shown below (Fig. 2a-d). For the last image, the calculated MR temperature map is overlaid (Fig 2d).

Discussion Two other studies have investigated the relation between MR signal and temperature in the cryogenic range using UTE imaging[4,5]. However, this study is the first to map this relation with high spatial and temporal resolution at 11.7T. Nevertheless, temperature averaging, both within a voxel due to the spatial temperature gradient as well as over time due to temporal temperature changes during the UTE acquisition time, remains a factor influencing measured SI values. This effect is expected to be greatest for the sensor closest to the cryoneedle as both freezing rate (°C/min.) and spatial temperature gradient are highest at this position. Possibly, this explains the apparent hysteresis observed in SI values for the same temperature between the three sensor positions during freezing and thawing. Also, an effect of the presence of the temperature sensor itself on the local cold distribution around each sensor could have affected correct correlation between SI and temperature.

Conclusion MR thermometry of frozen tissue using signal intensity is feasible. This enabled assessment of temperatures within the cryoablation iceball as low as -40°C in high resolution. Further work into the accuracy and consistency of this method is required. Clinical application of this approach may allow interventionalists feedback on the effective treatment zone inside the iceball during MR-guided cryoablation procedures.

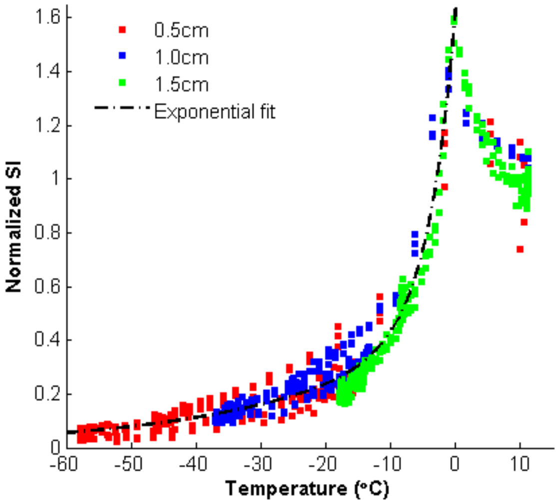

Fig. 1 – Normalized SI related to temperature for the three temperature sensors. For subzero temperatures, the signal decay is fitted by a double exponential. Mean temperature error of the fit was 3.9°C.

References (1) Gangi et al. Eur Rad 2012. (2) Bomers et al. Radiology 2013 (3) Gage et al. Cryobiology 1998. (4) Wansapura et al. Acad Radiol 2005. (5) Kaye et al. JMRI 2010.

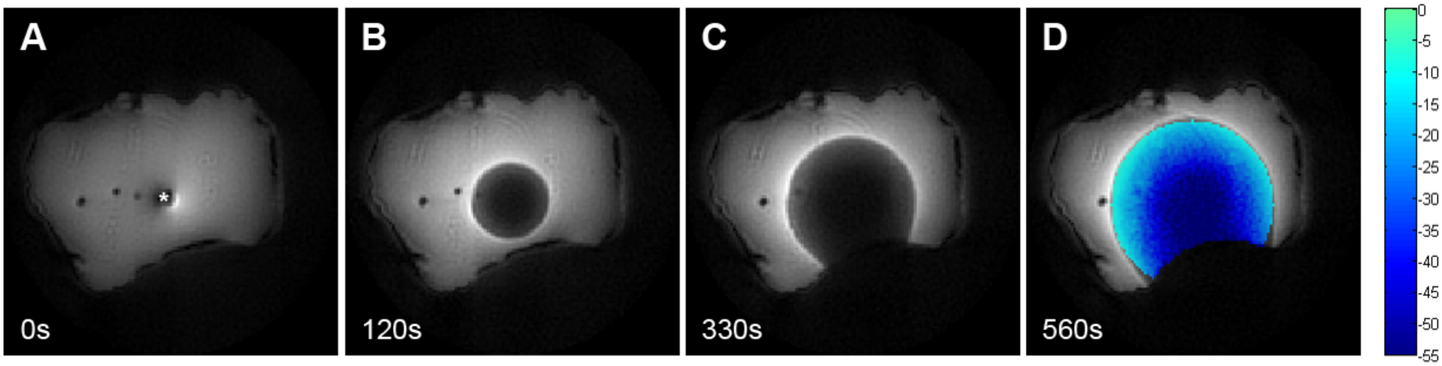

Fig. 2 – UTE images as acquired during the experiment at time points 0s (a), 120s (b), 330s (c) and 560s (d), showing the cryoneedle (*) and three temperature sensor positions (black dots). For each sensor, three voxels at the same radial distance from the cryoneedle were used to obtain representative SI values. Within the frozen tissue, MR signal can still be appreciated, with intensity decreasing towards the center of the iceball. In the last image, acquired at the end of the first freezing phase, the MR temperature map calculated using the curve fit is overlaid.