3D UTE MR thermometry of frozen tissue during cryoablation: clinical feasibility at 3T

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Purpose MR-guided cryoablation is a promising minimally invasive therapy for localized prostate cancer[1,2]. Effective treatment relies on achieving a sufficiently low end temperature of -40°C throughout the target area[3]. Temperature feedback during such procedures is therefore desirable. Invasive temperature probes only yield temperature measurements at discrete locations and pose issues with MR-compatibility. A non-invasive approach is still needed. Recent studies have demonstrated measurable MR signal from frozen tissue using ultrashort echo time (UTE) imaging at 0.5T[4,5]. This study investigates the clinical feasibility of 3D UTE MR thermometry of frozen tissue during cryoablation at 3T.

Methods An MR-compatible cryoneedle (IceRod, Galil Medical) was inserted into an ex-vivo porcine muscle specimen at room temperature in a 3T clinical MR system (Magnetom Trio, Siemens). Three fiberoptic temperature sensors (T1, Neoptix) were placed at one side parallel to the cryoneedle at lateral distances of 0.5, 1.0 and 1.5cm. Two cycles of 10:3 min. freeze-thaw were applied. Continuous MR imaging covering the entire iceball was performed using a 3D radial ramp-sampled UTE sequence (TR/TE/FA = 59.5ms/70µs/15°, voxel size = 1.63x1.63 x1.63mm, acq. time = 1.14min). For each temperature sensor, signal intensity (SI) values during the experiment were recorded for three voxels at the same radial distance from the cryoneedle. SI was normalized to its baseline value before cooling and related to temperature. All data points in the subzero temperature range were fitted by an exponential function. Using the fit as a calibration curve, 3D MR temperature maps of the frozen tissue could be derived from the UTE data at each imaging time point.

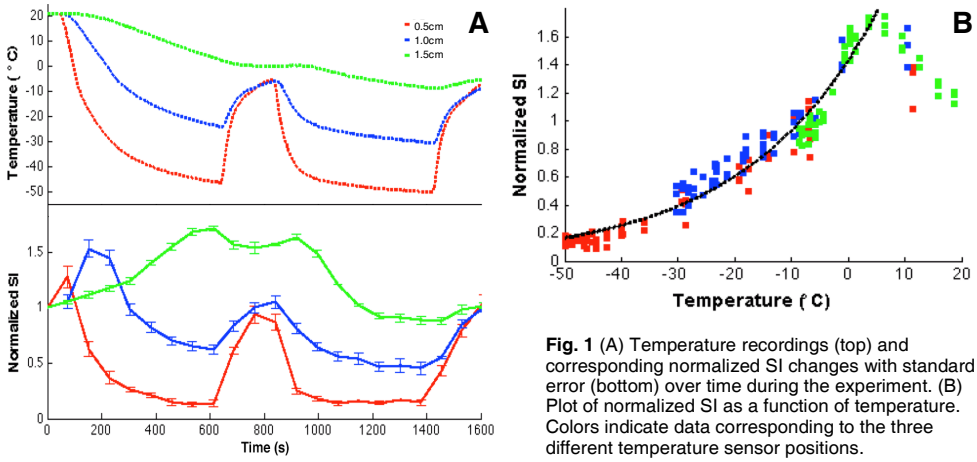

Fig. 1 (A) Temperature recordings (top) and corresponding normalized SI changes with standard error (bottom) over time during the experiment. (B) Plot of normalized SI as a function of temperature. Colors indicate data corresponding to the three different temperature sensor positions.

Results Temperature readings during the experiment strongly correlated with corresponding normalized SI changes over time (fig.1A). After an initial T1-related signal increase at cooled but non-freezing temperatures[6], normalized SI decreased mono-exponentially with temperature in the freezing range, with the signal decay fitted by normalized SI = $1.43e^{0.04T}$ (R^2=0.94) (fig. 1B). UTE images at different time points during the experiment showed the MR signal distribution within the frozen tissue over time and demonstrated signal changes during different phases of cryoablation (fig. 2A). MR-derived temperature maps visualized the spatial temperature distribution within the frozen tissue in 3D, shown here in axial and coronal view at the end of the second freeze cycle (fig 2B). A reference T1-weighted VIBE image (TR/TE/FA = 6.0/2.0ms/6°) showing total ice extent is shown for comparison with full window setting, illustrating the necessity for ultrashort TE imaging to obtain measurable MR signal from frozen tissue inside the iceball (fig. 2C).

Discussion Our study is the first to explore the feasibility of 3D MR thermometry of frozen tissue during cryoablation on a clinical MR system at 3T. We demonstrated 3D UTE imaging to achieve measurable MR signal from frozen tissue down to temperatures as low as -40°C within a clinically realistic time-frame (~1min.) and with clinically sufficient spatial resolution (1.63mm isotropic). Using a calibration curve, normalized SI of the UTE images allowed the 3D estimation of temperatures induced inside the iceball over time during cryoablation. Limitations of this work were that only a single experiment is presented, our feasibility study did not include T1/T2* quantitation and an independent validation of the MR-predicted temperature maps was not available as recorded temperature data was used as input to obtain the curve fit.

Conclusion 3D MR thermometry of frozen tissue using UTE signal intensity at 3T is clinically feasible. Further work into the accuracy and consistency of this approach is required. In vivo application of this technique could allow interventionalists essential feedback on the effective treatment zone during MR-guided cryoablation procedures, however a robust calibration method will be needed.

References (1) Bomers et al. Radiology 2013. (2) Woodrum et al. Urology 2013. (3) Gage et al. Cryobiology 1998. (4) Wansapura et al. Acad Radiol 2005. (5) Kaye et al. JMRI 2010. (6) Overduin et al. Med Phys 2014.

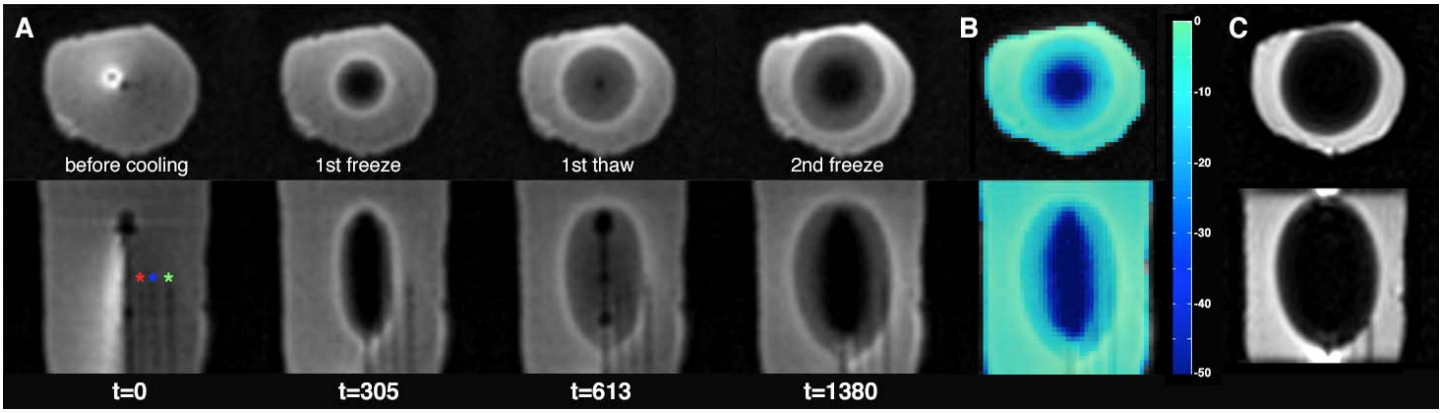

Fig. 2 (A) Axial (top) and reformatted coronal (bottom) UTE images at 0, 305, 613 and 1380s into the experiment with sensor locations overlaid (*) and colors corresponding with the data in Fig.1. (B) MR-derived temperature maps of the last images shown in A. Note that estimated temperatures are only accurate for the frozen zone, as the calibration curve applies to temperatures <0°C. (C) Reference T1w VIBE image for comparison.