Investigation of temperature dependent phase shift in frozen tissues during cryoablation

A. Lu[1], B. L. Daniel[1], and K. Butts Pauly[1]
[1]Department of Radiology, Stanford University, Stanford, CA, United States

INTRODUCTION

MR-guided cryoablation is a promising minimally invasive treatment for localized prostate cancer[1]. For an effective treatment, temperature sensitive probes are often used clinically to ensure tumor destruction at a sufficiently low temperature while avoiding damaging vital organs[2,3]. However, placing these probes is time-consuming and invasive and they only provide information at limited discrete locations. Therefore mapping tissue temperature throughout the frozen region is desirable. While previous work has focused on relating the MR parameters R2* and relative signal intensity to temperature[4], our recent *in vivo* and *ex vivo* experiments demonstrate that there is also a temperature dependent phase shift within the frozen tissue that is significantly larger than the proton resonant frequency shift (PRF) effect[5,6]. The purpose of this work was to characterize this phase change with temperature and to investigate the possibility of using it as a novel temperature index.

MATERIALS AND METHODS

In-vivo canine experiments were approved by our institutional animal care and use committee and were performed on a 0.5T GE Signa scanner (GE healthcare, Milwaukee, WI). A two-element phased array coil and an ultra short TE sequence was used to obtain signal from the frozen tissue[7]. Two cryoprobes were inserted into the prostate with MR guidance, each close to a thermal probe placed medially in the prostate. One side of the prostate was frozen once and the other side twice. Images were acquired in coronal plane with TR/slice thickness/ resolution = 14 ms / 7 mm / 1.25 mm. Two sets of data were acquired with TE1 = 0.1 ms and TE2 = 0.7 ms in an interleaved fashion.

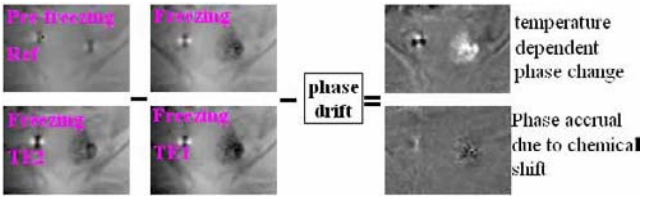

Fig. 1 Diagram showing the calculations of phase variations related to temperature and phase accumulation due to TE difference.

As illustrated in Fig. 1, phase variation images were obtained by subtracting the phase images acquired during freezing from the pre-freezing reference phase image (upper row). A phase drift correction was applied, as is commonly done for monitoring PRF changes during a thermal therapy. To demonstrate the contribution of PRF shift to the observed phase, the frequency shift was calculated from the images acquired sequentially (little temperature change) at the two TEs (lower row). A time series of phase variations were plotted then along with the readouts from a nearby thermal probe to demonstrate their temperature dependence.

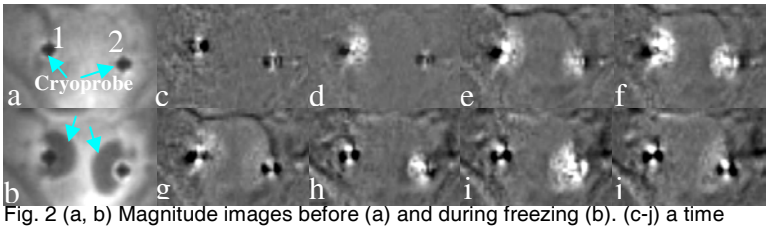

Fig. 2 (a, b) Magnitude images before (a) and during freezing (b). (c-j) a time series of temperature dependent phase variation images. Higher intensities are observed within the frozen region.

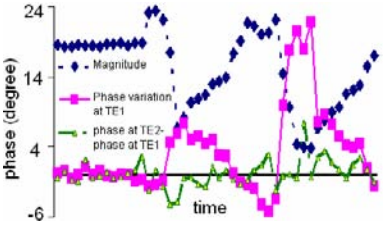

Fig 3. Time series of magnitudes, phase variations at TE1 and phase accruals due to chemical shift in the same ROI. The vertical label is for phase only.

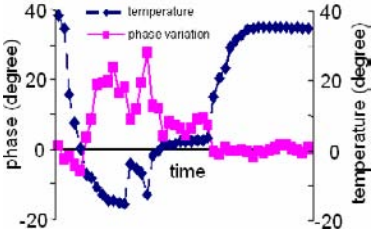

Fig 4. Time series of phase and temperature variations show a nice correlation.

RESULTS AND DISCUSSION

Fig. 2a and b are magnitude images acquired before and during freezing showing the cryoprobe positions and the iceballs formed (arrows). Fig. 2c-j show a time series of phase variation images. Phase variations are well localized within the frozen tissue and are clearly visualized with elevated intensities, which means the phase of the signal decreases at lower temperatures.

In Fig. 3, the solid curve shows a time series of phase variations with respect to the reference, while the dot-dashed curve shows the corresponding phase accrued between TE1 and TE2 in a ROI near cryoprobe 2. The solid line clearly shows two peaks that correlate to the two freezing-thawing cycles indicated by the signal intensity plot (dotted curve). However, no such pattern is seen in the frequency shift (dot-dashed) curve. Hence PRF shift has little effect on the observed phase variation, as is expected due to the ultra short TEs used. Phase variations in a region near cryoprobe 1 are plotted along with reference temperatures measured from a nearby thermal probe in Fig. 4. The phase shift tracks the temperature changes at subzero temperatures and varies very little at normal body temperature.

Phase shift independent of TEs have been demonstrated as a result of changes in tissue conductivity and dielectric properties with temperature[8]. However, the results shown here have an opposite phase-temperature relationship. In addition, the effect here is seen within a relative small frozen region, while a large heating region was necessary to demonstrate the phase offset variation in ref. 8.

CONCLUSIONS

We have demonstrated a significant temperature dependent phase shift in our *in vivo* cryoablation experiments that is independent of the short TEs used. The phase shift is well localized to the frozen region and its magnitude increases with lowering tissue temperature, which makes it a promising parameter for temperature mapping during cryoablation.

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