Improvements in R2* Mapping During In Vivo Cryoablation

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INTRODUCTION

MR-guided cryoablation is a promising minimally invasive therapy for prostate tumors that are soliatary and unilateral.[1] Studies have shown that cryoablation is most effective when sufficiently cold temperatures are reached throughout the tumor,[2-5] and the most effective treatments have used a number of implanted thermocouples to ensure this condition is met.[3] Temperature mapping within the frozen tissue with MRI would be preferable as it would provide maps throughout the frozen area, not just at discrete thermocouple locations. Tissue R2* is a particularly promising MR parameter to quantify and relate to temperature as it appears to be relatively linear over the temperature range of interest and need not be related to initial conditions, as is necessary with the signal intensity measurement.[6] Unfortunately, mapping of R2* in vivo has been sensitive to eddy currents. The purpose of this work was optimize our R2* mapping by using a PR sequence, reducing the earliest echo time to 0.1 ms, and carefully measuring and compensating for eddy currents. We then demonstrate *in vivo* R2* mapping in the canine prostate during cryoablation.

MATERIALS AND METHODS

The pulse sequence used is shown in Fig. 1. Half-RF pulse excitation is employed to achieve an ultra-short echo time of 0.1 ms. Both B0 and linear eddy currents induced by an ideal selective gradient are measured first. Linear eddy currents are then corrected by pre-compensating the RF pulse accordingly; in addition, selective gradient is compensated to cancel long time constant eddy currents. B0 eddy currents are corrected by varying the RF phase during excitation. A multiple-echo PR readout is used for data acquisition. Starting immediately after the RF pulse, four echoes are acquired in each TR.

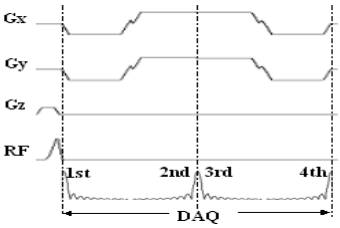


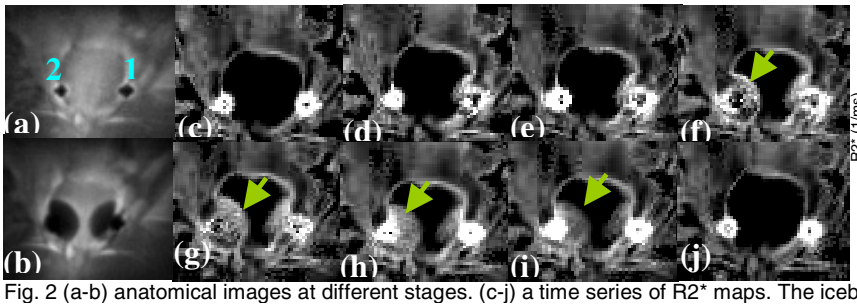
Fig. 1 Multiple-echo PR sequence. Four radial lines are acquired in each TR as noted.

To calculate the R2*, four sets of data are acquired with TEs of 0.1 ms, 0.4 ms, 0.7 ms and 1.0 ms for the first echo. These relatively short TE intervals are designed to accurately quantify short T2*, and later echoes are needed for better calculation of R2* for tissues with longer T2*, especially those surrounding the ice ball. The first echo and the third echo are both acquired with "center-out" radial line in k-space and have similar point-spread-function (PSF) for a given T2*. Moreover, the definition of TE interval between them is straightforward. Therefore, a simple algorithm is developed to employ only the first echo to qualify tissues with large R2*, while the third echo is also included to calculate smaller R2*. R2* is obtained on a pixel-by-pixel basis using a non-linear least square fitting algorithm.

In-vivo experiments were approved by our institutional animal care and use committee and were performed on a 0.5T GE Signa open scanner (GE healthcare, Milwaukee, WI). Two cryo probes were inserted into the prostate with MR guidance (Fig. 2a) with temperature probes placed medially in the prostate. Images were taken in coronal plane, acquisition parameters include BW/TR/TE1/TE3 = 31.25 KHz) /14 ms/0.1 ms/5.0 ms (TE1 and TE3 vary for R2* mapping), slice thickness = 7mm, FOV = 32cm, and resolution = 1.25mm. During the experiment, probe 1 first froze to ~ –2°C and was then turned off, while probe 2 started freezing quickly to ~26 °C near the end of the first probe's freezing process. Both probes reached their lowest temperature in the experiment at about the same time. Probe 2 then started thawing. After the temperature went back to normal, it was frozen again. The experiment then completed at the end of second thaw on probe 2.

RESULTS AND DISCUSSION

Fig. 2a and b are anatomical images reconstructed from the first echo, acquired shortly after probe 1 started freezing and at both probes at low temperatures, respectively. High signal is measured in the frozen tissue owing to the ultra-short TEs. Fig. 2c-j are a time series of R2* maps throughout the experiment. The positions of both probes and the iceball are well depicted in all R2* images. Fig. 2c and 2g are the corresponding R2* maps for Fig. 2a and 2b, respectively. Fig 2c-2d were acquired when probe 2 has relatively high temperature, while probe 1 was slowly freezing. From Fig. 2e-i, probe 2 temperature increase from ~-20 °C to 0.2 °C, a nearly linear decrease in R2* values is observed (arrows). Fig 2j was acquired at the end of the experiment with temperature near both probes back to normal, therefore no R2* elevation is seen as expected. The R2* at the location of the thermocouple demonstrates a linear relationship with temperature as shown in Fig. 2k.



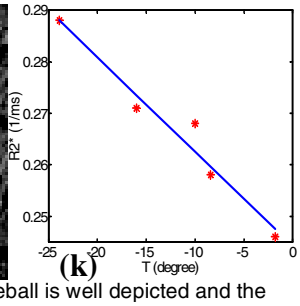


Fig. 2 (a-b) anatomical images at different stages. (c-j) a time series of R2* maps. The iceball is well depicted and the positions of the probes well defined in all images. The decrease in of R2* intensity with increase in temperature is clearly seen (arrows in f-i). (k) R2* measured near probe 2 suggests a linear relationship with temperature.

CONCLUSIONS

With effective compensation for both B0 and linear eddy current for half-RF pulse excitation and a multiple-echo readout, R2* maps with improved quality have been obtained throughout the whole frozen process. The proposed technique has been shown to be a very promising approach for temperature monitoring during cryosurgery. Future work will improve the protocol by interleaving the acquisitions and further optimization of acquisition parameters.

REFERENCE

1. ONIK G, TECHNOL CANCER RES TREAT 2004; 3:P.365 2. BAUST J, CRYOBIOLOGY 1997; 34: P373. 3. WONG WS, CANCER 1997; 79: P.963. 4. GAGE AA, CRYOBIOLOGY 1998; 37: P.171. 5. LARSON TR, UROLOGY 2000; 55: P.547. 6. WANSAPURA J, ACAD RADIOLOGY; 12: P1080.

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