V-09
MRI guided cryoablation: in vivo assessment of measuring temperature adjacent to ablated tissue using the PRF method

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Objective

Cryoablation is a promising minimally invasive therapy to effectively destroy localized tumors on an outpatient basis. MRI guidance is well suited for both accurate placement of the cryoablation needle into the target tissue and online monitoring of the iceball growth, such that the tumor is completely treated and adjacent structures are not damaged. In addition, there has been recent research on measuring temperature within the iceball using ultra-short echo times and R2* mapping [1, 2]. The purpose of this work is to investigate in vivo the use of the proton resonance frequency (PRF) shift method [3] for measuring temperature in close proximity to the region being ablated. The presented cryoablation workflow is fully MR-guided using specially designed multiplanar real-time sequences and an intuitive tool for accurately visualizing the progress of thermal treatment at the time of the procedure.

Materials and Methods

In vivo pig experiments were approved by the institutional animal care and use committee and were performed on a 1.5T Siemens Magnetom Espree scanner (Siemens Healthcare, Erlangen, Germany). Three pigs were pre-anesthetized, intubated, maintained on isoflurane, and positioned head-first, supine in the scanner. A 6-element body matrix coil was used for signal reception. Cryoablation was performed using an MRI-compatible cryotherapy

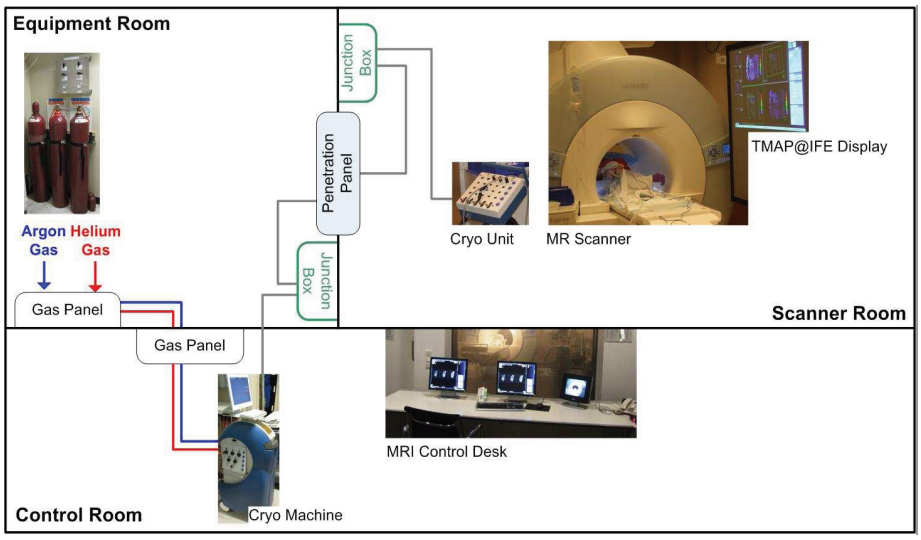


Figure 1. System setup visualizing the flow of argon gas for freezing and helium gas for active thawing. The flow of gas is handled at the cryo machine in the control room and the cryoablation needles are connected to the cryo unit inside the scanner room. The display of the developed thermal therapy monitoring and guidance system, called TMAP@IFE, is projected onto a screen next to the MR scanner.

system (GalilMedical, Yokneam, Israel) which uses argon gas for freezing and helium for thawing (see Fig. 1).

Both cryoablation needle placement and treatment monitoring were performed in the MR scanner as illustrated in Figure 2. As the iceball size is strongly dependent on the number of cryoablation needles used and the distance between them, we used one 17-gauge cryoablation needle (IceRod®, GalilMedical) in one pig and two in the other two pigs. We further inserted a fiber optic temperature probe (Neoptix, Québec, Canada) into the kidney for ground truth temperature measurement. The needles were placed through the lateral abdominal wall into the kidney using a custom real-time interactive Turbo FLASH sequence (BEAT_iRTTT, TE = 2.65msec, TR = 832msec, resolution = 2.3 x 2.3 x 10mm, flip angle = 20°), coupled to IFE, an interactive multiplanar navigation software [4]. Ice formation during the two freeze-thaw cycles (15-5-10-5 minutes) was monitored every minute under breathhold conditions using a multislice PRF gradient echo sequence (TE = 5msec , TR = 51msec, resolution = 2.3 x 2.3 x 5 mm, flip angle = 25°). Three parallel scan planes were placed perpendicular to the cryoablation needle at distances of 1, 2 and 3 cm from the needle tip (see Fig. 3). For advanced visualization of the progress of thermal treatment, we used

TMAP@IFE, a custom-built thermal therapy guidance application [5], built on the IFE framework and fully integrated into the standard scanner network. The TMAP@IFE was displayed in the MR control room and also duplicated to a projection screen in the scanner room (see Fig. 1). Post-ablation imaging was performed when the kidney returned to body temperature after the end of the second freeze-thaw cycle.

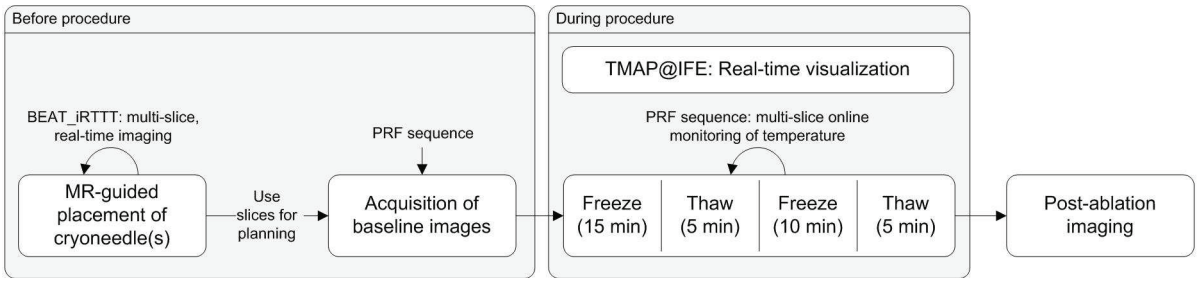


Figure 2. MR-guided cryoablation workflow covering both cryoablation needle placement and treatment monitoring. The cryoablation needle(s) and the fiber optic temperature probe were interactively placed using the BEAT_iRTTT sequence, a specially designed multiplanar real-time Turbo FLASH sequence. For online temperature monitoring of the two freeze-thaw cycles a custom PRF gradient echo sequence was used. The acquired images were sent via TCP/IP socket connection to our thermal therapy guidance framework (TMAP@IFE) for advanced real-time visualization of the ablation progress.

Results

Temperature sensitivity for PRF is maximized when TE = T2* for a given tissue. However, needle artifacts increase with increasing TE. For the 17-gauge cryoablation probe, it was observed that the resulting needle artifact from PRF imaging with TE = 20msec nearly covered the entire iceball (see Fig. 3 and 4). Therefore, TE = 5msec was chosen to allow for monitoring of the iceball growth.

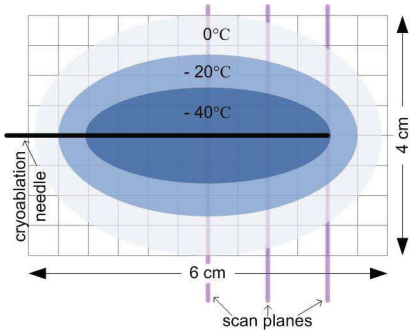


Figure 3. Expected iceball size and placement of scan planes.

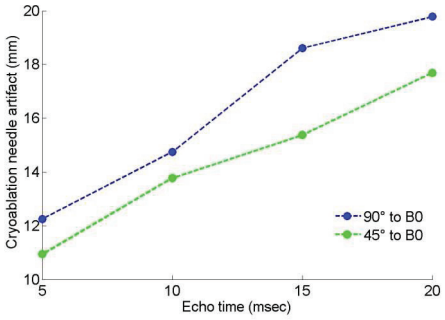


Figure 4. Cryoablation needle artifact (mean diameter in mm) for different TEs at 45° and 90° with respect to B0.

As shown in Figures 5 and 6, we could successfully measure the temperature in close proximity to the iceball giving an indication if nearby critical structures are harmed. In addition, we could verify by the temperature probe that the temperature around the iceball increases very fast during active thawing. In about two minutes the temperature was back to body temperature. As expected, the iceball size is strongly dependent on how close to each other the cryoablation needles are placed (compare Fig. 5 and 7). In addition, an increasing iceball size results in an increasing susceptibility artifact which strongly influences the PRF method. The artifact is most pronounced perpendicular to the external magnetic field B0 (see Fig. 7). Methods to efficiently calculate phase changes from estimated susceptibility distributions have been proposed [6, 7]. However, these methods need further validation for accurately determining temperatures within the iceball-induced susceptibility artifact.

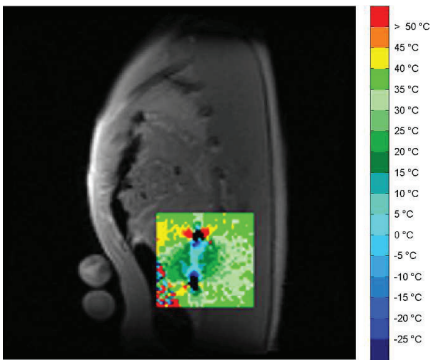


Figure 5. A cross-sectional PRF magnitude image of two cryoablation needles placed 4.2cm from each other with the corresponding phase-derived temperature map overlaid. Temperature measurements between the two probes show a smooth freezing profile.

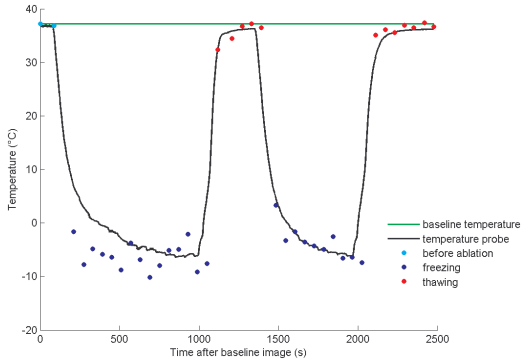
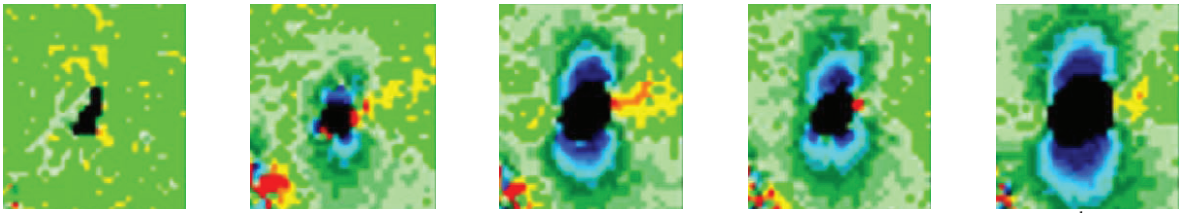


Figure 6. Temperature over time at a voxel close to iceball border. Both the PRF method and the temperature probe show that the temperature drops very fast but also rises rapidly during active thawing.



before ablation | 10min of freezing 17 x 18 mm | after 1st freezing 26 x 22 mm | after 1st thawing 21 x 17 mm | after 2nd freezing 31 x 27 mm

Figure 7. The progression iceball growth through two freeze-thaw cycles for two cryoablation needles separated by 1.3cm in a pig kidney. The susceptibility artifact induced by the iceball was most pronounced perpendicular to B0 and increased with increasing iceball size (given in second line for each image). The cryoneedle artifact in the left figure is colored black as well as the iceball in the other four figures. The temperature scale is the same as in Figure 5.

Conclusion

This study demonstrates the feasibility of accurate temperature measurements using the PRF method in close proximity to the iceball. However, the susceptibility artifact induced by the iceball needs to be considered for large iceball sizes. Using the PRF method for online thermometry might reduce the need for placing additional, invasive temperature probes which can be time consuming and difficult.

References

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