A fast phase-correction algorithm for improved real-time PRF shift thermometry

R. J. Stafford[1], R. J. McNichols[2], A. Gowda[2], and J. D. Hazle[1]
[1]Imaging Physics, The University of Texas M. D. Anderson Cancer Center, Houston, TX, United States, [2]BioTex, Inc., Houston, TX, United States

Introduction

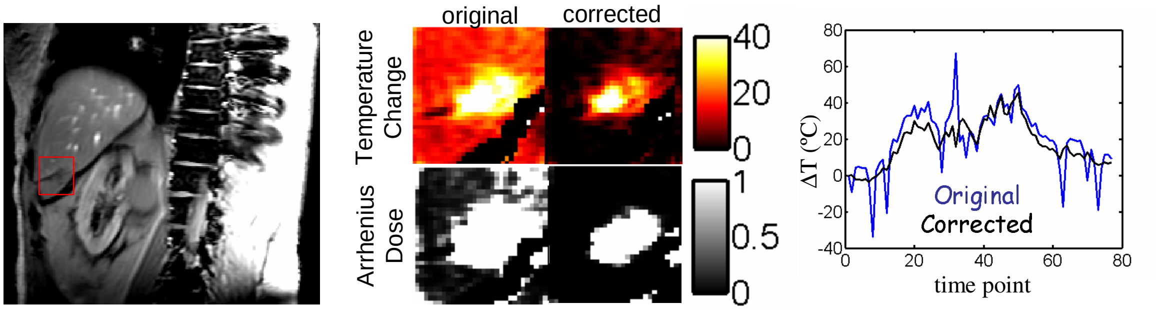
Minimally-invasive thermal therapies are an emerging therapy for the treatment of a variety of cancers. Proton resonance frequency (PRF) shift MR temperature imaging (MRTI) can be used to qualitatively or quantitatively monitor the progress of these treatments in real-time thereby potentially enhancing both the safety and efficacy of these therapies [1]. However, PRF based MRTI relies on phase-subtraction techniques and is thus highly susceptible to motion artifacts, such as those caused by respiratory motion in liver treatments or swelling in prostate treatments, which both obscure the ability to visualize the treatment area and add substantial error to quantitatively estimating the extent of damage [2]. Correction of motion artifact for the PRF consists of two interleaved problems. When possible, the treatment regions need to be registered for subtraction as well as for monitoring cumulative exposure during therapy. Since this registration does not compensate for the induced distortions in the background field, the background phase must also be corrected to avoid phase errors. In this work, we investigate the latter problem of phase correction and propose a simple algorithm for reducing the errors due to changes in the background phase in real-time. We test the method during laser ablation in canine prostate, canine vertebral bodies, canine brain, and human liver.

Materials

All imaging described in this study was performed on 1.5T whole body MR scanners (Signa and Excite HD platforms, GEHT, Waukesha, WI). All animals and human subject studies were conducted in accordance with the local independent review panels for ethical execution of these studies. All MR-guided laser ablation procedures in humans, animals and phantoms were performed using 980-nm cooled catheter diode laser system (Visualase®, BioTex, Inc, Houston, TX) with MRTI feedback to monitor and control therapy delivery. Generally single-plane fast spoiled-gradient echo imaging or multi-planar, fat suppressed, multi-shot interleaved EPI techniques were used for acquisition. The real-time phase-correction algorithm works by providing a loco-regional linear phase correction to each image followed by second constant background/drift correction calculated by phase-histogram correlation. Unlike the "referenceless" PRF technique [3], it does still rely on phase-subtraction to calculate temperature. First the user selects a region of interest encompassing the treatment zone as well as unaffected tissue. For each acquired image, a linear phase-correction is calculated by calculating the center of mass in k-space. After applying the linear correction, a background phase-correction is calculated using a weighted sum of the complex data. These phase corrections are applied to the phase images prior to subtraction to minimize the effects of changes in the background phase on the PRF MRTI. After complex phase subtraction of the linear-phase corrected images, a further refinement is made using another simple background correction obtained by histogram correlation. The histogram of the first subtraction is calculated then shifted to zero. Cross-correlation of this histogram with subsequent histograms is performed and the location of the maximum used to correct the background phase in the subtracted images. Changes in background noise, conspicuity of lesions against the background and estimated lesion size versus imaging correlates (when available) were evaluated for treatment of human liver (n=3), canine prostate (n=4), canine vertebral body (n=4) and canine brain (n=4). The brain was to evaluate the case of no motion, but potential drift.

Results

In general, the full phase-correction algorithm decreased noise in the surrounding image by 5%-50% depending on the extent of motion. Additionally the algorithm generally increased the correlation between estimated Arrhenius integral dose estimates and post-therapy imaging correlates. In the case of the brain, the extent of damage didn't change significantly. Human liver showed a large range of results from the inferior aspect of the liver (Figure 1) to the large motion in the dome. In the case of large motion, such as the dome, the algorithm suppresses noise and increased correlation between dose and imaging correlates, but to a lesser degree than seen in other areas of the liver, prostate, verterbral bodies and brain. To make the technique more effective in such cases, image registration would need to be employed to further refine the results in the subtracted images as well as the integral dose.



(a) (b) (c)

Figure 1: Results during MR-guided ablation of colorectal metastases in human liver: (a) Magnitude MRTI image demonstrates the region in the edge of the inferior aspect of the liver containing the laser fiber. (b) Temperature maps (top) and resulting Arrhenius integral dose estimates (bottom) demonstrate the effectiveness of the proposed technique. Note the increased conspicuity of the treatment region in the corrected images. Without correction, the Arrhenius dosimetry overestimated the lesion size by 145.5% with respect to contrast-enhanced perfusion imaging of the treatment area. The histogram-correlation correction for background (not shown) overestimated the lesion by only 59.0%. The linear-phase correction algorithm (not shown) overestimated by 21.6%. The combination of the linear-phase algorithm with histogram-correlation correction (shown) resulted in an overestimation of only 2.3%. This enhancement is for phase correction only, no image-registration was performed to further enhance the degree of correlation. (c) A plot of the temperature change versus time point is shown for the corrected and uncorrected images in the border of the lesion demonstrating how the phase-correction helps remove the large phase jumps due to respiratory induced phase-errors during the delivery of therapy.

Conclusions

A technique is presented to correct the phase in PRF thermometry that can be applied in real-time and substantially increases the quality of both the resulting temperature map and thermal dose estimate. By using a large region of interest which does include the treatment zone, processing time is kept to a minimum and phase-correction results are loco-regional. Work needs to be done to better characterize this filter and analyze the effects of region of interest selection as well as looking at the impact of integrating image-registration to better tolerate larger scale motion, especially to handle the dome of the liver. Multi-planar techniques and registration in conjunction with this technique will be investigated to observe effects on errors due to through plane motion.

Acknowledgements

Dr. Paul Legmann, Hopital Cochin, Université Paris for work on ablative studies in human liver and Kamran Ahrar, MD for studies in canine vertebral bodies.

References

[1] Hindman C, J. Chem. Phys. 44:4582-92 (1966).; [2] Ishihara Y., et al, MRM **34**:814-823 (1995); [3] Rieke V, et al, ISMRM (2003).