Real Time Respiration Based Steering for High Intensity Focused Ultrasound in the Liver

A. B. Holbrook[1,2], C. L. Dumoulin[3], J. M. Santos[4], Y. Medan[5], and K. Butts Pauly[1]
[1]Radiology, Stanford University, Stanford, CA, United States, [2]Bioengineering, Stanford University, Stanford, CA, United States, [3]University Cincinnati College of Medicine, Imaging Research Center, Cincinnati, OH, United States, [4]HeartVista, Palo Alto, CA, United States, [5]InSightec, Tirat Carmel, Israel

Introduction

High Intensity Focused Ultrasound (HIFU) treatment of the liver during free breathing requires maintenance of the ultrasound focus on the desired target. This requires tracking both the liver and the transducer, whose motions are quite different. Several real time approaches have been presented to tracking of the liver or its vessels in real time [1,2]. We propose a model-based method utilizing a respiratory belt to provide the respiratory position, which is used to find the target and transducer positions from a lookup table acquired before treatment. A respiratory belt provides higher temporal sampling than image based strategies, allowing for decreased latency and potentially more accurate steering. The purpose of this work was to quantitate steering accuracy with the respiratory belt model-based approach.

Methods

An extracorporeal phased array transducer (ExAblate Conformal Bone System, InSightec, Ltd, Tirat Carmel, Israel) was placed below a phantom in a water bath inside a 3T scanner (GE Excite, GE Healthcare, Waukesha WI). A servo-motor moved the phantom in a 2.5-3 cm pk-to-pk sinusoidal motion, while, in this case, the transducer remained fixed. A respiratory belt was attached to the motor to provide the simulated motion.

Using a custom built Application Specific Interface for RTHawk [4] (HeartVista, Inc, Palo Alto, CA), the following work flow was performed. First, a collection of SSFP images was obtained prior to heating. The phantom/air edge of the phantom was marked as the diaphragm and tracked [3] through the simulated respiratory cycle. The transducer position was measured from the built in tracking coils. Once the target location was selected, the lookup table for the appropriate transducer phase pattern for beam steering as a function of the respiratory belt data was determined.

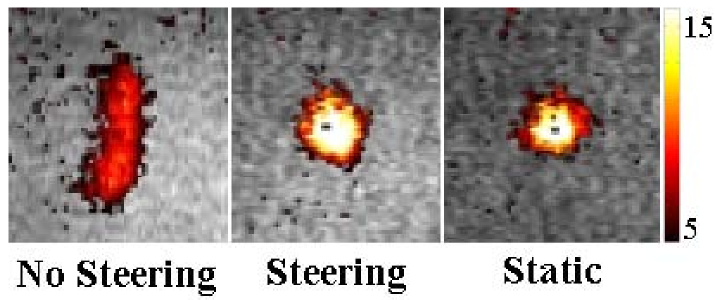

Figure 1. Representative thermal ablations without steering (top), with steering (middle) and with no motion (bottom). Motion is primarily along the vertical direction.

Single shot spin echo EPI MR Acoustic Radiation Force Imaging (TE = 74.5ms, TR > 3000ms (gated)) was performed at each phase location of the phantom's simulated respiratory cycle to calibrate the system and fix imperfections in the tracking system. After calibration, thermal baselines were collected with the real-time reduced FOV RS-EPI sequence (TE = 15.9ms, TR = 117ms) and HIFU ablation proceeded using a hybrid multibaseline/referenceless technique to reconstruct thermometry images. Ablations were performed with and without steering and compared to stationary ablations. Each ablation lasted for 55 seconds at 150 acoustic watts.

Results

Figure 1 shows a comparison of the temperature images in the phantom after each respective HIFU ablation. The targeted, steered ablation has a higher temperature rise than the non-steered ablation with a much tighter thermal profile. Table 1 highlights a few of the properties of each hotspot. The size of the temperature spot is significantly reduced along the motion direction with the respiratory steering, approaching that of the static spot. Despite this, the maximum temperature is still less. Numerous factors could explain this discrepancy, including remaining tracking error, power differences between ablations, some out of slice motion by the phantom during motion, and motion blurring of the moving lesion.

	No Steering (n=5)	Steering (n=6)	Static (n=5)
Extent of Sonication in Motion Direction (cm)	2.87 +/- 0.31	1.53 +/- 0.19	1.47 +/- 0.22
Extent of Sonication in Stationary Direction (cm)	1.44 +/- 0.43	1.42 +/- 0.09	1.35 +/- 0.24
Max Temperature (ºC)	12.7 +/- 2.99	22.5 +/- 3.0	27.0 +/- 2.25

Table 1. Thermal lesion characteristics of each sonication type. Values are the mean +/- the standard deviation. Measurements were determined from the part of the lesion greater than 5 ℃ above baseline.

Discussion

We have demonstrated the ability to steer a HIFU sonication based on the respiratory belt information and motion of an artificial diaphragm collected prior to a thermal ablation. Future work will verify this functions in vivo with both diaphragm and vessel fiducials. By disconnecting respiratory tracking from imaging, the system latency is decreased to the current sampling rate (currently 40Hz). By separating tracking from thermometry, more complex thermometry can be performed, such as scanning multiple slices without concern of tracking latency.

Acknowledgements: We acknowledge support from Alex Kavushansky, Tanya Zelikman, and Omer Brokman at InSightec for technical support and grant funding from NIH: RO1 CA121163, P41RR09784.

References: **1.** de Senneville et al. MRM 2007; 57(2): 319-330. **2.** Takao et al. 8th Interventional MRI Symposium; 2010. 233-235. **3.** Hormuth et al. ISMRM 18th Scientific Meeting, 2010. 4121 **4.** Santos et al. Conf Proc IEEE Eng Med Biol Soc 2004; 2: 1048-1051.