Tissue acoustic properties using MRI temperature measurements of low powered ultrasound heating pulse.

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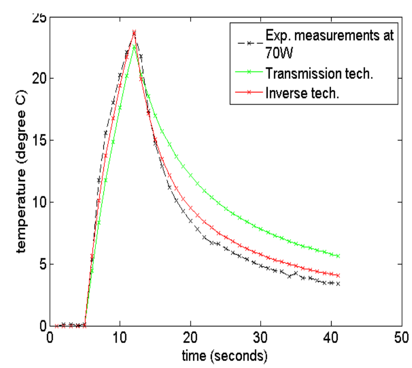
INTRODUCTION: MR guided focused ultrasound surgery causes selective tissue necrosis using a focused ultrasound beam. Reflection, refraction and absorption of the ultrasound beam in the complex inhomogeneous tissue environment of the body leads to shifting and distortion of the beam focus. Beam simulation software that uses ultrasound tissue property values for different tissue types can be used to predict and control for these aberrations. The most recent and comprehensive review of the ultrasound tissue property values reported in literature found different measurement techniques, tissue preparations used by different investigators led to a large variation in the properties reported[1] (a four-fold variation is seen in reported values of liver ultrasound absorption coefficient at 1 MHz). The use of ex-vivo tissue samples and invasive thermocouples measurements make these values at best an estimate of the average ultrasound tissue properties. In this paper we present an inverse parameter estimation technique that non-invasively determines ultrasound tissue properties (speed of sound, attenuation) using MRI temperature maps using low level ultrasound heating and MRI temperature monitoring. These tissue properties can then be used to predict and control the shape and location of the ultrasound beam in the inhomogeneous media resulting in accurate patient-specific treatment plans for MRgFUS treatments.

METHODS: *Theory:* It has been shown theoretically and experimentally that the SAR (specific absorption ratio) information can be obtained from the rate of temperature increase (before thermal conduction or perfusion effects become significant) following a step change in applied power[2]. Using an iterative parameter estimation technique that minimizes the difference between the experimentally determined SAR distribution (using MRI temperature maps) and the SAR distribution predicted using beam propagation technique (using table estimates of ultrasound tissue properties) results in the final ultrasound tissue properties (speed of sound, absorption coefficient) of tissue. The beam simulation software developed in our group called the hybrid angular spectrum method[3] (HAS) is able to predict SAR distribution in inhomogeneous media accurately and results in more than three orders of magnitude decrease in calculation time compared to the well established and frequently used finite difference time domain technique. The speed of the HAS beam simulation technique (each run in a 201x201x201 model takes 4 seconds) makes it well suited for an iterative parameter estimation technique where frequent calls to the forward solution require the forward solution to be fast. *Experiment:* . All experiments were performed in an MRgHIFU system consisting of a Siemens TIM Trio 3T scanner, a 256-element phased-array HIFU transducer (Imasonics, inc), and hardware and software for beam steering and data visualization (Image Guided Therapy). HIFU heating was performed on an agar phantom and monitored with a 2D gradient echo sequence with parameters: TR/TE = 65/9 ms, 128x64x5 imaging matrix, 2x2x3mm spatial resolution (3mm slice thickness) and 4.2 sec temporal resolution. A homogeneous tissue mimicking agar phantom material was made with unknown ultrasound properties and poured into two containers. SAR maps in the phantom were experimentally determined using MRI to find the initial rise in temperature observed when heating the geometric focal zone of the phantom at different power levels (that resulted in different temperature rises) for 30 seconds.

Ultrasound tissue properties using transmission-substitution technique		
	Speed of sound (m/s)	Attenuation (Np/m/MHz)
	1.517e3	0.056
Ultrasound tissue properties using parameter estimation technique		
Power (Watts)	Speed of sound (m/s)	Attenuation (Np/m/MHz)
30	1.6565e3	0.050
40	1.6554e3	0.049
50	1.7081e3	0.052
60	1.6533e3	0.051
Average	1.655e3	0.051

RESULTS: The tissue ultrasound properties determined using the iterative parameter estimation technique using the HAS beam propagation technique as the forward model were compared to independent measurements made using the through transmission-substitution technique given in table 1. The ultrasound tissue properties given by the two methods (average values from parameter estimation) were used to predict the temperature rise in the model using the Penne's Bioheat equation and compared to the temperature rise experimentally seen in the phantom for an ultrasound heating pulse at 70 W for 30 seconds in the phantom. The inverse parameter estimation technique was run on a 4GB windows laptop using MATLAB version 7.8 optimization toolbox and took about two minutes to converge for each power level.



DISCUSSION: The inverse parameter estimation technique using MRI temperature maps results in accurate ultrasound tissue property values (within 10%). This technique can be used with very lowered ultrasound heating pulses, is non-invasive and can be extended to inhomogeneous tissue geometries.

[1]S. A. Goss, R. L. Johnston, and F. Dunn, "Comprehensive compilation of empirical..," [2]Roemer RB, Fletcher AM, and Cetas TC, "Obtaining local SAR and blood perfusion data from temperature measurements…" [3]Urvi Vyas and Douglas Christensen, "Ultrasound beam propagation using the hybrid angular spectrum method".