Simultaneous monitoring of MRgFUS temperature and tissue stiffness in real time

Y. Le[1], S. V. Primak[2], K. J. Glaser[2], A. Manduca[2], R. L. Ehman[2], J. P. Felmlee[2]

[1]BME Program, Mayo Clinic College of Medicine, Rochester, MN, United States, [2]Department of Radiology, Mayo Clinic College of Medicine, Rochester, MN, United States

Introduction

MRI guided focused ultrasound surgery (MRgFUS) is a new clinical technique to treat uterine fibroid disease noninvasively, in which MRI plays a key role measuring temperature during treatment (1). Unfortunately temperature does not always indicate tissue ablation; however, it has been shown that tissue stiffness may directly indicate ablation. Tissue stiffness can be detected by MR elastography (MRE) (2) or ultrasound elastography (3) using shear waves induced by pulsed focused ultrasound (4). In a previous study, we found that 2D MRE can be used to measure temperature and tissue stiffness simultaneously (5). We also have shown that a real time monitoring method based on 1D MRE measured displacement is useful to assess tissue ablation at the FUS focus during treatment (6). The purpose of this work is to study the feasibility of using real time 1D MRE to monitor FUS by measuring both the temperature and displacement change at the focus simultaneously.

Materials and Methods

To calibrate the temperature measurement by 1D MRE in a homogeneous phantom of uniform temperature, a 1.5% agarose phantom was slowly heated in a insulated incubator. A fluoroptic thermometry system (Model 750, Luxtron Corporation, Mountain View, CA) was used to measure the temperature in the tested material. The 1D MRE data were collected on a 1.5 T MR scanner (Signa, GE Healthcare, Waukesha, WI) at about 20 minute intervals. The MRE data were processed differently in order to determine the phase shift due to temperature, as shown in Eq1(5):

$$\Delta\Phi_{temperature}=(\Delta\Phi_1+\Delta\Phi_2)/2-(\Delta\Phi_{1b}+\Delta\Phi_{2b})/2 \quad [1]$$

where $\Delta\Phi_1$ and $\Delta\Phi_2$ represent the MRE phase data collected using positive and negative motion sensitizing gradients, and $\Delta\Phi_{1b}$ and $\Delta\Phi_{2b}$ represent the phase data in the baseline image, with positive and negative motion sensitizing gradients. The measured $\Delta\Phi_{temperature}$ was regressed with the temperature measured by the thermometer.

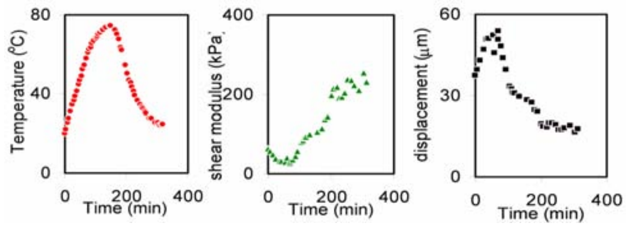

Figure1. Temperature and stiffness data from ex vivo bovine tissue from previous study and the displacement calculated according to these data.

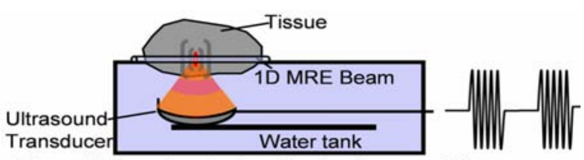

Figure 2. Experiment set up for simultaneous 1D temperature and displacement measurement.

The 1D measured temperature at the ultrasound focus was compared with the temperature measured by 2D MRE. A Mark 0 focused ultrasound single element 1.5 MHz transducer system (Insightec Inc. Dallas, TX) was used to generate ultrasound. Ex vivo porcine muscle tissue was used as shown in figure 2. Pulsed ultrasound was applied to ablate the tissue as well as induce shear waves. 1D MRE data were acquired with motion sensitizing gradients synchronized with pulsed ultrasound and motion at the focus. Displacement and temperature were calculated using the acquired phase data according to equation [1] and [2] (7):

$$\Phi(r,\alpha) = \frac{2\gamma NT(G\cdot\xi)}{\pi}\sin(k\cdot r+\alpha) \quad [2]$$

At intervals during 1D acquisitions, the ultrasound was stopped and the 2D MRE images were acquired using an external mechanical driver. Temperature was calculated from these 2D images and compared with the 1D measurement. In a separate experiment, 1D MRE was used to measure the temperature and displacement at the same time during FUS treatment in *in vivo* breast tumor in a mouse.

Results

Figure 3 shows that the phase shifts in 1D MRE are highly correlated with temperature change. The correlation coefficient is 0.996 and the slope is 0.008 ppm/°C. Figure 4 shows the temperature and displacement measured with 1D and 2D MRE. The 2D MRE measured temperature data are shown as square symbols with error bars (figure 4a). The error bars show the standard deviation within the eight phase offsets in one phase cycle of 2D MRE. Figure 5 shows the temperature and displacement measured in *in vivo* breast tumor.

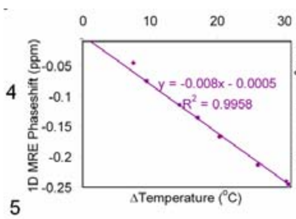

Figure3. 1D MRE PRF shift vs. temperature

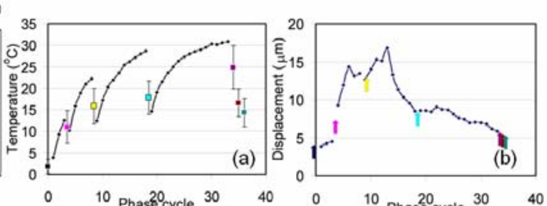

Figure4. (a)Temperature measured by 1D and 2D MRE; (b) Displacement measured by 1D MRE.

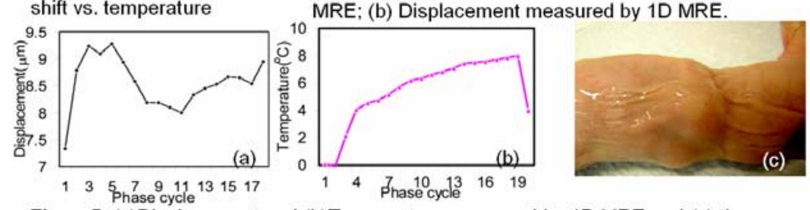

Figure5. (a)Displacement and (b)Temperature measured by 1D MRE and (c) the mouse with breast tumor after treatment.

Discussion

Our study shows that it is possible to use 1D MRE to monitor temperature change and displacement change (which indicates change in tissue stiffness) at the same time during FUS treatment. The proton resonance frequency (PRF) shift can be detected using 1D MRE acquisition and the measured phase shift correlates well with the temperature change measured by thermometer. The 1D MRE measured temperature shows clearly the increase and decrease of temperature during FUS ablation and correlates well with the 2D MRE measurement. In *in vivo* tests, it was demonstrated that the displacement curve and the temperature curve can be acquired simultaneously. These results support the further study of real time simultaneous temperature and displacement measurement as a means to monitor FUS treatment.

Reference

1. Cline HE, *et al.* Magn Reson Med 1996;35(3):309-315. 2. Wu T, *et al.* Magn Reson Med 2001;45(1):80-87. 3. Souchon R *et al.* Ultrasound Med Biol 2003;29(7):1007-1015. 4. Sarvazyan AP *et al.* Ultrasound Med Biol 1998;24(9):1419-1435. 5. Le Y, *et al.* MRM 2005, in press. 6. Le Y, *et al.* ISTU Proceeding 2005 s08. 7. Muthupillai R, *et al* Science 1995;269(5232):1854-1857.