Temperature effect in high intensity focused ultrasound therapy control using dynamic MR elastography

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INTRODUCTION

High intensity focused ultrasound (HIFU) is a method for non-invasive tumor therapy. The high energy density in the focal spot leads to local tissue heating and finally to thermal coagulation in the focal area (Fig.1) [1]. To monitor this treatment, the focus position can be detected online with temperature sensitive MR imaging. However characterization of the induced lesion is difficult.

It has been shown that HIFU lesions have a decreased elasticity and that the change in elasticity is larger than change in relaxation times [2]. This new parameter for characterization of the lesions can be measured with MR elastography (MRE). In dynamic MRE [3], images of mechanical wave propagation are acquired using oscillating bipolar gradients. Determination of the local wavelength allows reconstruction of the local elasticity. The problem to generate mechanical waves inside samples can be solved using HIFU itself: The ultrasound absorption in the tissue causes a small but continuous radiation force in the direction of wave propagation. The radiation force has its maximum in the focus of the sound field. Thus a pulsed HIFU sonication induces shear waves with a propagation perpendicular to the sound direction and with the ultrasound focus as the origin point (Fig. 1) [4].

The aim of this work is to improve the significance of the HIFU therapy control by visualization of the generated shear waves using dynamic MRE.

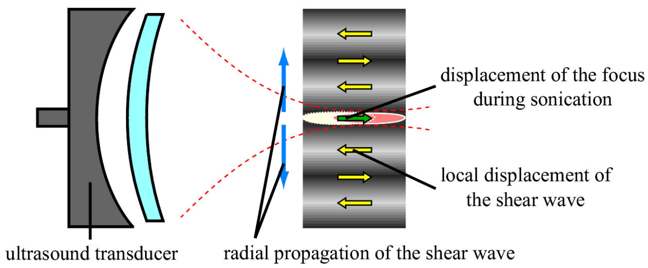

Fig. 1: Schematic illustration of shear waves from a pulsed focused ultrasound.

MATERIALS AND METHODS

In dynamic MRE, oscillating bipolar gradients are switched with the same frequency as the mechanical wave to be visualized. These gradients are implemented inside a standard FLASH sequence (Fast Low Angle SHot). The displacements of the mechanical wave cause changes in the phase of the acquired images. Two images are acquired with inverse amplitudes of the bipolar gradients and subtracted from each other, to get only phase effects from the mechanical wave.

For this experiment radial shear waves are generated inside a polyacrylamid gel with frequencies of f=200Hz and f=400Hz (acoustic power of 35W). To visualize the circular shape of these shear waves, the imaging slice position was chosen perpendicular to the ultrasound beam and the oscillating bipolar gradients are switched in direction of the ultrasound propagation (local displacement of the shear wave). Further parameters are: amplitude and number of bipolar gradients G_b=22mT/m and $N(f$=200Hz/400Hz)=5/23, $T_E(f$=200Hz/400Hz)=70ms/40ms, $T_R(f$=200Hz/400Hz)=90ms/70ms, FOV=140mm, 128×128 matrix and slice thickness: 5mm. The measurement times were 16s and 24s. With a duty cycle of 50%, the effective sonication times were 8s and 12s and thus a typical value for HIFU treatments [1].

RESULTS

The shear waves acquired with the two frequencies are shown in figure 2. The measured wavelengths are λ =15.3mm for f=200Hz and λ =7.0mm for f=400Hz. Assuming a phantom density equivalent to water (ρ=1g/cm^3), an elastic modulus of $E=\rho\cdot\lambda^2\cdot f^2=9.4\cdot10^3$ Nm^{-2} and $E=7.8\cdot10^3$ Nm^{-2} was calculated.

In addition, the amplitude images (Fig. 2) of the FLASH sequence revealed the ultrasound heating in the HIFU focus: If additional images are acquired after HIFU treatment, these spots get larger and vanish after a short time. This effect was not described before and could also be found in the phase of the images: If the two phase images (taken with inverse amplitude of the bipolar gradients) are added up - instead of a subtraction - the local spot can be clearly seen.

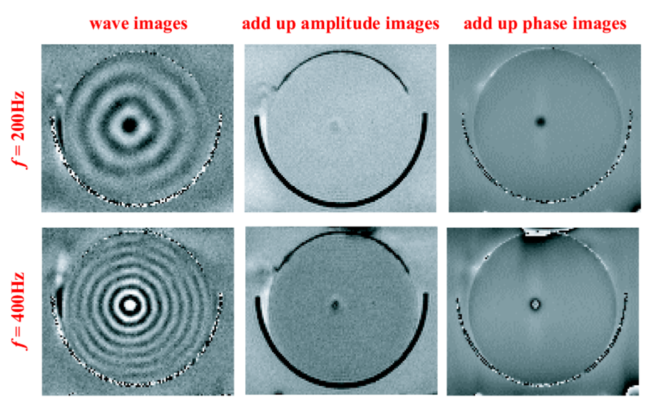

Fig. 2: Shear wave images with an excitation frequency of f=200Hz and 400 Hz. In the sum of the acquired amplitude and phase images the focus is clearly visible.

DISCUSSION

In this experiment it was possible to visualize the shear waves generated with HIFU during the treatment. To determine the local elasticity it is necessary to acquire a couple of wave images with different phase offset between the shear wave excitation and the oscillating bipolar gradients. Because this means a longer measurement time, the effective sonication per focus would be too long for the acquisition of an elasticity weighted image. But the wave images contain general information about the elasticity in the region of the focus.

The investigated changes in the amplitude of the images and the added phase images are an effect of the heating inside the HIFU focus. Possible reasons for the temperature sensitivity of this method are:

- The bipolar gradients: They cause a diffusion weighting of the acquired images and therefore temperature sensitivity.
- The FLASH technique: Temperature changes cause shifts of the proton resonance frequency, which could be observed especially with gradient echo sequences.

Further experiments indicate that the spots in the position of the HIFU focus were an effect of the temperature sensitivity of the FLASH sequence. These changes should be investigated as a function of the rise in temperature. In future, the acquisition of the shear waves will probably allow an MR temperature monitoring. Furthermore, information about the elasticity could be supplied. In HIFU therapy many different positions are treated to cover the volume of interest. Therefore, this method could give additional information about the success of the already performed sonications.

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