Static MR-Elastography for Improved Characterization of High-Intensity Focused Ultrasound Lesions

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Abstract

The in-vivo characterization of high-intensity focused ultrasound (HIFU) induced lesions is very important for an efficient therapy control. It is known that HIFU-lesions cause decreased elasticity. Thus, a new parameter for the characterization of the lesions is available. Therefore the relative change in elasticity due to HIFU treatment was investigated using static MR elastography of three lesion in ex-vivo porcine muscle with different applied energies (40 W, 55 W and 70 W, duration: 9 s). It was demonstrated that elasticity shows high sensitivity to HIFU energy and that the relative changes are larger than in relaxation times and spin density.

Introduction

High-intensity focused ultrasound (HIFU) is a method for non-invasive cancer therapy. Magnetic resonance temperature monitoring is used to detect the focus position. However characterization of the induced lesion is very 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 [1]. In this work changes are investigated with respect to the applied HIFU energy to access the applicability of magnetic resonance elastography (MRE) to HIFU therapy control.

Materials and Methods

With a HIFU setup [2] foci can be arbitrarily positioned inside tissue. This cause a coagulation due to increase in temperature. For the experiment three lesions were created with nine single shots inside an ex-vivo sample of porcine muscle (8×4×4 cm^3). The acoustic power of the ultrasound was 70 W, 55 W and 40 W respectively. Each shot lasted for 9 s. A delay of 30 s between each shot was necessary to avoid an uncontrolled rise in temperature inside the tissue.
For static MRE the porcine muscle has to recover to its original state after compression; to guarantee this, the sample was embedded into agarose gel (3 percent by weight).
The relative changes between the lesions and the untreated tissue in relaxation times and spin density were measured before MRE experiment.
The change of elasticity in dependency of the applied HIFU energy was measured with static MRE [3]: The sample was compressed by a pneumatic piston on the top (Δy = 1 mm, same direction as the HIFU-beam), which creates two discrete compression states. The induced internal displacement is encoded by the phase shift proportional to a bipolar gradient (G_d = 22 mT/m, δ = 6.5 ms) switched during both static states. In order to suppress motion artifacts from pressure waves, the switching between the compression states is performed during the mixing time T_M of a stimulated echo sequence (STEAM). Sequence parameters included: T_M = 150 ms, T_R = 1270 ms, matrix: 256×256, FOV = 140 mm.

Results

In all images, we observed enlarged lesion sizes in HIFU-beam direction for large HIFU energies. This is caused by changes in the absorption coefficient during the application of the ultrasound. The lesion grows in direction of the ultrasound transducer.
The relative changes between the lesions and the untreated tissue of all measured parameters are summarized in Tab. 1. The given values are the medians over three independent measurements. The errors are the corresponding standard deviations. For the investigation of elasticity, the first spatial derivative of the displacement in direction of the deformation (strain ε, Fig. 1b) was used corrected for the different lengths of the lesions inside the sample.
Except elasticity, all measured parameters show a continuous change with HIFU energy. Elasticity is nearly the same for the two smaller HIFU energies and changes markedly in the 70 W lesion.

***Tab. 1:** Relative changes between each lesion and the untreated tissue in relaxation times T_1/T_2, spin density ρ and strain ε.*

P_{HIFU} [W_{ac}]	70	55	40
Change in T_1 [%]	33 ± 1	27 ± 1	21 ± 1
Change in T_2 [%]	20 ± 3	14 ± 3	10 ± 2
Change in ρ [%]	25 ± 3	14 ± 2	9 ± 1
Change in ε [%]	57 ± 8	23 ± 9	29 ± 7

Discussion

HIFU lesions are coagulations due to heating. The difference in spin densities is assumed to be caused by water displacement. T_1 might be the effect of the greater coagulation with higher HIFU energies.
Previous experiments using dynamic MRE [4] show that the elasticity of tissue suddenly decreases if the temperature is above a limit of 65° C. This could explain the sudden increase of the relative change in elasticity above the applied HIFU power of 55 W.
The large changes in elasticity demonstrates, that an improved characterization of HIFU induced lesions is possible using MRE. Further investigations are needed to analyze effects of slice position or tissue type.

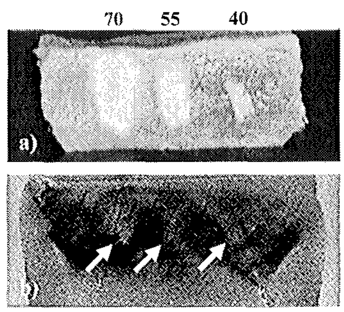

***Fig. 1:** HIFU-lesion with an acoustic power of 70 W, 55 W and 40 W. Photo through a cut of the investigated slice a) and strain image b). The directions of the HIFU-beam and the compression were both from the top.*

References

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[2] Jenne J et al., Ultrasound Med. Biol. 26:A55 (2000)
[3] Chenevert TL et al., Magn. Reson. Med. 39:482-490 (1998)
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