Optimal Ultrasonic Focusing through Strongly Aberrating Media using Radiation Force Magnetic Resonance Guidance

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Background

When focusing ultrasound through strongly aberrating layers such as bones, adaptive focusing techniques need to be used. They aim at recovering the delays to be applied to each emission channel of the ultrasonic (US) therapeutic array in order to compensate the phase shifts induced by the aberrator. We recently proposed a new energy-based technique requiring the sole knowledge of the acoustic intensity at the desired focus (1).
MR-Acoustic Radiation Force Imaging (MR-ARFI) was first proposed in 1998 to map the displacement induced by the radiation force of a focused ultrasound beam (2). When properly acquired, the MR phase signal can be shown to be directly linked to the local acoustic intensity.
The use of MR-ARFI for the proposed adaptive focusing technique is demonstrated experimentally in the present work.

Material & Methods

Proof of concept experiments were done in a Bruker 7T scanner with a motion sensitized multi-slice spin echo sequence (TE=15ms/TR=500ms). A 64-element linear phased array operating at 6MHz was used to emit 400µs US bursts into a tissue mimicking gelatin-based phantom. The acoustically induced motion pattern in the US focal plane was encoded in the MR phase with a high sensitivity (<1µm) and a high imaging resolution (300µm*200µm*2mm). In a first experiment, an aberrating law with strong phase shifts was added numerically to the ideally beamformed US beam. In a second experiment a physical aberrator was placed between the array and the phantom. A non-iterative process was applied based on the spatial decomposition of the phase aberration on the Hadamard basis. It consists in the emission of ultrasonic coded excitations synchronized with the MR acquisition coupled with the indirect measurement of the resulting acoustic intensity at the focus. The set of time delays and amplitudes to be applied on each element of the US array for the optimal focusing is recovered by a direct inversion of the MR phases at the focus.
Preliminary experiments were done in a 1.5T clinical scanner using a 512 elements US phased array dedicated to transcranial human brain experiments and operating at 1MHz. They were conducted in phantom gels, excised lamb brains and *ex vivo* human heads. A motion-sensitized spin sequence (TE=49ms/TR=1000ms) has been implemented on a Philips Intera 1.5T scanner. The motion sensitizing gradients are bipolar trapezoidal gradients with a 40-mT.m^{-1} amplitude and a 11-ms duration. The spatial resolution is 1x1x3mm^3.

Results

MR-ARFI allowed mapping the distribution of the radiation force at the focus of the array. After the recording of the MR phase signals for a set of 256 different US emissions, the proposed adaptive focusing was able to recover the spatial distribution of phase aberrations up to 2π radians for both numerical and physical phase aberrating layers. A relatively low error was found on the non invasive phase aberration estimation (standard deviation of 0.3 radians). Moreover, the acoustical power at the focus was increased five fold after phase correction (see Figure 1).
At 7T, the focal spot was also detected and accurately quantified *in vivo* in rat brains with a 1.5MHz US transducer. On the clinical setup at 1.5T, the focal spot was detected in gelatin phantoms and *ex vivo*.

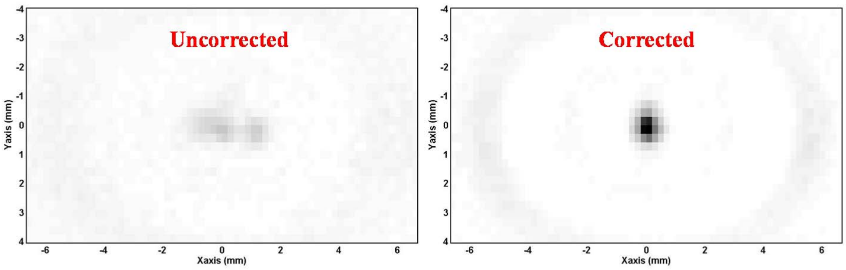

Figure 1: 2D maps of the MR-ARFI signals in the focal plane for uncorrected and corrected ultrasonic emissions through an aberrating layer.

Conclusion

An adaptive focusing technique based on the sole knowledge of the acoustic intensity at desired focus is here demonstrated to perform optimal focusing through strongly aberrating layers using MR motion sensitive sequences at 7T. This corresponds to a first experimental evidence of extremely efficient MR guidance for US aberration correction. Beyond this proof of concept, current work focuses on applying this technique to the aberration correction through a human skull bone with a lower field clinical system dedicated to human transcranial HIFU.

References

[1] Herbert et al, 2009.
[2] Sarvazyan et al, 1998.