MR guided High Intensity Focused Ultrasound for tumor ablation in brain: preliminary results

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Introduction

Brain therapy with transcranial focused ultrasound is a scientific and technological challenge [1,2]. A novel prototype is presented here (SuperSonic Imagine, France), working at the highest frequency envisioned currently for transcranial brain treatment (1MHz). A non invasive time-reversal focusing technique based on CT scans is performed for that purpose [3]. Such a brain therapy device operating at 1MHz should be particularly suited for well defined targets such as metastases and essential tremors. Thanks to the ability of MR to provide temperature maps with a good accuracy every few seconds, ultrasonic ablation of tissues has been implemented clinically and used successfully for the treatment of uterine fibroids [4]. The aim of this study was twofold. The first goal was to check if the new prototype was fully MR-compatible. The second aim was to heat a PVA-gel, and *ex vivo* brain tissues, directly or through a human skull. The changes in temperature were monitored with MRI.

Material and methods

An MR-compatible high power prototype made of 512 transducers able to deliver up to 20 W/cm2 has been constructed and installed in a 1.5T Philips Achieva scanner. 3D finite differences time domain simulations were used to compute the propagation of the wave field through human skulls. The simulated phase distortions were used as inputs for transcranial correction. The total acoustical power has been measured in a water tank with a radiation force balance. A turkey breast sample was placed at focus behind a human skull in the same tank in order to check the ability of the system to induce thermal lesions.
The system was built in order to be compatible with the MRI environment. The compatibility was checked at each step of the installation process. The MRI bed was designed especially for this new prototype. A Leksell stereotactic frame (Elekta Limited, UK) was used to ensure a good accuracy in patient positioning.
Temperature rise has been mapped in the MR scanner every 1 to 2s with a proton resonance frequency shift MR technique [5]. Temperature was calculated from the phase difference obtained with an image reference taken before shooting. A spoiled gradient echo EPI sequence with echo train = 7 was used. The parameters were optimized for two configurations and are summarized in Table 1. Phase subtraction was calculated by a complex number subtraction instead of a direct phase subtraction in order to avoid phase wrapping [6]. The increase in temperature was studied in two cases: first in a 7%-PVA gel for different levels of applied power, and second, in veal brains embedded in 6%-gelatin as shown in Figure 1. The gels were placed against a membrane filled with degassed water which ensured the impedance continuity between the transducers and the gels.

Table 1: MRI parameters

	PVA Gel	Skull + veal brains embedded in gelatin
TE/TR	30/220	50/355
α [°]	55	60
Echo train	7	7
Spatial resolution [mm^3]	1×1×3	1×1×3
Temporal resolution/image	~1.16s	~1.9s

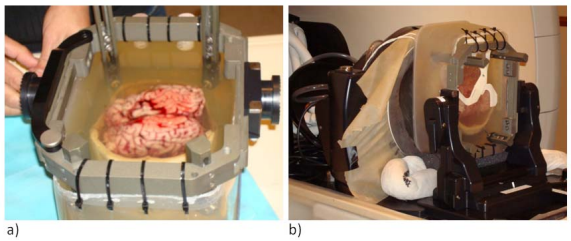

Figure 1: *Veal brains embedded in gelatin (a) placed on the HIFU bed (b) in the MRI environment.*

Results and Discussion

For a total electrical power ranging from 200W to 5kW, the efficiency of the transducers was equal to 57% +/- 2.6%. At maximum power, the peak negative and peak positive pressure at focus were respectively 5.0 MPa and 9.2 MPa. A thermal lesion of 4 mm in diameter has been generated in a turkey breast located behind a human skull at half the maximum power (2kWac).
MR-compatibility was checked for each element of the therapy system. No artifact was observed due to the HIFU prototype, but only to the stereotactic frame (Figure 3). Beyond this, good image quality was obtained at each heating session.
Results in PVA gel showed good correspondence between induced power and measured temperature (see Figure 2). A localize heating of the veal brain through the human skull is displayed in Figure 3.
We showed in this study that a system as complex as this new HIFU prototype is fully compatible in an MRI environment. The results showed it is possible to heat the brain through the skull at a high frequency and monitor the heating process with MRI. After validation on cadaver heads, this work will open new horizons to tumor brain therapy in animals and then in humans.

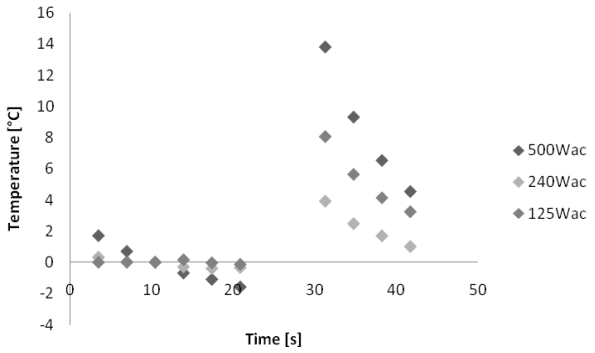

Figure 2: *Increase in temperature with increasing power in a PVA gel.*

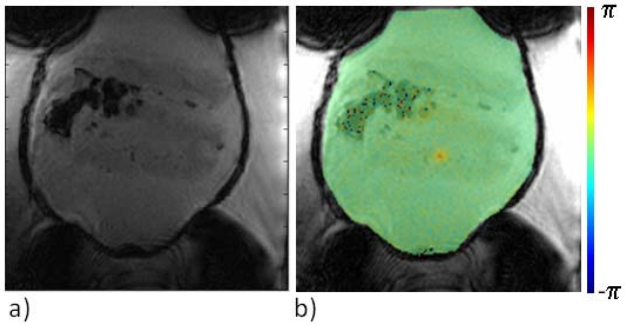

Figure 3 : *Magnitude (a) and superimposed phase difference images just after shooting (b). Artifacts due to the stereotatic frame are present at each corner of the skull. Moreover, a clear spot is visible at the focal distance.*

References

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