MRI-guided, percutaneous thermoablation in liver using interstitial applicator of contact ultrasound under active temperature control : a feasibility study in vivo.

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Introduction.

Percutaneous coagulation with RF needle is been accepted as a clinically effective tool for minimally invasive, in situ ablation of liver tumours. However, therapeutical indications are currently limited to 3cm tumor diameter or less. With the RF technique, the thermal energy is basically delivered near the RF antenna and the ablation ball is being formed by heat conduction in tissue. Unlike this « passive » mechanism, contact ultrasound permits accurate control of the spatial pattern of heat deposition, with directive and angularly controlled beams. In this study we investigated the feasibility of percutaneous thermoablation in liver using an MR compatible device, delivering High Intensity Contact Ultrasound (HICU). Fast MR thermometry was used for therapy monitoring and active feedback on the applied power.

Material and Methods.

An MRI compatible prototype of interstitial HICU device was built, incorporating a flat 3mm x 10mm US transducer, operating at 5.2 MHz. A probe holder and a manually operated positioning system were constructed, providing five freedom degrees of motion, of each two translations and three rotations (Fig.1). The therapeutic sequence consisted of directive heating of a flame-like volume of tissue in front of the transducer, followed by a step-wise rotation of the device (18° each) without voluntarily waiting delay between sonications. A complete treatment is thus obtained after 18 steps (Fig. 2). The device was initially tested ex vivo on freshly excised pig liver and further the in vivo feasibility was studied on 5 pigs (male, average bw 40kg, approved protocol by the Local Bioethics Committee, Fig.3). PRFS-based fast MR thermometry was performed on a clinical 1.5T scanner, using a 4-element phased array coil, with a SENSE accelerated (factor of 1.7) segmented EPI, RF spoiled gradient echo (FOV square 192mm, matrix size 128 x 128, slice thickness 6.5mm, TR=250ms, TE=14ms, respiratory gating window = 1250ms, 15 k-lines/TR). A single slice was acquired per respiratory cycle, under mechanical ventilation (3 to 3.2 s per cycle). The driving electronics was feedback coupled to an active temperature controller, based on a physical model and including a PID compensation algorithm. A target temperature of 58°C (starting from 38°C baseline) was defined to be reached in 90s and further maintained for another 60s (Fig.4, blue plot), at 10 mm depth in liver parenchyma with respect to the device tip sheath. The same target curve was defined for each step-wise sonication. MR follow up was performed at Day3 post treatment with Gd-enhanced T1w sequence and *post mortem* macroscopic histology was performed at Day4.

Results

The HICU device demonstrated excellent MR compatibility: only small artifacts, without incidence on the therapy control, were noticed extending less then 2 mm from the device tip. No sonication-related RF artifacts were detected in any experiment. The standard deviation of the MR thermometry baseline was 1°C. The temperature controller converged to the target curve and further maintained the steady-state regime within a standard deviation of 2°C (Fig. 4, red plot). Records of the temperature controller performance showed large variability of the applied average power from one sonication to other, *ie* significant anisotropy of tissue response to identical beam pattern. However, the temperature evolution under active control was found very similar from one sonication to another. In addition, MR followup and post mortem histology demonstrated that all individual sonications lead to near identical shape of the lesion (15±2 mm depth, 3cm equivalent diameter).

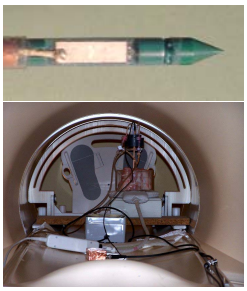

Fig 1: Head of the HICU device and the positioning system.

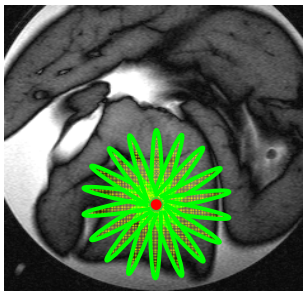

Fig 2: Principle of step-wise treatment of a cylindrical ROI.

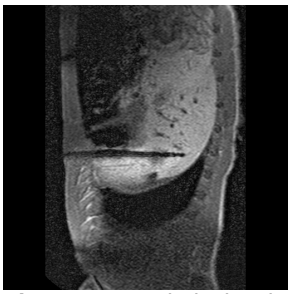

Fig 3: Inserted device in the pig liver (MRI guided procedure).

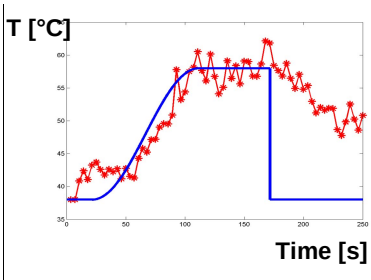

Fig 4: Experimental *versus* target temperature evolution at the control location (10mm from the tip)

Discussion.

To our best knowledge, this is the first time when a percutaneous interstitial device of therapeutic ultrasound is operated *in vivo* on pig liver, under active MR feedback control of temperature evolution. Such automatic control of the temperature, and consequently of the delivered thermal dose, enabled reproducible shape of lesions, despite tissue inhomogeneity and anisotropy. Maximum size of ablation and effectiveness of the procedure in anatomical region including large blood vessel will be further investigated.