Interventional Magnetic Resonance Elastography for MRI-guided percutaneous procedures.

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TARGET AUDIENCE – Physicists and physicians in Interventional MRI / Magnetic Resonance Elastography

PURPOSE – MRI-guided thermal ablations are increasingly used for the treatment of solid tumors. The monitoring of these procedures is essential to ensure a complete destruction of the tumor, while avoiding damage to surrounding healthy tissue. MR-thermometry[1] provides an instantaneous external monitoring parameter but gives no direct information on intrinsic changes in tissue structure. Elastography has been proposed as an interesting alternative to monitor tissue ablations: liver stiffness has been found to change from 6 to 40kPa during a radio-frequency ablation by using ultrasound elastography[2]. Magnetic Resonance Elastography (MRE)[3] allows to measure the mechanical properties of tissue in vivo. MRE requires (1) a mechanical exciter that generates a shear wave inside the observed tissue, (2) a motion sensitizing pulse sequence that encodes the displacement induced by the shear wave on phase images and (3) an inverse problem that returns an elastogram knowing that the propagation speed of the wave depends on mechanical properties. Currently, typical MRE acquisition times are not suitable for real-time guidance, and conventional surface exciters are limited to investigate deep-lying regions. This work aims at developing interventional MRE dedicated to the monitoring of MRI-guided thermal ablations.

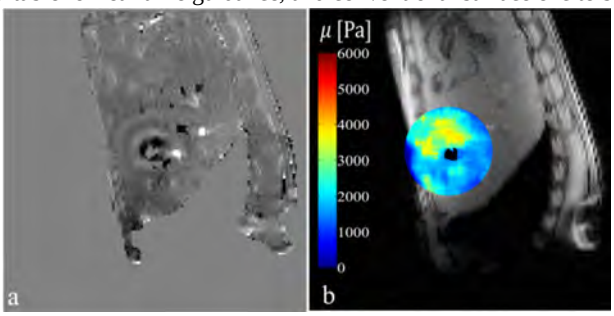

Figure 1: *In vivo real-time MRE in the liver in swine. a) unwrapped phase difference image; b) elastogram (reconstructed every 2.56s).*

METHODS – A complete interventional MRE protocol was developed. (1) A piezoelectric-actuated needle MRE driver was used as a source of shear waves generated directly in the region of interest. (2) Bipolar motion sensitizing gradients (MSG) were implemented on a fast and interactive spoiled gradient echo pulse sequence (Beat_IRT, Siemens, Germany) used in interventional MRI. TR was equal to one mechanical excitation cycle using fractional encoding[4]. A phase difference image was reconstructed from 2 images with opposite MSG polarities in order to cancel constant noise and increase motion encoding. (3) Elastograms were reconstructed using an online, real-time Local Frequency Estimation (LFE)-based solver[5,6]. In conventional MRE, at least 4 phase-offsets, obtained by varying the phase shift between the mechanical excitation and the MSG, are required for the reconstruction of one elastogram. Preliminary phantom experiments were conducted to study the effect of reducing the number of phase-offsets. The best tradeoff between total acquisition time and elastogram quality was found for 3 phase-offsets. Using these 3 phase offsets, the elastogram update rate was increased by using a sliding window scheme that consists in reconstructing a new elastogram with every new phase difference image and the two previous ones. The complete protocol was tested in healthy swine liver in vivo to evaluate the capability of providing elastograms in real-time (Fig. 1). A phantom experiment was carried out to evaluate the ability of monitoring changes of elasticity in real-time. An approximately 4 cm hole in diameter was scooped out from a homogeneous 8% gelatin phantom. The needle MRE driver was inserted vertically in the phantom. A small volume (200 mL) of 10% gelatin was prepared and cooled down to 20°C. This liquid gelatin was poured in the hole and its gelation was monitored using real-time MRE over 30 minutes. Experiments were performed in a 1.5T-scanner (MAGNETOM Aera Siemens, Germany), using the following imaging parameters: mechanical excitation frequency 100 Hz, MSG frequency 210 Hz, MSG amplitude 20 mT m^{-1} encoding through slice, one slice orthogonal to the needle MRE driver, slice thickness 10 mm, FOV 350 mm × 350 mm, matrix 128 × 128, TR/TE 10/7 ms, FA 15° and BW 380 Hz/pixel, image acquisition time 1.28s. Six images corresponding to 3 phase-offsets, each with 2 opposite MSG polarities, were used for the reconstruction of one elastogram.

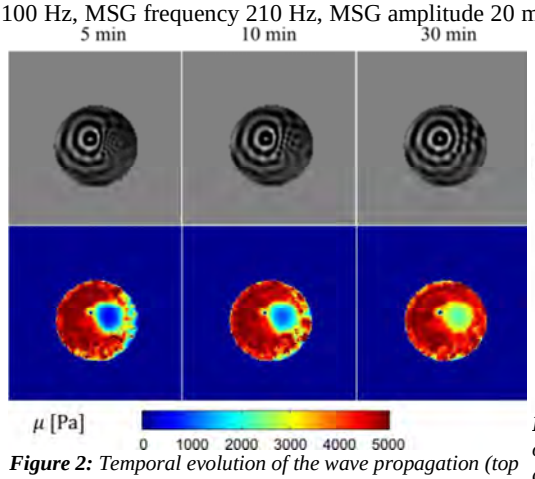

Figure 2: *Temporal evolution of the wave propagation (top row) and corresponding shear modulus μ in elastograms (bottom row) during the gelation process in the inclusion.*

RESULTS – The well-defined cylindrical shear wave pattern obtained with the needle MRE driver was visible in the liver (Fig. 1) and in the gelatin phantom (Fig. 2). The increase of elasticity was clearly measured over time within the 10% gelatin during the gelation process (Fig. 2). Using the sliding window scheme, elastograms were updated in 2.56 s with every new phase difference image. The method was able to accurately monitor the gelation process with a mean standard deviation around 2% of the averaged shear modulus in a small region of interest (Fig. 3).

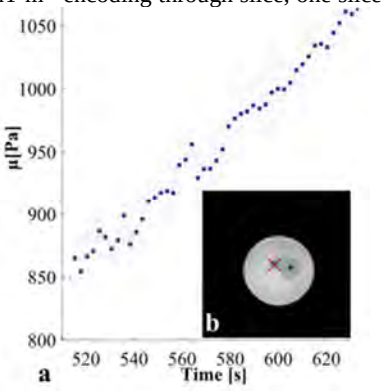

Figure 3: *a) Evolution of the shear modulus over 2 min in the 10% gelatin during its gelation. b) Amplitude MR image with the region of interest in blue and the needle MRE driver as a red cross.*

CONCLUSION – For the first time, a complete MRE protocol was developed specifically for Interventional MRI. MRE excitation, image acquisition and elastogram reconstruction were specifically adapted to interventional-related requirements. In vivo feasibility was established in swine liver and feasibility to monitor elasticity changes in real-time was demonstrated in a gelatin phantom during its gelation. This additional information of elasticity is expected to help better assess the treatment response during thermal ablation.

REFERENCES –1/ Quesson B. *et al. J. Magn. Reson. Imaging* 2000. 2/ Mariani A. *et al.J. Surg. Res.* 2014. 3/Muthupillai, R. *et al. Science* 1995. 4/ Rump J. *et al Magn. Reson. Med.* 2007. 5/ Knutsson H. *et al. Image Processing, 1994.* 6/ Manduca A. *et al. Med. Image Anal.* 2001.