Overhauser enhanced MR elastography at very low field

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Introduction

MR elastography (MRE) is a powerful non-invasive tool that can be used to assess the mechanical properties of living tissues. It has shown its potential for the diagnosis of chronic liver diseases and breast cancer. However this technique suffers from major limitations: the number of motion encoding gradients (MEG) used to increase the sequence sensitivity adds up to the initial sequence TR and is restricted by the intrinsic T_2's of the targeted tissues. This leads to limited SNR compensated by higher number of averages (NA), leading in turn to longer acquisition times. This drawback hinders its routine use by radiologists. The aim of the present study is to show the feasibility of enhancing the signal via the Overhauser effect to shorten MRE acquisition times.

Materials & Methods

MRE was performed on a custom-built MRI scanner consisting of a bi-planar 6.5 mT electromagnet with bi-planar gradients [1]. Overhauser enhancement was performed using an EPR coil tuned to the low energy transition of 140.8 MHz of a nitroxide radical. The ESR coil was placed inside of a 16 cm long solenoid coil used for NMR excitation and detection at 276 kHz [2]. A 7%-PVA gel containing 5 mM hydroxy-TEMPO dissolved in water (Sigma-Aldrich Co, St. Louis, MO, USA) was obtained after 2 cycles of freezing/thawing at -20 ℃. An acoustic waveguide was placed on top of the gel. A loudspeaker, positioned outside the Faraday cage on the other side of the waveguide, was used to generate a 103 Hz acoustic wave synchronized with a modified 3D gradient echo sequence (Figure 2). Four MEG (N=4) were used with the following parameters: matrix 128×64×8, resolution 2×1×7 mm^3, TE/TR = 67/87 ms, α = 90 °, NA = 1. Six temporal steps evenly distributed over one period (T) were acquired leading to an acquisition time of ∼4 min per direction. One additional scan was performed without any vibrations in order to have a reference scan for B_0 drift correction. The total phase accumulation is given by equation 1 [3]:

$$\Phi = \frac{2\gamma NT(G \cdot \xi_0)}{\pi}\sin(k \cdot r + \theta),\qquad \text{Equation (1)}$$

were Φ is the accumulated phase, γ the gyromagnetic ratio, **G** the gradient vector, **ξ₀** the displacement vector, **k** the wave vector, **r** the position vector, and θ the phase offset. A total ESR irradiation time of 50ms/TR was used to enhance the NMR signal. Displacement fields were obtained after phase unwrapping and correction of B_0 drift using Matlab (MathWorks, Natick, MA, USA).
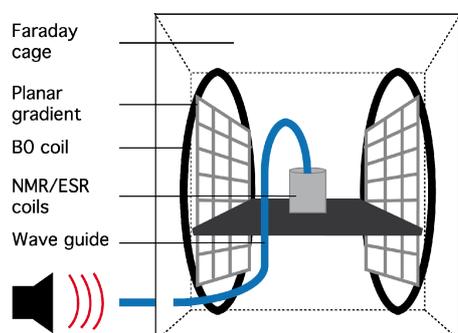
Figure 1: Set up of the experiment. The phantom was placed inside of the ESR and NMR coils. Acoustic waves are guided through a tube placed on top of the gel.
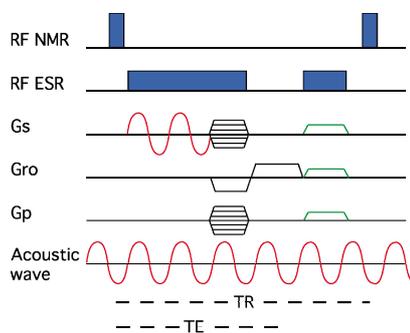
Figure 2: Diagram of the modified 3D gradient echo sequence used for MRE. MEG, as well as the acoustic wave, are shown in red and crushers in green.
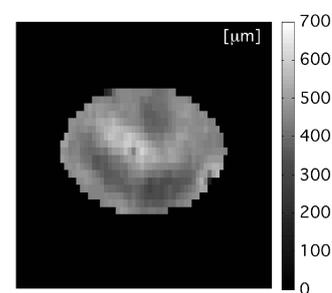
Figure 3: Displacement field after unwrapping and drift correction obtained in the readout direction after using equation (1).

Results and conclusions

An enhancement factor of ∼30 was obtained. 3D phase maps were calculated and showed good wave propagation inside the gel (Figure 3). We had shown for the first time that the Overhauser effect can be used to perform MR elastography at 6.5 mT with sensitivity and acquisition times being equivalent to those using standard spin echo et gradient echo sequences referred in the literature at much higher fields. Furthermore, shorter acquisition times can easily be reached by making use of fast imaging strategies. This study opens new perspectives in clinical applications when short T_2's of biological tissues constrain the sensitivity of MRE leading to prohibitive acquisition times.

References:

[1] Tsai LL et al, JMR 2008; 193: 174-85 [2] Sarracanie M et al, MRM 2012; submitted [3] Mutthupillai R et al, Science 1995; 269: 1854-57

Acknowledgments: