Application of DENSE MR-Elastography to the human heart: first in vivo results

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Introduction

Typically, MR-Elastography (MRE) encodes the propagation of monochromatic acoustic waves in the MR-phase images via sinusoidal gradients characterized by a detection frequency equal to the frequency of the mechanical vibration [1]. Therefore, the echo time of a conventional MRE sequence is typically longer than the vibration period, which is critical for heart tissue exhibiting a short T2*. Thus, fast acquisition techniques like the "so-called" Fractional Encoding of Harmonic Motions (FEHM) were developed for cardiac applications [2]. However, FEHM is limited since it is two orders of magnitude less sensitive to motion than conventional MRE sequences for low frequency vibration. Here, an MRE sequence (Fig. 1) is derived from the "so-called" Displacement Encoding with Stimulated Echoes (DENSE) sequence [3], and it is adapted to *in vivo* acquisitions of the human heart for two volunteers.

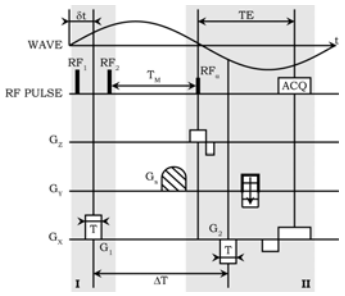

Fig. 1: DENSE-MRE sequence diagram

Material & Methods

All the experiments were conducted with a 1.5 T MRI scanner (Philips 1.5 T Achieva scanner, Eindhoven, Netherlands) with the commercial SENSE-cardiac coil. The external vibration was generated via an electrodynamic shaker located at the *apex* of the heart for the two volunteers. The scans parameters were: FOV = 128x128 mm^2, voxel = 2x2x8 mm^3, flip angle = 90°, 1 slice (short axis view), 4 dynamic scans, TE = 4.4 ms, 1 heart phase (PPU trigger), Motion Sensitizing Gradients (G_1 and G_2) strength = 21 $mT.m^{-1}$ and duration = 2 ms, and a frequency of externally induced vibration = 50 Hz. Each dynamic scan was acquired during an end-expiration breath hold by using an EPI read-out with factor 3, and the motion was separately encoded for the two in-plane directions. Thus, a full acquisition was performed for one heart phase within 8 breath-holds (4 dynamic scans and the 2 motion directions). In addition, two perpendicular saturation bands were used to avoid fold-over, and a registration algorithm was performed for the different dynamic scans in order to suppress artefacts due to different heart position within the FOV.

For one volunteer, multiple data were acquired in order to show the feasibility of cardiac DENSE-MRE. A first set of experiments were made with external vibration and motion encoding. The second set was performed without external vibration and with motion encoding. The third set was conducted with external vibration and without motion encoding. In addition, DENSE-MRE acquisitions were conducted for 4 different heart phases during the diastole for the two volunteers. Elastograms were estimated for both volunteers out of the two in-plane motion by assuming that the heart tissue is isotropic.

Results & Discussion

Fig. 2 shows the motion amplitude of the two in-plane directions extracted from the feasibility experiments using equations linking the phase dispersion to the displacement. The first column corresponds to the first set of acquisitions. Displacements of about 20 µm are observed for both directions. The second column corresponds to the second set, and no displacement is observed. This result shows that DENSE-MRE is not creating pseudo displacement and no global heart motion is encoded. The third column corresponds to the third set, and no displacement is observed. Thus, the electrodynamic shaker is not creating artefacts in the MR-phase images. Moreover, the blood inside the ventricle is visible as no motion encoding gradients are applied.

Fig. 3 shows elastograms estimated for two volunteers during the diastole. For both volunteers, the shear modulus is increasing during the blood filling of the ventricle while its volume remains the same. The fourth heart phase corresponds to a position just before the systole, and the shear modulus decreases. This decrease can be justified by the fact that the heart is going to twist and thicken, and it needs to soften in order to create large strain.

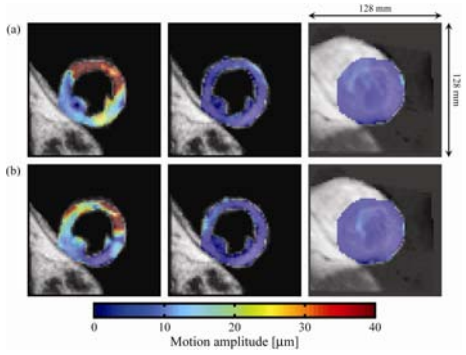

Fig. 2: *in vivo* validation data.

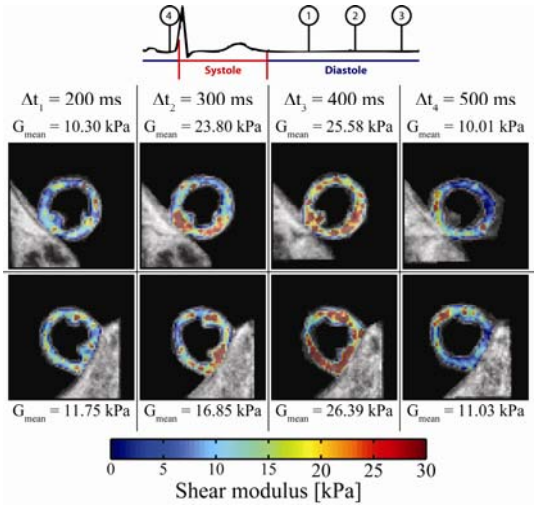

Fig. 3: *in vivo* elastograms for 4 heart phases during diastole.

Conclusion

Via DENSE-MRE, low frequency mechanical waves can be used in order to estimate *in vivo* cardiac elastograms. For two heathy volunteers, elastograms were estimated for four heart phases during the diastole, and they were similar in terms of mean shear modulus for both volunteers. The first *in vivo* results are promising, and the estimated shear modulus is equivalent to anterior ultrasound measurements [4].

Furthermore, DENSE-MRE sequence is not particularly dedicated to cardiac applications. This sequence is about ten times faster than conventional MRE sequences, and it is extremely efficient for short T2* tissue. Thus, applications of DENSE-MRE can be considered for instance for liver or kidney.

References

[1] Muthupillai *et al.*, Magn Reson Med 1996; 36: 266-274. [2] Rump *et al.*, Magn Reson Med 2007; 57:388-395. [3] Aletras *et al.*, J Magn Reson 1999; 137: 247-252. [4] Kanai, IEEE UFFC 2005; 52: 1931-1942