DENSE-MR-Elastography For Cardiac Application

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Introduction

The myocardium viscoelastic properties are expected to locally change depending on the tissue damage degree after an infarct for instance. Thus strain imaging like tagging [1] or DENSE [2] have been developed to provide information about the regional abnormal mobility, but not on inherent physical properties of the tissue. On the contrary, imaging of mechanical shear waves via MR-Elastography (MRE) allows the assessment of inherent viscoelastic tissue parameters which are likely to characterize in a more objectively manner tissue damage and thus carries the potential to better diagnose myocardial viability. However, cardiac MRE poses several technical challenges: small relaxation times, time dependant viscoelastic properties during the heart beat, respiratory motion.

To overcome the short relaxation time problem, the use of a gradient echo MRE sequence is mandatory [3]. However, the damping of the tissues between the heart and the chest increases with frequency, which means that externally generated high frequency mechanical waves barely reach the heart. To overcome this constraint, a MRE sequence has been adapted from a DENSE sequence [4]. This motion sensitive sequence is validated for monochromatic steady state mechanical waves in a PolyVinyl Alcohol (PVA) phantom and it is compared with a spin echo MRE sequence which is considered as the reference.

Sequence design

Figure 1 depicts a possible DENSE MRE sequence which is based on a preparation part and an acquisition part. The preparation encodes part of motion while the acquisition part is retrieving the data after encoding another part of the motion. Between the two parts, a gradient spoils the residual magnetization within the xy-plane. The duration between the motion sensitizing gradients (rectangular red gradients) is critical: it must last an odd multiple of half a mechanical period. Although the acquired k-space contains three distinct echoes, using strong enough gradients leads to only one echo which MR phase dispersion is linked to the motion sensitizing gradient strength and duration, the motion amplitude, the mechanical waves frequency and the gyromagnetic ratio.

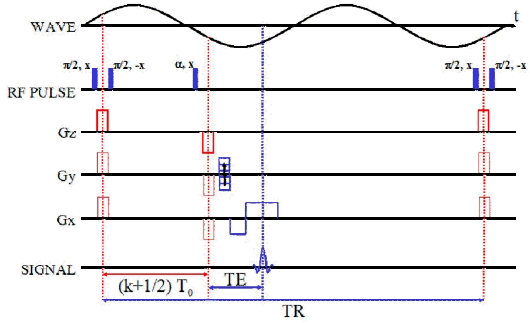

Fig. 1: DENSE MRE sequence scheme.

Material & Methods

Validation experiments were conducted on a PVA phantom with a 1.5 T MRI scanner (Philips 1.5 T Intera scanner, Eindhoven, Netherlands). The PVA phantom was placed in a MRE dedicated coil (Philips Research, Hamburg, Germany) which induces mechanical vibrations within the phantom and images the phantom. The external excitation signal is generated by a function generator for six different frequencies (40 Hz, 50 Hz, 64 Hz, 80 Hz, 100 Hz, 125 Hz).

The Spin Echo MRE (SE-MRE) experiments used the following parameters: flip angle = 90°, 7 slices, 8 dynamic scans. The DENSE MRE experiments used the following parameters: TE = 4.4 ms, G_{01} = 42 mT.m^{-1}, T = 2.4 ms, flip angle = 15°, 1 slice, 10 dynamic scans. The DENSE MRE acquired slice is identical to the central slice of the seven SE-MRE slices. The motion sensitizing gradient was applied separately in the two in-plane directions for both methods.

Result & Discussion

Figure 2 compares three theoretical sensitivities: SE-MRE (red line), DENSE MRE (blue line), and Fractional Encoding of Harmonic Motions (green line). The Fractional Encoding of Harmonic Motions (FEHM) [5] was introduced to image wave propagation in tissues like the heart (small T2). The DENSE MRE sequence is less sensitive than the SE-MRE (for a 50-Hz mechanical wave, about ten times smaller). However, the magnetization is in the xy-plane for at least 40 ms using SE-MRE for a 50-Hz mechanical excitation, while it stays in the xy-plane for 4.4 ms using DENSE MRE. For a similar timing (TE~4.4 ms), the FEHM sensitivity is about ten times smaller than the DENSE MRE sensitivity for a 50-Hz mechanical excitation.

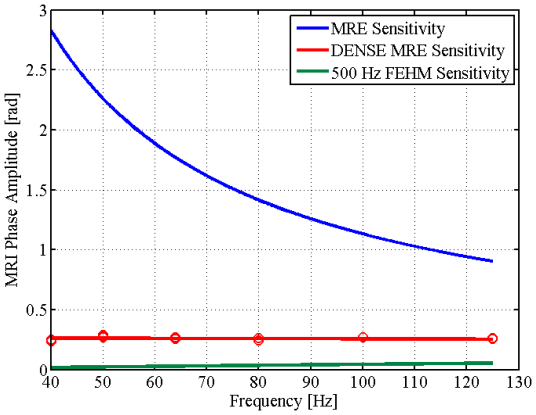

Fig. 2: comparison of MRE and DENSE MRE sensitivities.

Figure 3 compares the SE-MRE (blue line) and the DENSE MRE (red line) spectral specificities. The DENSE MRE specificity reaches a maximum for the detected frequency (50 Hz), while the SE-MRE does not reach its maximum for the detected frequency but for a smaller frequency. The same timing FEHM spectral specificity is not drawn on fig. 3 because of too small MR phase amplitude. However, it should be noted that the FEHM spectral specificity is growing from 0 Hz to 500 Hz, which means that FEHM is less frequency discriminating than DENSE MRE.

Theoretical results on the spectral sensitivity and the spectral specificity were confirmed by experimental data (circles on fig. 2 and fig.3) in the PVA phantom.

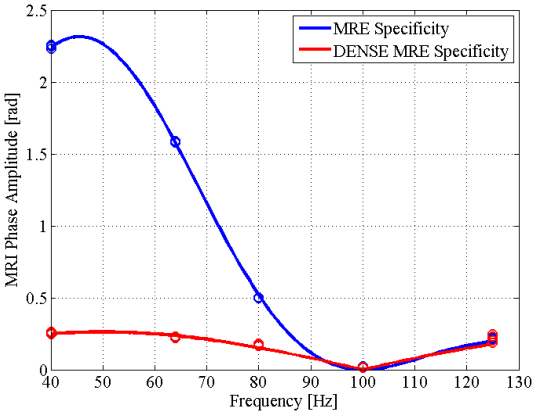

Fig. 3: comparison of MRE and DENSE MRE specificities.

Conclusion

Via the DENSE MRE, low frequency mechanical waves can be used in order to penetrate tissues and reach the heart. Although the DENSE MRE spectral sensitivity is not like the SE-MRE, MR data are still useful since the DENSE MRE sequence decouples the preparation phase and the imaging phase via storing the magnetization in the z-direction. Thus the DENSE MRE sequence is designed for cardiac MRE and an in-vivo analysis is currently conducted.

References

[1] Wen et al, MRM 54, 538-48, 2005. [2] Denny et al, MRM 49, 743-54, 2003. [3] Bieri et al, MRM 55, 233-41, 2006. [4] Kim et al, Radiol 230, 862-71, 2004. [5] Rump et al, MRM 57, 388-95, 2007.