Single Breath Hold Transient MR-Elastography of the Heart - Imaging Pulsed Shear Wave Propagation induced by Aortic Valve Closure -

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Introduction

The assessment of myocardial viability is of great diagnostic importance, for instance after a stroke. It is expected, that the elastic properties of the cardiac muscle change locally depending on the degree of tissue damage. Therefore, techniques such as for instance tagging [1] or displacement-encoding with stimulated-echoes (DENSE) have been developed to measure regional strain generated by the inherent contraction of the cardiac muscle [2]. Reduced strain response relative to known stress would thereby demonstrate increased elasticity. Unfortunately, the stress is not known for these kind of measurements. Recently, Kanai [3] demonstrated with high-speed ultrasound the presence of transient shear waves within the septum generated by the aortic valve closure (AVC) at end systole (Fig.1a: end of cardiac phase 2). This effect coincides with the appearance of the second heart sound (Fig.1a: heart sound II). The speed of these shear waves was estimated at 60Hz to be around c=3-5m/s with typical values for the shear modulus of μ=24-30kPa and a maximum amplitude of ~120μm. Given these high values for the shear modulus, it is most challenging to induce high-frequency shear waves (~300Hz) via an external mechanical transducer still detectable by classical MR-elastography (MRE) [4]. Thus, one can propose to utilize the natural waves generated by inherent cardiac activity as source for MRE-contrast.

Materials & Methods

A retrospectively-gated, ECG-triggered balanced FFE-sequence was extended by a sinusoidal motion-encoding gradient ending just before the read-out gradient. The relative high shear modulus of the septum necessitates the coding of a comparable high frequency component of the wave. Thereby sufficiently short wavelengths can be observed within the ~5cm long septum. Phase-locking the sequence to the 300Hz component (i.e. T_0=3.33ms) allows to select TE=1.5*T_0=5ms and TR=3*T_0=10ms. Within a single breath hold of ~20sec, 20 cardiac phases were acquired for a single slice with FOV=320mm, slice thickness 8mm, 128^2 resolution, α=50° and 72% phase sharing among neighboring cardiac phases. A 5-element cardiac coil was used in conjunction with SENSE (reduction factor 1) in order to get phase images. Experiments were performed on a Philips Intera 1.5T system (Philips Medical System, Eindhoven, The Netherlands).

Results

Fig.1b) shows the obtained phase-map within the septum at the beginning of the heart-phase 3, i.e. after closure of the aortic valve. Modulations resembling wave effects are clearly visible from the root of the aortic valve towards the apex. They are statistically significant when compared to the image obtained in a second experiment with the motion-encoding gradient turned off (Fig.1c). Fig.1d) shows at five different cardiac phases (see Fig.1a) the obtained phase-profiles (red lines in b) and c)) from the root of the aortic valve towards the apex. When compared to the phase-profiles in Fig.1e) (without motion encoding) it is obvious that transient shear waves are measured during the beginning of the diastole, i.e. shortly after AVC. An estimate of the wavelength yields λ~ 15mm, i.e. c ~ 4.5m/s, i.e. μ~20kPa.

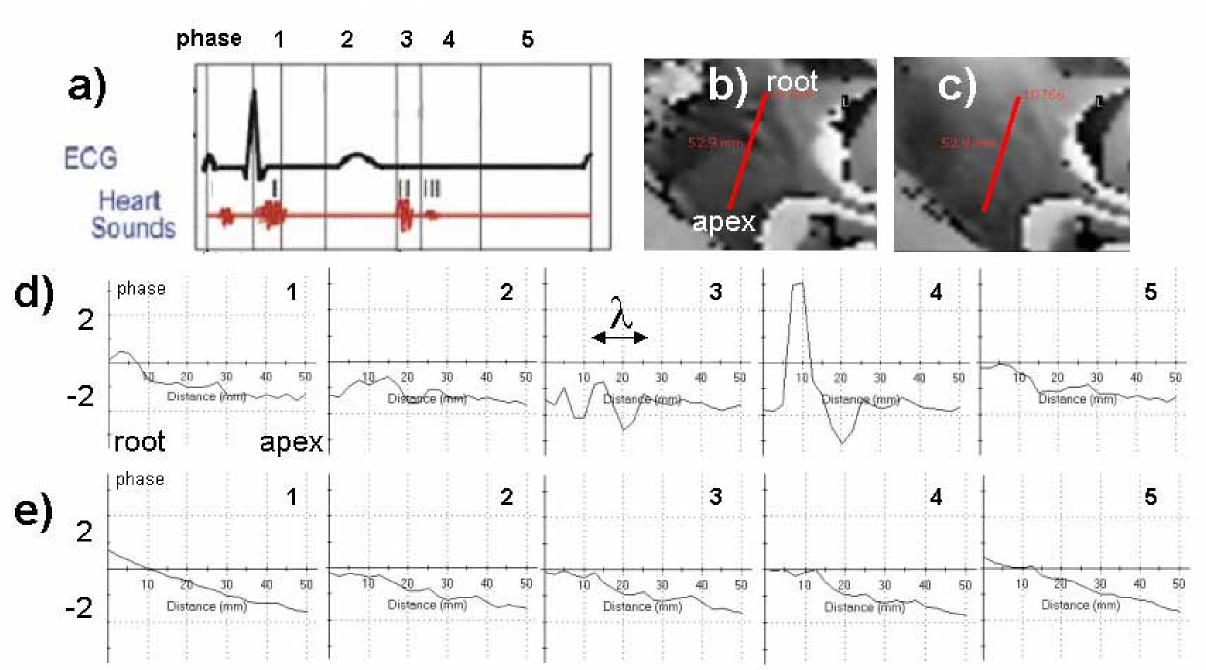

Fig.1: a) Sketch of the heart cycle with respect to ECG and generated heart sound. b) MRE phase image of the septum with motion encoding after AVC and c) without motion encoding. d) Phase-profiles along the septum for different heart phases with motion coding and e) without.

Discussion & Conclusions

The application of classical MRE (i.e. using an external mechanical transducer) to the heart is rather difficult since the stiffness of the myocardium necessitates utilization of high excitation frequencies (~300-500Hz) in order to generate sufficiently short wavelength. Efficient penetration from outside to the heart is counteracted by strong attenuation. Utilization of intrinsically generated waves by AVC allows to overcome this limitation. Estimated values for the speed agree with recent data obtained with ultrasound. Elasticity is estimated around the isovolumic relaxation, which mainly provides information about the passive state of the myocardium. Stronger gradients for the motion encoding gradient should for instance enable visualization of waves generated during the first heart sound, which would provide information about the active state of the myocardium. Repetitive breath holds could provide 3D datasets enabling utilization of advanced reconstruction techniques for the correct estimation of viscoelastic parameters.

References

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