2D non-linear MR Elastography - preliminary results

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Synopsis

In MR Elastography (MRE) tissue vibrations are determined for evaluating the shear stiffness of soft tissues in terms of local wave lengths. Beyond the linear stress-strain response of materials, their non-linear elastic behavior is of special interest for the characterization of biological tissue. Here, a method is proposed to image spatially resolved non-linear wave propagation in MRE. The technique relies on the detection of higher harmonic vibrations, at a multiple of the fundamental frequency. These frequencies are selected by the specific motion encoding gradient and evaluated for their spatial amplitude functions. Potential applications for 2D mapping of non-linear elastic coefficients of *in vivo* tissues are discussed.

Introduction

In rheology, the non-linearity of elasticity is a sensitive means to characterize tissue mechanically [1]. Dynamic MRE reflects a non-linear stress-strain function of the investigated material in terms of higher harmonic shear vibrations [2]. The spectral content of such inharmonic oscillations indicate how the shear waves accumulate their non-linear behavior while traveling through a non-linear elastic object [3]. The frequency selectivity of MRE caused by the application of motion encoding gradients (MEG) [4] requires a distinctive setup for each experiment to select specific harmonics.

Methods

Non-linear MRE experiments were performed on a 1.5 T Siemens Sonata scanner using a standard head coil. A phantom (1% agarose gel) was prepared and excited by 125 Hz (f_v) shear vibrations with maximum deflection of 1 mm. Encoding of the vibrations was achieved by a gradient echo sequence including sinusoidal MEG with 26 mT/m amplitude, variable frequency (f_G), and variable period number (n_G). Acquisition parameters were TR = 112 ms, flip angle = 30°, FOV = 200 mm, image matrix size = 128x128, and slice thickness = 5 mm. f_G was set to 500 Hz to select the 500 Hz component of the inharmonic tissue vibrations. n_G was chosen to either fulfill the following filter condition:

$$n_G = f_G / f_v \cdot n; \text{ with } n = 1, 2, 3..., \quad (1)$$

or to allow certain contributions of fundamental vibrations to be encoded by the MEG, i.e. n_G = 24 and 25, respectively. A variable time delay between the start of mechanical excitation and MEG was 32 times incremented for achieving time resolved snap shots of the propagating waves.

Results

The experimental phase contrast wave patterns (Figs. 1a/b) show the 4th harmonic of the fundamental vibration in the agarose gel. Corresponding to Eq. 1 in Fig. 1a both 4th harmonic and a tiny ratio of the fundamental frequency are superimposed. In contrast, Fig. 1b shows solely the filtered 500-Hz vibration. The spatially resolved amplitude of this oscillation is shown in Fig. 1c. It is visible that the intensity of this harmonic is firstly growing with increasing distance to the actuator and then decreasing again due to damping. This behavior of non-linear wave propagation is better demonstrated in the profile plot of Fig. 1d. From there a 'shock' distance, i.e. the distance the waves need to accumulate a detectable non-linear effect, was estimated to be 25 mm.

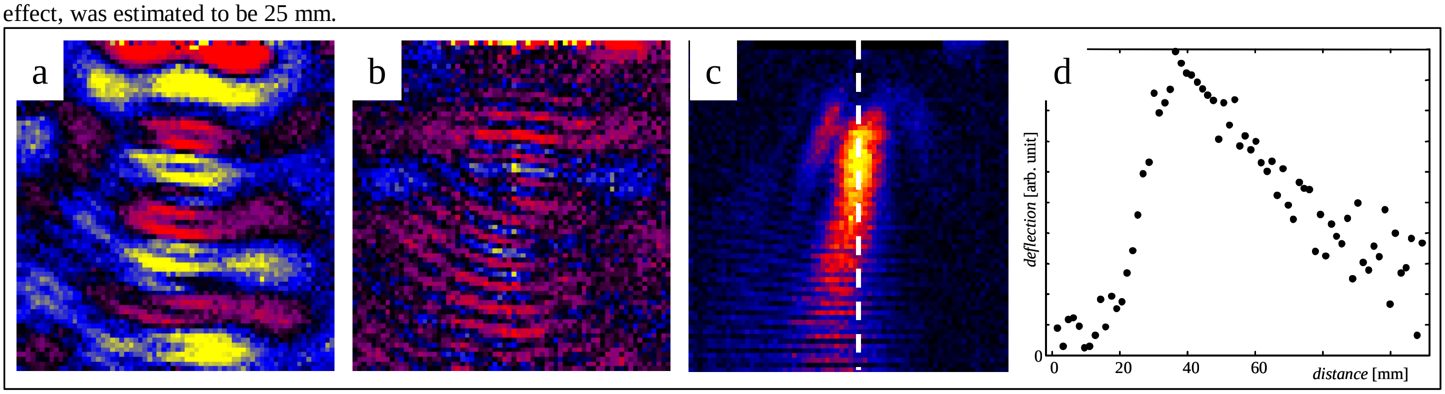

Fig. 1 Non-linear MRE experiments of an agarose sample with 125 Hz shear wave excitation at the top. **a:** shear wave pattern acquired with f_G = 500 Hz and n_G = 25. **b:** same as **(a)** but with n_G = 24 to demonstrate the match of the filter condition (Eq. 1). **c:** Fourier-filtered 500 Hz-component of **(b)**. **d:** profile plot of the cross section indicated as dashed line in **(c)**. It is well visible that the non-linear elasticity of agarose causes a growing amplitude of the 4th harmonic vibration with increasing distance to the actuator.

Discussion

Due to the finite bandwidth of the MEG a match of a filter condition (see Eq.1) needs to be considered. While a match of Eq. 1 yields single frequencies, a deviation from Eq. 1 allows to measure the amplitudes of several harmonics in one experiment. Since for a quantitative evaluation of the non-linear elastic coefficients the amplitude ratios of several harmonics are required, the scenario displayed in Fig. 1a allows to increase time efficiency of non-linear MRE. However, the accumulative character of non-linear wave propagation (see Figs. 1c/d) prevents a direct relation of higher harmonic amplitudes to spatially resolved elastic parameters. To compare the signal intensity along rows in Fig. 1c differences of the deflection amplitudes must be considered. This is particularly important for future applications of spatially resolved non-linear MRE.

References

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