Shear Wave Imaging by using B_1 gradients

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Target audience :

Researchers working on the MR elastography with high resolution.

Purpose :

The main goal of this study is to show the feasibility of using B_1 gradients in detecting the shear properties of tissues at kilohertz range frequencies. With this method, shear waves on stiff and small tissues can be detected with high resolution without the frequency limitation faced up with in methods using B_0 gradient coils due to the slow gradient switching times.

Theory:

Magnetic resonance elastography (MRE) is an imaging technique used for the visualization of elastic properties of biological tissues. Wave images can be obtained from MR phase images when motion sensitization gradients (MEGs) are synchronized with the shear wave excitation pulse generated by an electromechanical actuator [1]. The phase (ϕ) measured using MEGs (G) can be expressed as in Eq.(1), where ξ_0 is displacement vector, T is the period of the MEG, N is the number of the gradient cycles, k is the wave number, and r is the spatial location of the spin. Due to the gradient amplitude and slew rate limitations of the MR system, in order to detect the stiffness of the small and stiff tissues (e.g. hyaline cartilage tissue), a new gradient coil has to be constructed [2]. But using gradient coils at higher frequencies causes an increase in the eddy currents induced by fast switching rates, and also it causes an increase in the noise induced by the gradient coils. In previous NMR studies [3, 4], usage of the B_1 gradient instead of the B_0 gradient has been proposed to detect the diffusion, fluid flow, and mechanical vibration at low frequencies. Based on these studies, in this study, we apply an RF pulse with a phase alternating between 0 and π in synchrony with motion and we observe the signal only due to the motion and therefore the displacement of the shear wave can be calculated by using the magnitude image. Eq. (2) gives the relation between the B_1 gradient ($dB_1/d\xi$) and the displacement (ξ_0). Figure 1 shows the pulse sequence used in this method.

$$\phi = \frac{2\gamma N T \bar{G}\cdot\bar{\xi}_0}{\pi}\sin(\bar{k}\cdot\bar{r}+\alpha) \quad ..(1)$$

$$M = M_0\frac{2\gamma N T\frac{d\bar{B}_1}{d\xi}\cdot\bar{\xi}_0}{\pi}\sin(\bar{k}\cdot\bar{r}+\alpha) \quad ..(2)$$

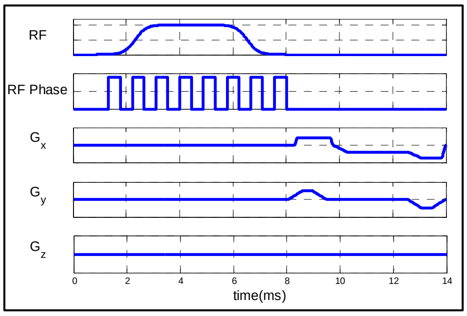

Figure 1: Pulse sequence with 8 ms RF pulse with alternating phase at 1 kHz

Experiments & Results:

In order to verify the method, MR experiments were performed by using the B_0 gradients and the B_1 gradients. The displacement values obtained with two methods were compared. To acquire a sufficient B_1 gradient value that could be used in the detection of the shear wave displacement, a loop coil with 1cm diameter was used. 3% agar gelatin phantom with 2×1×2cm dimensions is prepared as a model of the stiff and small tissue. A mechanical actuator is used to create mechanical shear waves along the z-direction with frequencies in the range of 1 and 5 kHz [2]. The experimental setup is shown in Figure 2.

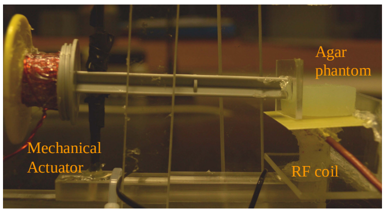

Figure 2: Experimental Setup

All experiments were performed using a 3 tesla Siemens Tim Trio scanner. The maximum allowed slew rate for the scanner is given as 180mT/m/ms. The imaging parameters were: no slice selection, FOV=116mm, TR=100ms and resolution=256x256. Experiments are repeated for 1 kHz and 2 kHz frequencies. For the method using the B_0 gradients; for 1kHz frequency, number of MEGs is N=10 cycles and the magnitude of the gradient is set to 30 mT/m; for 2 kHz frequency, number of MEGs is increased to N=20 cycles and the magnitude of the gradient is decreased to 20 mT/m due to the slew rate limitation. In order to calculate the value of the B_1 gradient generated by the loop coil, B_1 maps are used [5] and the voltage level of the RF pulse is adjusted such that 25mT/m B_1 gradient is achieved. Duration of the RF pulse is set to 8ms, which is equal to the value of N times T, where T is 1ms and 0.5ms for 1 and 2 kHz, respectively. By alternating the phase of the RF pulse from 0 to π, positive and negative RF cycles are formed. By using MR trigger, the RF cycles are synchronized with the mechanical wave. Shear waves are detected by using axial and coronal slices. Note that in the sequence used for the proposed method, there is no slice selection gradient.

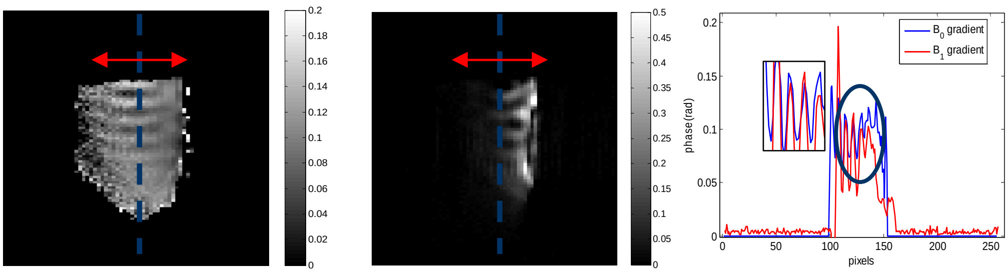

Figure 3: For 2 kHz wave frequency: (Left) Phase difference image obtained with B_0 gradients, (Middle) Normalized magnitude image obtained with B_1 gradients (Right) Comparison of the results along the blue dashed line for both method.

Figure 3 shows the comparison of the axial wave images obtained by B_0 gradients and B_1 gradients for 2 kHz. Direction of the motion is shown with a double headed red arrow. By using the peak to peak phase change, the displacement is calculated as 1.17µm with B_0 gradients and 1.34µm with B_1 gradients. The wavelength of the shear wave in 3% agar phantom is calculated as 3.2mm for 2 kHz. Same experiments are repeated for 1kHz and the displacement is calculated as 1.4 µm and 1.8µm with B_0 and B_1 gradients, respectively. The wavelength of the shear wave in 3% agar phantom is calculated as 6.4mm for 1 kHz as expected.

Conclusion and Discussion:

In this study, it is shown that B_1 gradients can be used to detect the shear properties at the frequencies in the kilohertz range instead of the B_0 gradients. With this alternative method the limitations due to finite rise- and fall-time of the gradient waveforms and therefore the maximum frequency of the wave that can be detected in the tissue can be solved. On the other hand, as a limitation in order to obtain the desired B_1 gradient at the level of B_0 gradient, high RF power is needed.

References: [1] Muthupillai et. al MRM 1996,36: 266-274. [2] Lopez et. Al JMRI 2007, 25: 310-320. [3] Karczmar et. al MRM 1988 ,7: 111-116. [4] Baril et. al JMR 2000, 146: 223-227. [5] Sacolick et al. MRM 2010,63:1315-1322.