Analytical Error Propagation in Microscopic Magnetic Resonance Elastography

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INTRODUCTION

Microscopic magnetic resonance elastography (μMRE) is a technique used to measure shear wave vector propagating through small biological sample with micron spatial resolution using a high field MRI system (1). The acoustic excitation device is synchronized with the MRI data acquisition system to produce shear wave images based on phase contrast MRI. Shear wave or phase difference image can be collected either by a gradient-echo or a spin-echo phase contrast sequence. In the case of spin-echo phase contrast pulse sequences, more than one scheme is available to manipulate the phase. These schemes are dependant on the location and timing of the bipolar gradient pulses in synchrony with the mechanical actuator. Error propagation models have been used in MRI previously, e.g., to estimate how noise propagates through diffusion tensor imaging (2) and estimate SNR for quasi static MR elastography (3).

The goal of this study is to provide an analytical model estimating the variance of shear wave images using error propagation technique and relate it to the signal-to-noise ratio (SNR) of the two MR magnitude images corresponding to the phase images used to produce the phase difference map. The analytically calculated variance of shear wave images has been compared with experimental results obtained using stationary phantoms and compared with previously published analytical models (4). The error propagation model for calculating the phase variance has been used to optimize the duration of the bipolar gradient pulses and the number of averages needed to obtain acceptable shear wave images with low noise or phase variance. Ultimately, the model will be used to incorporate and optimize most MR data acquisitions parameters.

THEORY

Using the error propagation equation for two independent measurements (4), the phase difference map variance can be represented by

$$\sigma^2_{\Delta\phi} = \sigma^2_{\phi 1} + \sigma^2_{\phi 2} = \frac{SNR_1^{\,2} + SNR_2^{\,2}}{(SNR_1 SNR_2)^2}$$

where $\sigma^2_{\Delta\phi}$ is the variance for the shear wave image, $\sigma^2_{\phi 1}$ and $\sigma^2_{\phi 2}$ is the variance for the first and second phase images, respectively. The SNRs of the corresponding magnitude images are given by SNR_1 and SNR_2. The phase variance of the shear wave image ($\sigma^2_{\Delta\phi}$) can be calculated experimentally by measuring the variance of the phase difference map over a region of interest for a homogenous phantom without the introduction of transverse shear wave excitation.

METHOD

μMRE experiments were conducted at 11.74 T (500 MHz for protons) using a 56 mm vertical bore magnet (Oxford Instruments, Oxford, UK). The scanner has a bore size of 56 mm with 10 mm available for imaging and is equipped with a Bruker DRX-500 MHz Avance Spectrometer (Bruker Instruments, Billerica, MA. USA). A Bruker linear triple axis gradient system with a maximum magnetic field gradient strength of 200 G/cm and a Micro 5 imaging probe were used for all experiments. The spectrometer is controlled by ParaVision imaging software on a Silicon Graphic SGI2 workstation (Mountain View, CA. USA). The Bruker 5 and 10 mm RF saddle coils were used for MR imaging. A block diagram summarizing a functional μMRE system including all major hardware and software components is shown in Fig. 1.

RESULTS

The theoretical and experimental phase varies in the shear wave images of a stationary agar gel phantom are shown in Fig.2. The experimental and theoretical values exhibited similar trends. The phase variance increased with an increasing number of bipolar pulses (i.e., a longer echo time). Increasing the number of averages reduced the phase variance significantly, as expected; and the theoretical and experimental values approached each other. The theoretical and experimental phase variances for different number of averages are shown in Fig. 3.

DISCUSSION AND CONCLUSIONS

The results demonstrated that the phase variance for shear wave images can be analytically predicted. The experimental and analytical values exhibit similar trends, although discrepancy was also observed. The analytical model, however, can be used to optimize the number of averages, pulse sequence used, and acceptable duration of the bipolar pulses. Bishop et al. estimated the phase variance of shear wave images based on only one of the SNR of the two magnitude images (4). They assumed that the SNR for both images is the same. A comparison between the variance measurement estimated using one MR magnitude image and the error propagation model is shown in Fig. 2. Clearly, the propagation technique produced results that were closer to experimental findings.

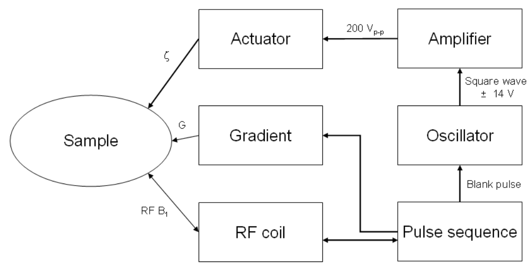

Figure 1. A block diagram summarizing a functional μMRE system

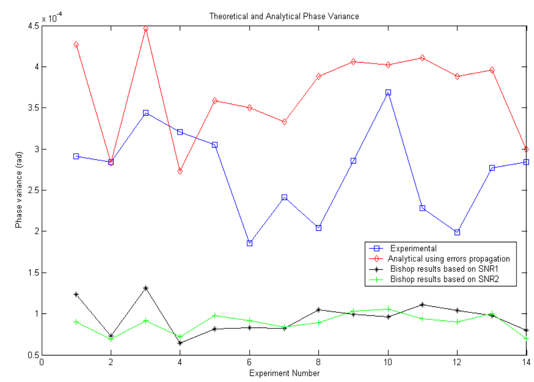

Figure 2. Comparison between experimental and analytically calculated phase varies using error propagation and Bishop models.

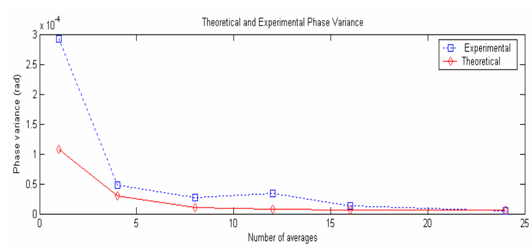

Figure 3. Dependence of phase variance on the number of averages

REFERENCES

[1] Othman SF, et al. 12th ISMRM, 2004.
[2] Poonawalla AH, et al. Magn Reson Imag 2004;19(4):489-98.
[3] Bevington, et al. Data reduction and error analysis for the physical sciences. McGraw-Hill, 2002
[4] Bishop, et al. IEEE Transaction on medical imaging 20:1183-1187, 2001.
[5] Gudbjartsson H, et al. Magn Reson Med 1995;34:910–914.