Data Reduction Analysis for Brain MR Elastography

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Introduction

Magnetic resonance elastography (MRE) is a method for quantitatively assessing the stiffness of tissue non-invasively by using phase contrast MRI to visualize and measure the propagation speed with which shear waves travel through the tissue of interest [1]. There is an increasing interest in applying the technology as a way to characterize the mechanical properties of the brain [2-4]. In order to ensure patient comfort, the acquisition time for MRE must be minimized, with particular interest being paid to the time during which shear waves are generated. The purpose of this work was to determine how much of k-space must be collected during active vibration, and to determine if the remaining portions of k-space can be filled with analogous data from a stationary acquisition or filled with zeros.

Methods

MRE wave images were collected in a normal human volunteer on a 1.5 T MR imager after obtaining informed consent and in accordance with IRB guidelines. 60 Hz shear waves were introduced into the brain using a system of two active drivers connected to two passive drums. The passive drivers were placed under the volunteer's head and operated alternately to induce a left-right motion of the head. Data were collected in the axial plane with a single-channel quadrature birdcage head coil. Four phase offsets of a single slice were collected using a gradient echo MRE sequence with phase encoding in the left/right direction. Other imaging parameters included TR/TE=50/27.7 ms, FOV=24 cm, slice thickness=4 mm, 256x256 imaging matrix, ±16 kHz bandwidth. Two data sets were collected. The first was collected with wave generation and 1 cycle of motion encoding gradients (MEG) with amplitude 1.6 G/cm (motion case), and the second was collected without wave generation but with the same MEG (static case). The k-space data for the motion case were then decimated in the phase encoding direction keeping only the central lines. The k-space data removed were then replaced with either static data from the same k-space locations (keyhole) or zeros (zeropad). Wave images were then reconstructed and prefiltered with a 4^{th} order Butterworth bandpass filter with cutoffs of 2.5 and 40 waves/FOV. Inversions were performed with a 2D LFE algorithm using a 3-axis displacement field [5]. An ROI including the entire slice was used to measure the mean and standard deviation of brain stiffness.

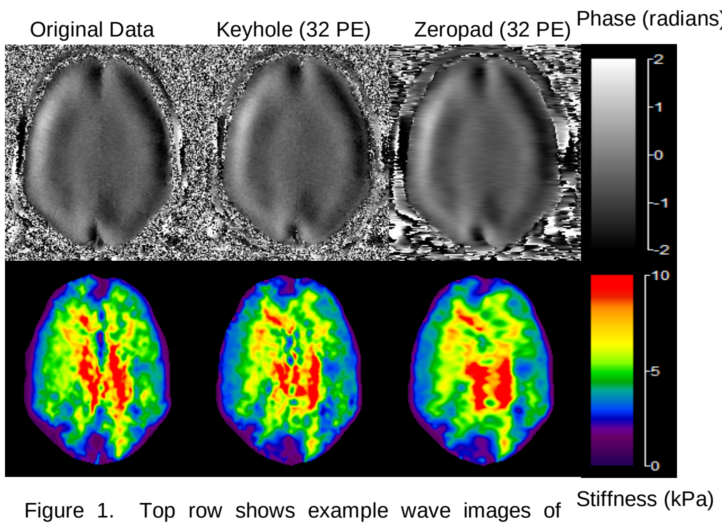

Figure 1. Top row shows example wave images of original data, keyhole data, and zeropad data. Below those images are the corresponding stiffness maps.

Results

Example wave images and the corresponding inversions are shown in Figure 1. A plot of brain stiffness versus the number of retained phase encodes (PE) is shown in Figure 2. The plot shows that decimation of the motion data in k-space has little effect on the resulting average LFE stiffness, particularly when compared to the variance of the stiffness estimates. The plot in Figure 3 indicates error, measured as the sum of the absolute value of the residuals resulting from subtraction of the decimated phase images from originals derived from the full k-space data, is inversely and linearly proportional to PE.

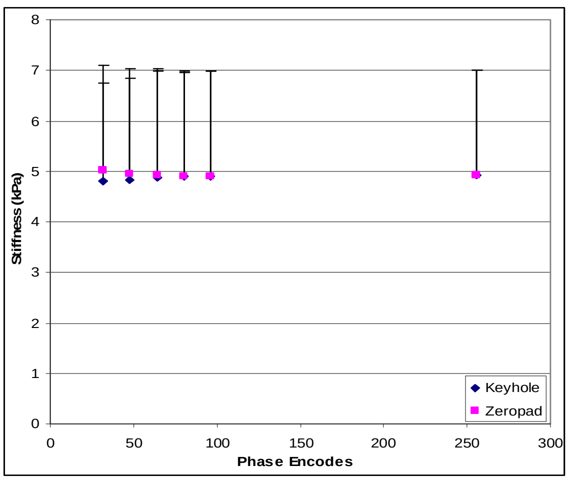

Figure 2. Plot of LFE stiffness versus number of phase encodes used from motion case. The relationship is flat, indicating an insignificant effect of the number of phase encodes on the LFE stiffness in brain.

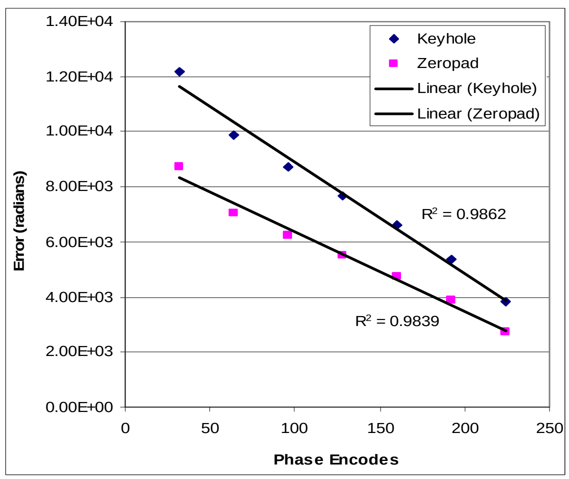

Figure 3. Plot of the total phase image error versus number of phase encodes. Linear regression indicates that these variables are linearly related.

Discussion

The acquisition time for brain MRE data can be greatly reduced by minimizing the number of PE. For any given application of MRE, a similar analysis could be performed to determine how the number of PE will affect the final stiffness estimate; here 60 Hz shear waves in the brain inverted with an LFE algorithm indicate that as few as 32 PE can provide a reliable stiffness estimate for the entire brain. Such a reduction in the number of PE could prove to be significant to reduce the time of 2D and 3D acquisitions.

References

[1] Muthupillai et al., Science. 269: 1854 (1995). [2] Kruse et al., NeuroImage. (2007). [3] Sack et al., NMR in Biomedicine. (2007). [4] Xu et al., Acta Radiologica. 48 (1): 112 (2007). [5] Manduca et al., Medical Image Analysis. 5: 237 (2001).