

Measuring the Transient before Steady-State in Brain MR Elastography

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Introduction

Magnetic Resonance Elastography (MRE) is an emerging method for noninvasively investigating the mechanical properties of tissue [1]. In dynamic, time-harmonic elastography, imaged waves must be fully developed and must have reached steady state conditions in order to satisfy the assumptions of the wave inversion methodology [2]. Typically, this condition is satisfied by vibrating tissue for a finite time interval prior to imaging, however little justification is given regarding the length of the required interval for brain MRE, save for an instance when 400 ms was employed [3]. In this work, we investigated how long it takes for brain shear waves to reach steady state during a typical MRE experiment. An alternative measure of visualizing the displacement of the brain was found in SPAMM tagging [4] and HARP processing [5], which provide higher temporal resolution than MRE.

Methods

In Vivo Experiments: Two healthy subjects were scanned with their heads placed in a rocker apparatus attached inside a Siemens 3T Allegra head-only scanner. Actuation occurred at 50hz and was driven through a long rod by an electromagnetic shaker, as has been previously used in MRE experiments [6,7]. Imaging was performed with a gradient echo sequence with twelve interleaved spiral readouts, with a FOV of 240mm and a 128x128 matrix size, with TR/TE = 10/1.5 ms. Interleaves were ordered such that a single shot was repeated 200 times, and that sequence was repeated 12 times to acquire the necessary interleaves for 200 images. This allowed for a very high temporal resolution of 10 ms to be achieved, while sampling over 2 seconds. SPAMM tagging [4] was applied at the beginning of each repetition, as was mechanical shaking. The entire acquisition was repeated four times: both axial and sagittal imaging planes, and with tagging in each in-plane direction.

Processing: HARP processing [5] was applied to the tagged images to recover the measured displacements. Both in-plane displacement measures were combined to get a measure for amplitude of displacement for each point in time. In order to extract information about steady-state behavior, the dominant displacement mode was determined using the Proper Orthogonal Decomposition (POD) [6]. The POD algorithm returns both the mode shape and its temporal profile.

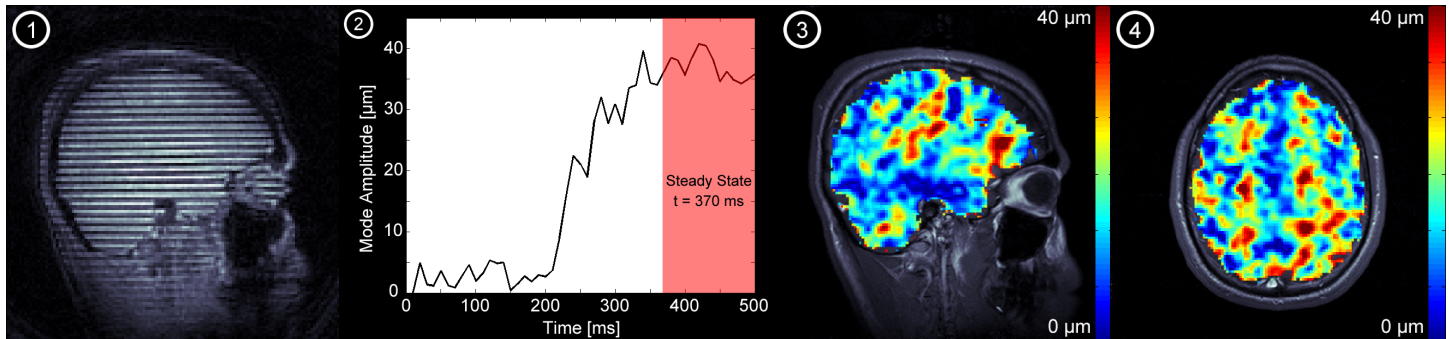


Fig. 1: SPAMM image in sagittal plane with S/I tagging

Fig. 2: Temporal profile of the amplitude of the dominant mode

Fig. 3: Steady-state sagittal in-plane displacement amplitudes

Fig. 4: Steady-state axial in-plane displacement amplitudes

Results & Discussion

An example of a SPAMM-tagged image in the sagittal plane with tags in the superior-inferior direction can be seen in Figure 1. In order to separate steady-state motion from transient phenomena, we looked at the persistent mode of the system using a POD algorithm. Since our temporal resolution is equal to half that of the vibration period, we expect the amplitude of the mode displacement to plateau in time, and simply oscillate in direction with each sample. Figure 2 presents a plot of the temporal evolution of the amplitude of in-plane displacement of the dominant mode in the sagittal plane. Only 500 ms of acquired data was used as the SNR became too low for reliable HARP processing at later time points. The steady-state time is marked on the plot where the amplitude levels off. This value was found to be approximately 370 ms for one subject, and 350 ms for the other, calculated from the sagittal plane, and 410 ms and 400 ms in the axial plane. The mode shapes with steady-state displacement amplitude is overlaid on anatomical images for both sagittal and axial cases and shown in Figures 3 and 4, respectively.

Conclusions

We have proposed and implemented a method to investigate the temporal profile of wave motion present in MRE experiments in the brain. It was shown that for a typical amount of vibration during an MRE scan, the tissue displacement reached a steady state at approximately 400 ms, which was true for two subjects. This result can be used to inform future MRE experiments in the brain and can potentially lead to better mechanical actuation protocols and better inversion algorithms.

References

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