Fast, Whole-Brain MR Elastography using a 3D Multislab Acquisition

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INTRODUCTION: Imaging the mechanical properties of the brain with magnetic resonance elastography (MRE) has developed as a promising new method for investigating neurodegeneration. However, the need to capture time-resolved, full vector field displacements limits achievable spatial resolution and brain coverage in order to keep acquisition times short. Thus, most studies only report property values averaged over a small imaging volume. Recently, a multishot acquisition scheme was presented that was capable of acquiring high-resolution brain MRE data with adequate SNR [1], though coverage was limited for an acceptable scan time of 10 minutes. In this work, we expand on the previous acquisition by taking advantage of the improved SNR efficiency of 3D multislab *k*-space encoding [2] in order to obtain high-resolution MRE displacement data with whole-brain coverage while maintaining SNR and short acquisition time.

THEORY: ***SNR Efficiency***: In typical 2D imaging acquisitions, every slice is excited and acquired during a single TR, and the TR of a sequence is often increased to accommodate more slices. This approach increases the total acquisition time, though minimally increases the SNR of the acquisition since there is only minor additional signal recovery as the TR becomes much greater than the T_1 of the imaged tissue. Alternatively, the increased acquisition time can be used to excite and image the same volume multiple times, either through averaging or with 3D imaging, thus contributing to the total readout duration per imaging volume, and the SNR of an acquisition is proportional to the root of this time. SNR efficiency describes the relative SNR per amount of total acquisition time, and can be used to find the optimal TR given the tradeoff with averaging. For brain it has been shown that a TR of approximately 1500 ms has optimal efficiency [2].

***3D Multislab Acquisition*:** While the optimal TR of 1500 ms in 2D imaging will result in very little coverage, in typical 3D imaging it will result in very long acquisition times. Instead, by dividing the desired volume in to smaller 3D slabs comprising multiple slices, whole-brain coverage can be achieved with improved SNR efficiency. In this case, the shortest acquisition time can be achieved using the maximum number of slabs possible per TR. The *k*-space trajectory used in this acquisition is a 3D stack-of-spirals, with in-plane spirals divided into multiple interleaves to reduce readout duration per repetition. This allows for reduction of field inhomogeneity distortions and T_2* blurring. Multishot acquisitions in MRE require correction for motion-induced phase errors [1], and a correction for errors in 3D is needed for this sequence [3]. A 3D navigator is acquired as a stack-of-spirals following refocusing after the imaging readout.

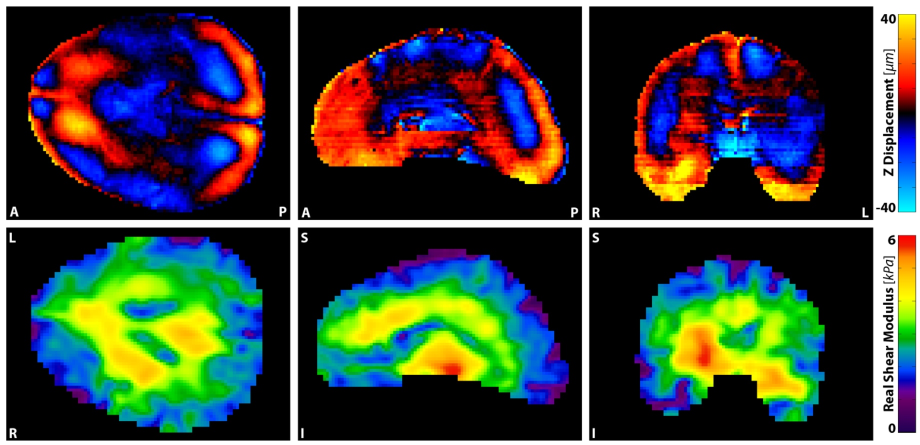

FIG1. axial (left), sagittal (mid), and coronal (right) views of motion in the Z direction (top) and corresponding real shear modulus (bottom); orientations are marked on each pane. The cerebellum is masked prior to inversion and in these images.

METHODS: One subject was scanned on a Siemens 3T Trio with a 12-channel head coil. MRE displacement data was acquired using the multislab sequence with the following parameters: TR/TE = 1600/73 ms; FOV = 240 mm; matrix = 120x120; 10 slabs of 8 slices with a 2 mm thickness, with 25% overlap between slabs to account for slab boundary artifacts. In-plane constant density spirals with four interleaves were designed, for a readout duration of 15 ms per interleaf, though only two acquired for a parallel imaging reduction factor of R = 2. Iterative image reconstruction incorporating motion correction, SENSE, and field inhomogeneity correction was performed using GPUs with IMPATIENT [4]. Imaging was repeated with motion encoding on each of the three gradient axes, with both positive and negative polarities, and four time points were captured over a single vibration period. The result was full vector field complex displacement data at 50 Hz with a 2x2x2 mm^3 isotropic spatial resolution and 120 mm coverage in the slice encoding direction acquired in just over 10 minutes. Mechanical properties were estimated using nonlinear inversion with a viscoelastic material model [5].

RESULTS and DISCUSSION: Quality of the data was assessed using the octahedral shear strain-based SNR measure (OSS-SNR). The OSS-SNR for this dataset was 5.56, which is well above the minimum needed for accurate inversion [6]. In this case, the improved SNR efficiency of the 3D multislab encoding scheme allowed us to reduce acquisition time through parallel imaging and acquire only the minimum number of MRE time points while maintaining excellent OSS-SNR. Figure 1 presents axial, sagittal, and coronal views of a single direction of displacement and the corresponding real shear modulus in the cerebrum. The high quality of the motion images is evident, with adequate wave penetration to the center of the brain. Property images reflect anatomical features of the brain, most noticeably the soft region of the lateral ventricles. Some slab-to-slab phase errors are visible in the displacements, though these are likely to appear as high frequency noise and won't affect nonlinear inversion, which is clear from the property images themselves.

CONCLUSIONS: Estimating the local mechanical properties of the human brain *in vivo* requires MRE displacement data to be acquired with high spatial resolution, high SNR, and whole-brain coverage, though this is difficult to achieve in a scan time that is acceptable for subject safety and comfort. Here we have taken advantage of the increased SNR efficiency of 3D multislab imaging to develop a sequence that allows for high-resolution, whole-brain MRE displacement data to be acquired with excellent SNR in just over 10 minutes. This acquisition scheme will ultimately allow researchers to study local mechanical properties throughout the entire brain.

REFERENCES: [1] CL Johnson, *et al.*, *MRM*, 2012, in press; [2] JL Holtrop, *et al., ISMRM*, 2012, p.1881; [3] AT Van*, et al., IEEE TMI*, 2011,30:1933-1940; [4] J Gai, *et al.*, *ISMRM*, 2012, p.2550; [5] MDJ McGarry, *et al.*, *Med Phys*, 2012,39:6388-6396; [6] MDJ McGarry, *et al.*, *Phys Med Biol*, 2011,56:N153-N164.