Accelerating MR Elastography by Means of Keyhole Imaging

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Introduction:

The measurement of tissue elasticity by means of MR Elastography (MRE) usually implies the acquisition of phase images. Minimal tissue displacements due to mechanical waves are phase encoded by motion-sensitizing gradients. In order to estimate tissue elasticity, phase maps with different offsets between the induced mechanical wave and the motion-sensitizing gradients [1] need to be acquired. This leads to long measurement times that may reach the limits of patient comfort, especially when measuring brain elasticity, where the patient bites on a vibrating bar, or when the patient is required to maintain an unusual position. Different approaches aim to shorten the measurement time, e.g. multi-echo acquisitions or SSFP-based MRE sequences [2]. In our approach, we used the keyhole technique to accelerate the acquisition [3].

Methods and Materials:

Theory: Partial coverage of k-space is one of the keys to accelerating data acquisition, especially when measuring dynamic changes. In dynamic imaging, one can sequentially 'recycle' part of the acquired k-space for the next image. Either the upper or the lower part of the k-space can be recycled (shared phases technique) or the centre of the k-space is repetitively updated (keyhole imaging). A completely covered k-space is then used for image reconstruction by combining older and newly acquired data.

In standard imaging, the k-space has a maximum in the middle of the k-space, and a more or less smooth decay to higher frequencies can be observed. The image geometry may introduce side maxima, e.g. the Fourier transform of a box corresponds to the sinc function. In motion-encoded MRE phase maps, other off centric maxima corresponding to the wavelength of the induced waves can be observed. The comparison of sequentially acquired images with different phase offsets reveals that changes in k-space typically mainly occur in the central eighth of k-space.

MRE Experiment: An agar gel phantom with 1 percent agar and a 2 percent inclusion was scanned. MRE was performed by mechanically inducing waves into the phantom with a custom-designed piezoelectric actuator [4] using a modified gradient echo phase contrast sequence. An excitation frequency of 100 Hz with an actuator displacement of 300 µm was used. Imaging parameters were: bandwidth=260 Hz/pixel, flip angle=15°, TR=120 ms, TE=33.3 ms, matrix 256x256. A total of 8 phase offsets were acquired. Three motion-sensitizing cycles with an amplitude of 30 mT/m were employed. The acquisitions comprised the entire k-space. All MRI experiments were performed on a 1.5T whole-body Siemens Sonata.

Post Processing: First, the fully covered k-space of the first (Dataset 1) and each subsequent phase offset (Dataset 2) (Fig. 1a-b) were Fourier transformed and the phase maps for MRE were calculated (Fig. 1c-d). Then a varying number of the peripheral k-space lines (Fig. 2) were replaced in Dataset 2 with data from Dataset 1. These k-spaces were Fourier transformed and phase maps calculated. These maps were then subtracted from the original, fully sampled phase image. The subtraction results are depicted in Figure 3.

MRE Processing: Shear moduli were calculated using local frequency estimation from the fully covered k-space datasets as well as from the keyhole images.

Results:

The reconstructed images clearly demonstrate the feasibility of the keyhole technique for MRE. Statistically, there were no differences in the calculated mean shear values between the acquisitions with full k-space coverage and the keyhole images using 128 to 32 central lines.

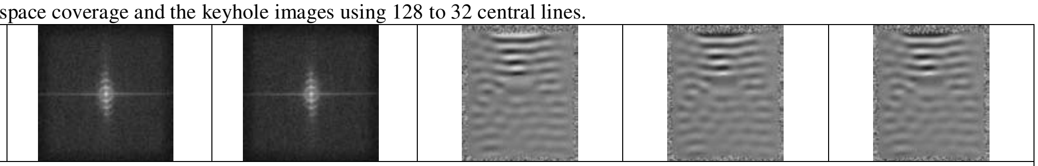

Figure 1: Original fully covered k-spaces (a-b) and reconstructed phase maps (c-d). Keyhole image with 32 of 256 updated k-space lines (e).

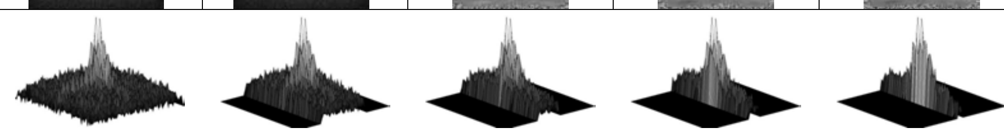

Figure 2: The central 256 (full coverage), 128, 64, 32, and 16 lines, respectively, are updated with the newly acquired data. The higher frequencies are reused from the first acquisition.

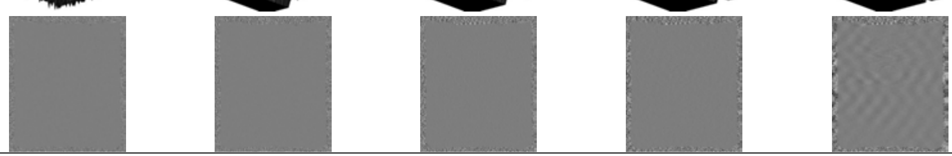

Figure 3: Difference images between full coverage k-space phase map and the keyhole technique.

Discussion:

The present study clearly demonstrates the feasibility and power of keyhole imaging for MRE. Further steps may reduce acquisition time even more by concentrating on only a few selected k-space lines, but one has to keep in mind that this technique works as a band filter and off resonant side effects as well as higher harmonics might be neglected. The necessary fraction of k-space for nearly lossless phase map reconstruction clearly depends on the wavelength of the induced waves. As long as the induced wavelength is significantly larger than the pixel resolution, keyhole imaging will be a viable tool for accelerating MRE data acquisition. Other obstacles to in-vivo application are not apparent. The combination of this technique with a multi-echo sequence may result in a single-shot phase offset acquisition.

References:

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