Decoupling motion navigation from imaging using spatial-spectral RF pulses

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Introduction and Background

Cloverleaf navigators can be used for real-time motion correction of anatomy that moves as a single rigid body, such as the head. For effective navigation using this technique, it is necessary that a reasonably large slab be excited at frequent intervals and that the magnetization be kept in a steady-state. The slab should contain most of the head, including the superior edge but excluding the non-rigid parts (lower jaw and neck). This has been demonstrated with navigators interleaved in steady-state 3D sequences such as 3D gradient echo (GRE) and 3D multishot EPI [1,2], where the same excitation is shared by the navigator and the imaging readouts (GRE), and where the excitations are separate but the navigator and imaging volumes have identical geometries (EPI). The utility of cloverleaf navigator motion correction could be expanded to include 2D imaging (such as clinical T2 imaging with 2D fast spin echo) and non-steady-state imaging methods (such as 2D EPI based diffusion tensor imaging) if the navigator and imaging components could be decoupled. We demonstrate that this is possible by separately exciting fat for navigation and water for imaging using spectrally and spatially selective RF pulses. We also demonstrate that there is sufficient fat in the scalp of a subject with normal body mass index (BMI) for estimating head translations using cloverleaf navigators.

Methods and Results

To investigate the distribution of fat in the head, we implemented a spatial-spectral RF pulse with a full bandwidth of 200 Hz (for use at 1.5 T and 3 T) and variable thickness rectangular spatial profile. The pulse consisted of a triangular EPI readout with 47 phase encoding steps and accompanying sinc pulses for spatial selectivity with a Hamming envelope for spectral selectivity. We incorporated the pulses in a single 3D GRE sequence with interleaved fat and water excitation, with an offset frequency of 220 Hz on the 1.5 T Siemens (Erlangen, Germany) Avanto and 440 Hz on the 3 T Tim Trio scanners. Figure 1 shows representative slices through the resulting 3D volumes from the 3 T Tim Trio. The axial slab selected for water imaging was chosen to have half the thickness of the slab tuned to fat to demonstrate that slab selection for fat and water are decoupled and do not interfere. The figure shows considerable fat in an outer ring in a healthy subject of average BMI.

We incorporated separate water and fat excitation in a 3D GRE sequence with interleaved imaging and navigation components (Figure 2). We collected example data for a pineapple on a moving platform with an attached bottle of mineral oil to provide a source of signal at the resonance frequency of fat for the navigators, and a human performing deliberate head movements. The estimated translations using the cloverleaf navigator and the uncorrected and corrected images (together with a reference image collected in the same way without motion) are shown in Figure 3 for the pineapple and Figure 4 for the human. The improvement with motion correction may be more noticeable for the pineapple because the motions in this case were truly constrained to translations, whereas the head motion may have included rotations.

Conclusion

Clearly, the sequence shown in Figure 2 is inefficient in terms of excitation time vs. total imaging time. However, it demonstrates that the separate excitation of different chemical species for decoupled motion correction and imaging of the brain should work in general, at least for detecting and correcting translations, and may be applicable in other sequences such as 2D EPI, where the effect on timing may be less substantial. Also, the duration of the RF pulse could be halved at 3 T where the frequency separation between water and fat doubles, an asymmetric SLR design could be used and/or parallel transmit methods could be used to shorten the RF pulse.

Since translations are corrected simply by modifying the phase of the k-space information, this can be achieved offline after acquisition and the correction need not be applied in real time. The spherical distribution of fat around the head may impede the accurate estimation of rotations using cloverleaf navigators; we have not tested this yet.

Acknowledgement

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References

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[2] Wastiaux et al., Proc. 14th ISMRM, 746, 2006.

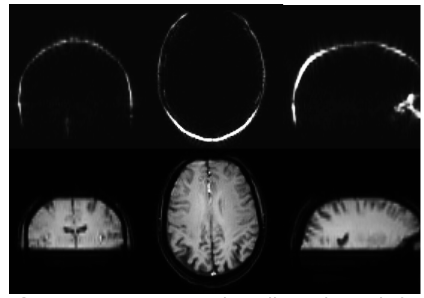

Figure 1: Representative slices through fat (top) and water (bottom) volumes of head collected during single 3D gradient echo interleaved fat/water excitation acquisition.

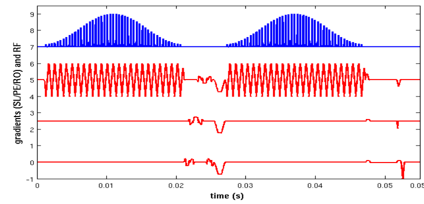

Figure 2: 3D FLASH sequence block including separate fat excitation for cloverleaf navigator (left) and water excitation for imaging (right) using a spatial-spectral RF pulse (200 Hz bandwidth).

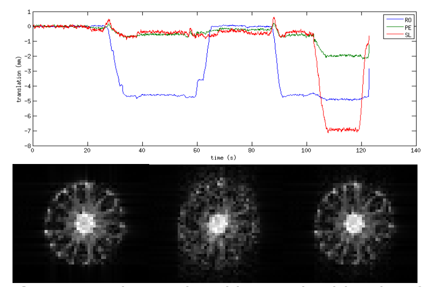

Figure 3: Pineapple with attached bottle of mineral oil on translating platform, motion plot (top) with water images (bottom): no motion (left), motion (middle), motion corrected using navigators (right).

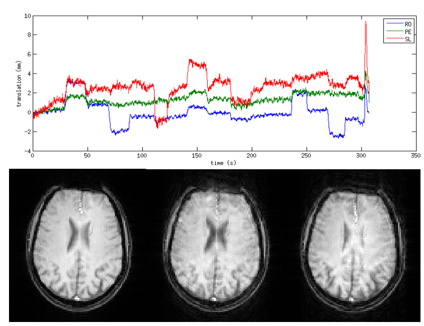

Figure 4: Human deliberately translating head, motion plot (top) with water images (bottom): no motion (left), motion (middle), motion corrected using navigators (right).