An optimized DENSE acquisition scheme for brain displacement mapping

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Introduction

Studying the pulsatile brain motion caused by cerebral blood flow allows insights into alteration of the dynamics in the cranium in certain brain diseases like hydrocephalus. DENSE (Displacement Encoded Stimulated Echo) [1] has been shown to permit the detection of small motions [2]. However, the quantitative analysis of the spatial and temporal characteristics and the generation of strain maps may suffer from spurious constant, temporally and/or spatially varying phase errors. Different schemes for the reduction of these errors using reference scans have been presented [1,3].

In this work we propose a data acquisition scheme similar to [4], but adapted to the needs for brain imaging. The method samples the stimulated echo and anti-echo in two consecutive measurements, which allows eliminating phases induced by the echo-planar readout train and the spoiling gradients.

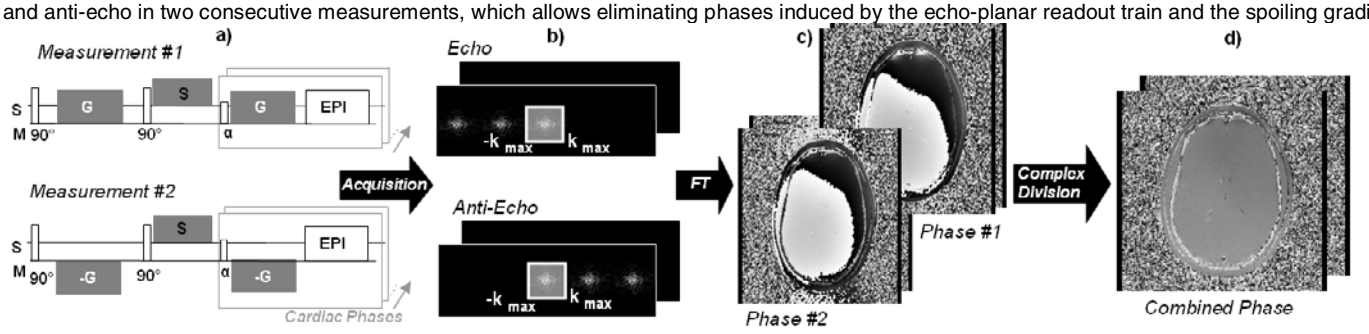

Figure 1: *Concept of displacement data acquisition for one encoding direction.* ***a)*** *A typical DENSE acquisition scheme with two positive encoding/decoding gradients (G) in measurement direction (M) and a spoiling gradient (S) in slice encoding direction applied. To acquire several cardiac phases the signal is subsequently flipped to the transverse plane, decoded and acquired with an EPI read-out train. For measurement # the encoding/decoding gradients are inverted (-G).* ***b)*** *In the two measurements the displacement encoded echo and anti-echo are acquired respectively.* ***c)*** *The phase images are reconstructed from both measurements and* ***d)*** *combined with complex division.*

Methods

Cine DENSE was implemented on a 3T Intera system (Philips Medical Systems, Best, The Netherlands). The sequence was modified to allow inversion of the displacement encoding/decoding gradients in consecutive measurements. In Figure 1a) the schematic of the sequence is given. Inverting the encoding/decoding gradients in the second measurement allowed sampling the anti-echo as illustrated in the lower row of Figure 1b) yielding an inverted displacement encoded phase. Remaining sequence parameters were: spatial resolution: 2x2x4 mm^3, temporal resolution: 25 ms, displacement encoding frequency: 5-10 cycles/mm, EPI factor: 3, T_E: 6.4/10.3 ms (for 5/10 cycles/mm displacement encoding), NSA: 4, ramped flip angles [6]. Two stacks were acquired with a relative rotation of 90° in-plane to map displacement values in two orthogonal directions. In post-processing the two data sets from the two measurements were combined by complex division thereby canceling unwanted phase terms. A 3D phase unwrapping method [5] was used to unwrap aliased phases as a result of the high motion sensitivity selected in the protocol.

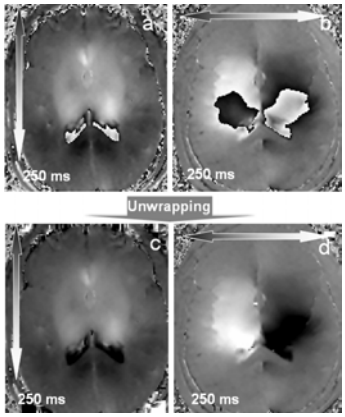

Figure 2*: Original (encoding sensitivity: 10 cycles/mm) and unwrapped phase maps for displacements along AP (a/c) and RL (b/d) acquired 250ms after the R-wave.*

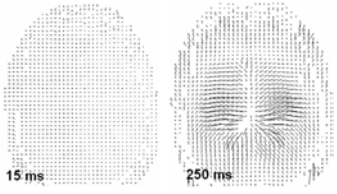

Figure 3: *2D reconstruction of brain motion in a transverse plane 15 ms and 250 ms after the R-wave from displacement encoded data acquired with an encoding frequency of 10 cycles/mm.*

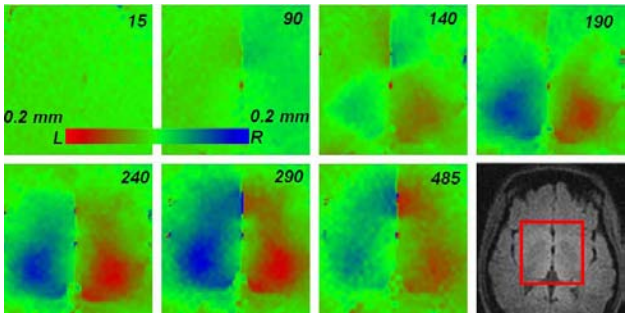

Figure 4: *Selected time frames of RL displacement maps acquired with an encoding frequency of 5 cycles/mm showing shearing between 40-190 ms along the anterior commissure, which then turns into the well known concentric expansion of brain tissue.*

Results

Using the proposed acquisition scheme displacement maps of the brain were successfully acquired. Figure 2 demonstrates the unwrapping step as done in post-processing. Figure 3 shows two-dimensional displacement maps derived from the unwrapped data shown in Figure 2. The subtraction method yields excellent suppression of spurious phase terms as reflected by the homogeneous flat phase seen in the time frame acquired at 15 ms after the R-wave.

Figure 4 displays color-coded displacement maps of right-left displacements for selected cardiac phases at the level of the third ventricle. Shearing of the brain during the first 200 ms of the cardiac cycle is well visualized.

Discussion

The method presented has been shown to allow the reconstruction of 2D displacement maps in the brain with a temporal resolution of 25 ms covering the whole cardiac cycle with sufficient SNR. Compared to methods acquiring a separate reference scan without displacement encoding for phase correction, the current methods provides increased SNR by utilizing two displacement encoded measurements.

Literature

1. Aletras AH et al, J Magn Reson 1999;137(1):247-252. **2.** Soellinger M et al, Proc ISMRM 2005. **3.** Epstein FH and Gilson WD, Magn Reson Med 2004;52(4):774. **4.** Aletras AH et al, J Magn Reson 1999;140(1):41-57. **5.** Rutz A et al, submitted ISMRM'06. **6.** Fischer SE et al, Magn Reson Med 1993;30(2):191-200.