Displacement-Encoded 3D Imaging Sequence using Pre-Section Encoding for Section-Following and Sparse Phase-Cycling

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Displacement-encoded imaging with stimulated-echo (DENSE)(1) has been applied to evaluating myocardial function, arterial wall motion and brain pulsations. To fully characterize the motion of a 3D structure it is desirable to acquire 3D volumetric data. However, with conventional 3D imaging the sections are stationary in space as tissue move through them, so that each section captures different material at different times. DENSE also uses phase cycling to remove part of the signal that is not encoded with displacement information, which prolongs the 3D acquisition. We designed a 3D cine-DENSE sequence to overcome these issues.

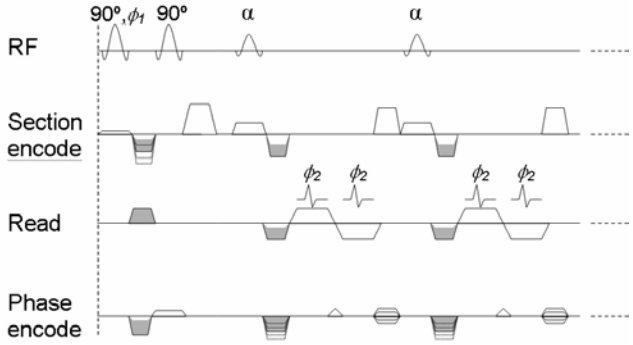

Figure 1 Pulse sequence diagram

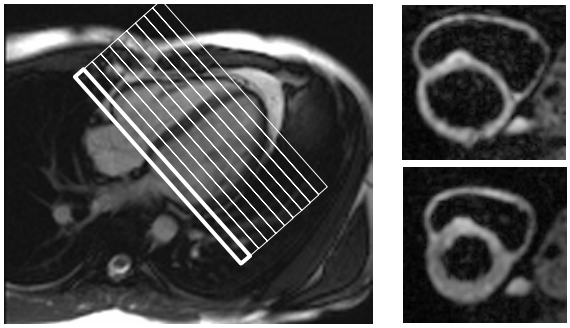

Figure 2 The highlighted section at end-diastole and end-systole.

In the sequence of Fig.1, as in previous 2D slice-following in tagged(2) and DENSE imaging(3), the slab selection occurs in the displacement-encoding part. This causes the same slab of material to be imaged in all subsequent stimulated-echoes. But additionally we also merge the section-encoding (SE) gradient pulse with displacement-encoding gradients, and the signal acquisition part contains only phase-encoding gradients. This ensures that each section of the 3D data corresponds to the same material slice regardless of through slice motion, which we term section-following (Fig.2).

Referring to Fig.1, if the SE moment is k_s, the displacement-encoding moment is k_e, the signal is then $I = I_s exp[i(-k_s z' + k_e d - \phi_1 + \phi_2)] + I_c exp[i(2k_e z' + k_s z' + k_e d + \phi_1 + \phi_2)] + I_{dc} exp[i(k_e z' + k_e d + \phi_2)]$, where d is the displacement vector, z' is the z position at the time of encoding, and ϕ_1 and ϕ_2 are the phases of the first RF pulse and the receiver respectively. The first term is the desired stimulated-echo. The second term is the complex-conjugate echo and is effectively suppressed with sufficient encoding moment k_e. The third is the un-encoded DC signal, and in 2D imaging it is separated from the rest by subtracting two scans of different ϕ_1's. In this 3D sequence it is the same for all SE steps which allows self-correction: for SE step n we set $\phi_1 = n\pi$ and $\phi_2 = -n\pi$, which alternates the sign of the DC signal between even and odd SE steps, therefore moving its contribution to an edge section, which is then discarded. In addition, sparse phase-cycling can be used where the first and last SE steps are phase-cycled to obtain their DC signals, and these are interpolated to correct the other SE steps. Both approaches reduce the scan time by nearly half.

Signal acquisition consists of a train of small-tip angle RF pulses with segmented-EPI readout, and divided into multiple time frames(4). The scan parameters for myocardial wall imaging were a matrix size of 128×48×10, imaging volume of 450×169×80mm^3, bandwidth of 1300 Hz/pixel, temporal resolution of 30 ms, sEPI ETL of 6, total scan time of 5 to 6 minutes with respiratory gating.

This sequence was tested in two volunteers. Sparse phase-cycling is more effective in removing the DC signal than self-correction, as plotted in Fig.3. Motion-tracking of the ventricles in 3D space are shown in Fig.4 for one of the 20 cine frames. In conclusion, this 3D sequence realizes section-following and scan-time reduction in displacement-encoded imaging.

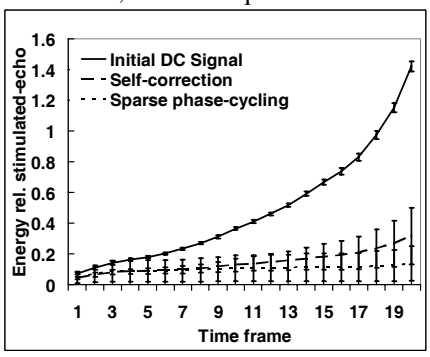

Figure 3 DC signal levels

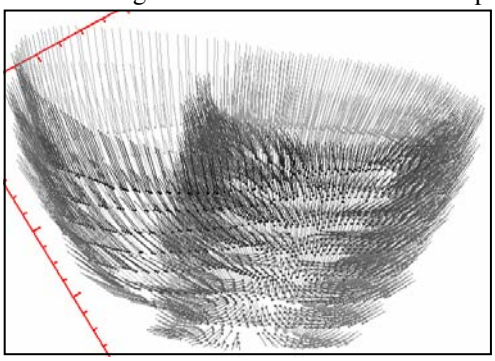

Figure 4 Displacement vectors in 3D

References: (1) Aletras AH, Ding SJ, Balaban R, Wen H. Displacement encoding in cardiac functional MRI. Proc.ISMRM 1998; 281. (2) Fischer SE, Mckinnon GC, Scheidegger MB, Prins W, Meier D, Boesiger P. MRM 1994; 31:401-413. (3) Spottiswoode BS, Zhong X, Lorenz CH, Meintjes EM, Bongani MM, Epstein FH. Proc. SCMR 2006; 187. (4) Kim D, Gilson WD, Kramer CM, Epstein FH. Radiology 2004; 230:862-871.