Navigator Gated Volumetric Spiral Cine DENSE MRI using Outer Volume Suppression

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Introduction Cine Displacement Encoding with Stimulated Echoes (DENSE) is a quantitative MRI method for imaging myocardial displacement and strain. Since the motion of left ventricle (LV) is complex and three dimensional (3D), using a technique that is 3D with respect to spatial coverage and motion measurement is advantageous for complete assessment of LV motion. The primary drawback of a 3D protocol is its long acquisition time, which reduces its usage in patients. The purpose of the present study was to develop a volumetric cine DENSE pulse sequence with reduced scan time and sufficient signal to noise ratio (SNR) to compute accurate displacement and strain values. Our approach was based on the ability of stimulated echoes to achieve outer volume suppression.

Method As shown in Figure 1, the sequence described in (1) was modified to perform two selective tailored sinc RF pulses, instead of the original nonselective hard pulses, in the displacement encoding module of the sequence. One of the two pulses is selective along the readout direction while the other is selective along the phase-encode direction. Because a stimulated echo will arise only for tissue that experiences all 3 RF pulses, a DENSE signal will be generated only for the volume of tissue defined by the 3 orthogonal selective pulses (5). Since the signal outside the region of interest will be suppressed, we can reduce the field of view without causing aliasing, which in turn can reduce the scan time. The modified navigator gated volumetric spiral cine DENSE sequence was evaluated in normal volunteers after informed consent was obtained and in accordance with protocols approved by the IRB at our institution. Specific pulse sequence parameters included: field of view = 240 x 240 x 140 mm^3, matrix = 86 x 86 x 28, thickness of the preparation pulses = 100 mm, ramped flip angles with the last angle = 20°, TR = 16 ms, TE = 1.3 ms, number of spiral interleaves = 4, fat suppression, temporal resolution = 32 ms, balanced four-point encoding strategy (2), displacement encoding frequency = 0.06 cycles/mm, and three point phase cycling for artifact suppression (3). Images were exported to a PC and computation of Lagrangian displacement and strain was performed as previously described (4).

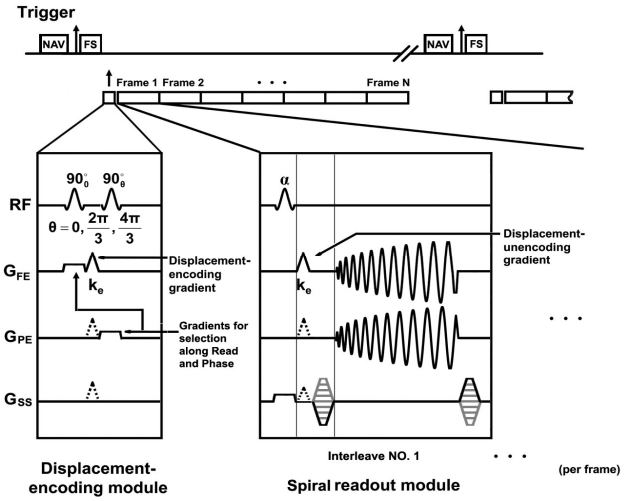

Fig 1. Pulse sequence timing diagram for navigator gated volumetric spiral cine DENSE with outer volume suppression. For clarity, the refocusing gradients for RF pulses were merged with the encoding or the unencoding gradients

Results The total number of navigator-accepted heartbeats to complete the entire 3D acquisition was reduced from 532 to 364, thus reducing the scan time approximately by one third. As expected there was a decrease in SNR primarily due to reduction in acquisition time and decrease in preparation efficiency of selective pulses. The SNR for magnitude reconstructed images of the mid-ventricular partition at the earliest and the latest cardiac phases were 60.49 and 22.45, respectively. Example displacement-encoded magnitude (A) and phase (B-D) reconstructed images of a mid ventricular slice at end systole are shown in figure 2. Example curves for mean normal strains (E_{rr} and E_{cc}), computed for a mid ventricular slice and shown in Figure 3, and is in good agreement with the literature (1).

Conclusion A navigator gated volumetric spiral cine DENSE sequence with outer volume suppression was developed to reduce the scan time required for 3D data acquisition. The method relies on inherent properties of stimulated echoes, which allow for an efficient implementation of outer volume suppression and, consequently, enable usage of a smaller FOV and a smaller matrix. While SNR decreases using this method, the resulting SNR remained greater than 20 and was sufficient for strain analysis.

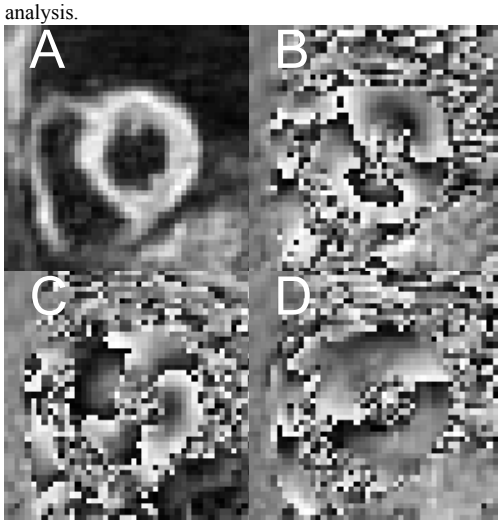

Fig 2. Example magnitude (A) and phase reconstructed (B-D) 3D spiral cine DENSE images of a mid ventricular partition at end systole. Images in B and C were displacement encoded in orthogonal in-plane directions, and D in the through-plane direction.

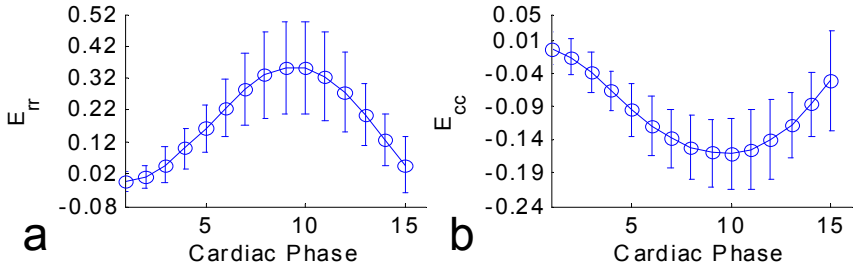

Fig 3. Mean strain-time curves for radial (a) and circumferential (b) strain for a mid ventricular partition. Data are shown as mean ± standard deviation.

References

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