Flip Angle Strategies for Multiphase DENSE

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Introduction: Displacement ENcoding with Stimulated Echoes (DENSE) is a method to acquire myocardial displacement during the cardiac cycle. Spatial position is encoded and stored in the longitudinal magnetization at one point in time, and then read out later in the cardiac cycle, thus directly obtaining the displacement during that interval. The stimulated echo experiment results in a different signal behavior compared to conventional imaging. In conventional cine imaging, longitudinal relaxation turns previously excited signal into usable signal later during the same cardiac cycle. In DENSE, the the longitudinal relaxation consumes the stimulated echo and turns it into an artifact generating echo during the rest of the cardiac cycle. Only at the time of the next position encoding, typically the next R-wave, is the signal usable again. Furthermore, the excitation also consumes the stimulated echo.

Since the signal from the stimulated echo fades during the cardiac cycle, a widely used technique is to vary the flip angle so as to produce constant SNR during the cardiac cycle [1]. This is achieved by using a low flip angle in the early cardiac phases, exploiting that the stimulated signal is strong, and not consuming the signal unnecessarily. Towards the end of the cardiac cycle, the stimulated signal is weak, and there is less reason to save signal, so a higher flip angle is used. The final flip angle can be optimized with regards to T1 and heart rate [2], to achieve highest constant SNR. In order to keep the same signal level through the entire cardiac cycle, however, significant sacrifices in SNR has to be made in the earlier phases. Previously, a constant SNR has been assumed to be the most desired, but no evaluation has been performed as to what cost this incurs. In this paper, we evaluate the performance of several flip angle strategies, including the one optimized for maximum constant signal, in terms of achievable SNR.

Methods: Seven healthy volunteers were imaged in Philips Achieva 1.5 and 3 T scanners, using the standard 5 and 6 channel cardiac coils. Each volunteer was scanned consecutively at both field strengths, in a randomized order. The same technologist performed both scans. On each field strength, three cine DENSE acquisitions were performed, with variable flip angle, fixed flip angle at 20 and fixed flip angle at 10 degrees. The acquisitions were performed in a randomized order.

Other imaging parameters were: field of view 350mm, slice thickness 8 mm, matrix 128x115, SENSE factor 2, TFE-factor 3, EPI-factor 7, heart phase interval 50ms, TR 8.9ms, TE 4.2ms. The flip angle optimization was based on heart rate, myocardial T1 and excitation pattern, as previously reported [2], but extended to the case of TFE excitation. Both in-plane displacement directions were measured using a displacement encoding of 0.35 cycles per pixel in three oblique directions [3]. This allows for the subtraction of background phase errors and increases the displacement-to-noise ratio without increasing the encoding strength. Each encoding direction was performed using complementary encoding, analogous to CSPAMM [4]. A k-space filter was used to suppress residual T1 echo signal [5]. Each direction was acquired in six heart beats, resulting in a total scan time of 18 heart beats, plus two heart beats for EPI phase calibration and one to reach steady state. After the end of the breath hold, a noise reference image was acquired in three additional cardiac cycles. The noise reference was acquired with RF and gradients turned off, in order to measure the receiver noise. Images were then reconstructed in SNR units [6]. Regional SNR was estimated by averaging the magnitude of the SNR images in manually selected ROIs in the LV region closes to the chest wall coil, where coil sensitivity is highest.

Results: The SNR over the cardiac cycle is shown in Fig. 1, for both 1.5T and 3T. SNR was higher in the early cardiac phases when using fixed flip angle schemes, when compared to the variable flip angle scheme, at the expense of a lower SNR at the end of the cardiac cycle. The time frame where the SNR of the fixed 20 degree flip angle data dropped below the SNR of the variable flip angle was studied. At 1.5T, this was at 69 ± 4 % of the imaged cardiac cycle. The corresponding value for 3T was significantly higher, 82 ± 7 % [p<0.001]. Corresponding numbers for using a fixed 10 degree flip angle were 73 ± 7 % and 76 ± 12 % [p=n.s.] at 1.5T and 3T, respectively.

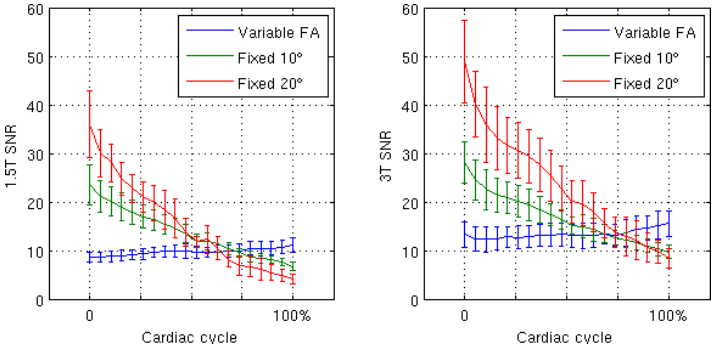

Fig 1. SNR over normalized time for 1.5T (left) and 3T (right), shown for fixed 20 degree (red), fixed 10 degree (green) and variable flip angle (blue) schemes. Error bars show one standard deviation over the subjects.

Discussion: The use of a variable flip angle resulted only in a only small improvement at the last 18% of the cardiac cycle, at the cost of a significantly lower SNR in the rest of the cardiac cycle. Since the signal is constantly disappearing due to relaxation, saving the signal for later in the cardiac cycle is ineffective. In deformation studies, the early phases of the cardiac cycle are often most interesting. In these cases, exploiting the signal while it is still available seems to be a better approach.

The advantage of the fixed 20 degree flip angle scheme over the variable flip angle scheme persisted longer in the cardiac cycle at 3T compared to 1.5T. This might be caused by the longer myocardial T1 relaxation time at 3T, reducing the signal decay of the fixed flip angle schemes. Note that only a limited number of flip angle scheme were tested. It is likely that some other variation can yield slightly better results for the specific case. As tagging type of imaging is based on a similar pulse sequence [7], we recommend basing the choice of flip angle approach in both DENSE and tagging MRI on the parts of the cardiac cycle of main interest for the application at hand.

References:

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