Improved Cardiac Cine Imaging at 3T Using Modulated Flip Angles

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Introduction

Imaging at 3T can provide a two-fold increase in SNR over 1.5T. However, there is also a concomitant four times increase in the Specific absorption rate (SAR). This is a serious problem in cardiac cine imaging using trueFISP (true fast imaging with steady-state precession), where rf pulses are continuously applied at high flip angles to achieve the desired blood-myocardial contrast (1). To alleviate the SAR, the flip angle can be reduced, or the rf pulse lengthened. Both these solutions can be detrimental to trueFISP image quality, as the former reduces the blood-myocardial contrast due to reduced T_2/T_1 weighting, and the latter increases TR that can lead to higher resonance offset susceptibility. In this work, we propose modulating the flip angles in k-space such that higher flip angles are used in the central part of k-space by compromising flip angles in higher k-space to achieve short TR's and maintain blood-myocardial contrast, while retaining the SAR within limits.

Methods

Sequence Design

The higher the flip angle, the higher are the blood signal and blood-myocardial contrast in trueFISP cine imaging. Therefore, increasing the flip angle when acquiring lines in central k-space can provide high signal and contrast for trueFISP cine imaging. However, steady-state in a trueFISP sequence is flip angle dependent, and abruptly changing the flip angle during acquisition can lead to transient signal oscillations, which may give rise to image artifacts. A number of dummy cycles at the higher flip angle may be used to reestablish steady-state but the potentially achievable higher flip angle will then be compromised. To overcome this problem, the flip angles were ramped slowly from the lower value (α_{low}) to the higher value (α_{high}), and then ramped down similarly (2). The lower flip angle was always half that of the higher flip angle. Signal acquisition was continuous through the flip angle ramps. Fourteen rf cycles were used for ramping the flip angle from the lower to the higher value. A schematic of the modulated flip angle cine sequence is shown in Fig. 1.

The potential increase in flip angle over the constant flip angle sequence is also dependent on how many central k-space lines are used with higher flip angles. After performing phantom studies, it was found that approximately 40% of the total number of k_y lines with higher flip angle were found to be suitable for a substantial increase in blood-myocardial contrast, while avoiding image artifacts due to signal modulation near the center of k-space.

Imaging

Healthy volunteers (n = 6) were imaged on a Siemens 3T Trio system with high performance gradients (40 mT/m, 200 mT/m/ms). The maximum flip angle allowed by the SAR limit monitor was used in all cases. The imaging parameters were as follows: TR/TE = 3.5 ms/1.75 ms, FOV = 216×300 mm^2, matrix = 150×256, lines/segment = 15, number of phases = 20, rf pulse length = 800 µs, rf bandwidth-time product = 3. A constant flip angle cine sequence was compared to the modulated flip angle cine sequence with identical imaging parameters. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were compared.

Results

Short axis cine images of the heart at multiple phases with the constant flip angle and the modulated flip angle sequences are shown in Fig. 2. The flip angle for the constant flip angle sequence was 31^o, while that for the modulated flip angle sequence was 41^o. The images show that the modulated flip angle sequence provides higher blood signal and blood-myocardial contrast with little compromise in image quality. However, images acquired using modulated flip angles appeared slightly blurred as compared to those acquired using constant flip angles, because of the low pass filtering effect of the modulated flip angle scheme. Note also that the first phase where the flip angles are ramped up and the last phase where the flip angles are ramped down do not show any artifacts. The average increase in flip angle for the imaging parameters used here was approximately 10^o for the modulated flip angle sequence over the constant flip angle sequence. The increase in blood SNR was found to be 19% and the increase in blood-myocardial contrast was found to be 27% with the modulated flip angle scheme as compared to the constant flip angle scheme.

Conclusion

The modulated flip angle trueFISP cine imaging approach can provide higher blood signal and blood-myocardial contrast than the constant flip angle approach, with a small penalty in spatial blurring. A possible solution to the blurring may be to use a high pass filter to post-process the data.

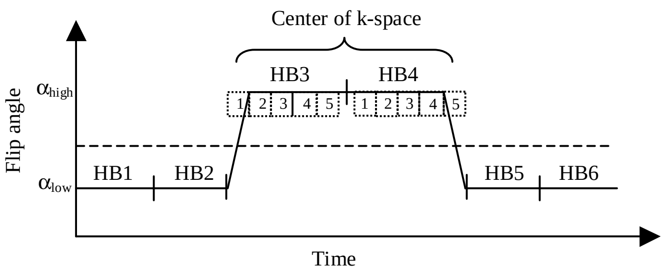
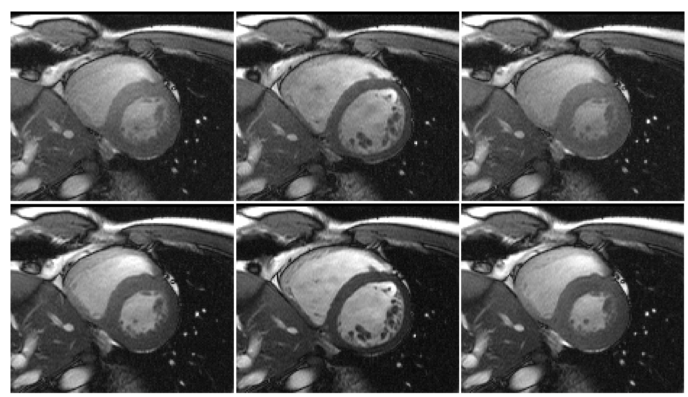


Figure 1. Schematic of the modulated flip angle cine sequence. An example with 6 heartbeats (HB) and 5 phases is shown. The flip angle for the constant flip angle sequence is shown as reference (dashed line). The flip angles in the modulated scheme are ramped up during the 1st phase in the 3rd HB, and ramped down again in the last phase in the 4th heartbeat. The higher flip angle in the center of k-space is achieved by compromising the flip angle in the outer regions of k-space.



(a) **(b)** **(c)**

Figure 2. **(a)** First, **(b)** Tenth and **(c)** Twentieth (last) phase in a cardiac cycle acquired using a constant flip angle approach (top row) and a modulated flip angle approach (bottom row). Note the higher blood SNR and higher blood-myocardial contrast in the images in the lower row. Also note there are no visible artifacts in the first and last phase even though the flip angles are ramped during these phases.

References

1. Carr JC et al., Radiology 2001; 219:828-834.
2. Nishimura DG et al., Proc. of 8th ISMRM, Denver, 2000; p 301.