Minimized Off-resonance Effects with Centric Radial SSFP for Imaging Cardiac Function

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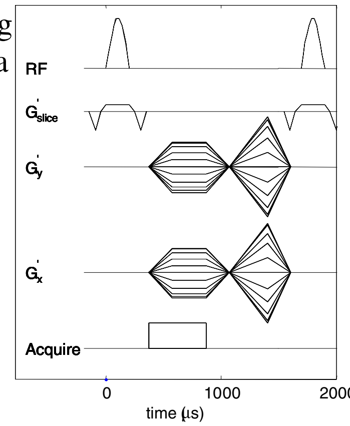
Introduction

Steady-State Free Precession offers excellent contrast to noise ratio when imaging the human heart, and when used as a single slice cine acquisition is the preferred approach for imaging cardiac function clinically. The Achilles heel of the SSFP approach lies in its off-resonance sensitivity. The sequence is "well-behaved" across a frequency band Δf, and Δf is related to the inverse of the repetition time ($\Delta f < (2TR)^{-1}$). Here we describe an approach that decreases the TR of the SSFP sequence by around 30-40%, and hence decreases the off-resonance sensitivity. This massive decrease is obtained by using a centre-out k-space acquisition, which includes ramp sampling, and variable ramp-times to avoid peripheral nerve stimulation effects. A schematic pulse sequence diagram is shown (fig 1a) for the new approach, and for the traditional raster 2D SSFP approach (fig 1b). This approach has already been demonstrated for 3D SSFP [1], but here we explore its potential for single slice imaging of the heart.

Methods

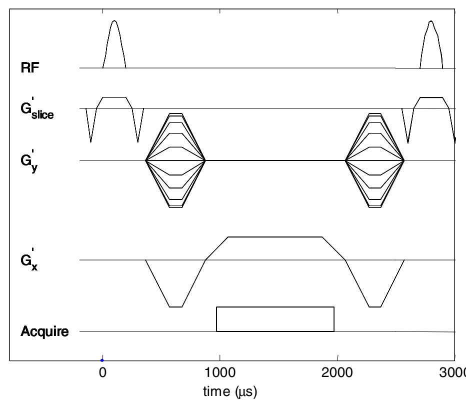
The cine radial centre out SSFP sequence was implemented on Siemens MRI systems with high-performance gradients (40mT/m, 200T/m/s). Reconstruction was implemented in the Siemens ICE environment on the MRI scanner. This code was based on the previous UTE sequence [2], but incorporated conventional slice selection, with a variable duration slice selection pulse. The sequence was implemented to allow multi-oblique acquisition, and differential gradient delays were calibrated by the scanner and corrected automatically in the reconstruction. The ramp-up and ramp-down times for the read-dephase gradient were each optimised to minimise the TR, subject to the peripheral nerve stimulation thresholds. ECG gating was applied. The SSFP steady-state was obtained over a single cardiac cycle and maintained with the use of dummy scans. K-space was segmented as segments of an orange for the radial acquisition. Images were acquired on static phantoms, and on normal volunteers at 1.5T (Siemens Sonata) and 3T (Siemens Trio). The sequence as implemented allowed different acquisition bandwidths, and RF pulse durations.

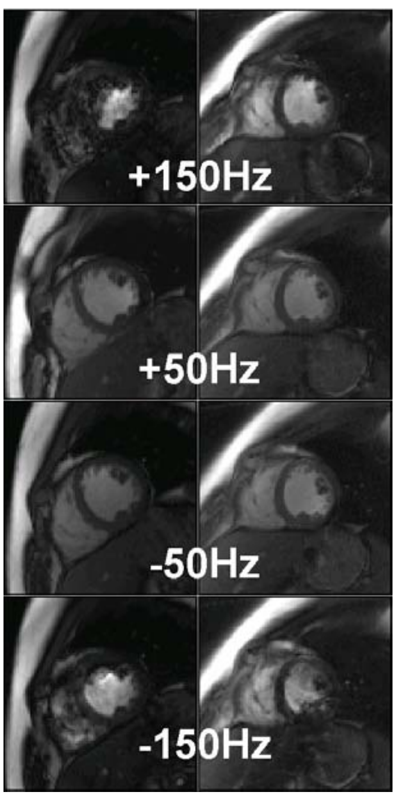
fig 1a



Imaging parameters for the centric-radial acquisition were: TR=2.35ms, flip angle 45º, 2x2x7mm resolution, 14 phases per cycle, 1ms RF pulse length, 256 radii, 10s breath-hold. Conventional 2D SSFP (TR=3.2ms) flip angle 47º, 2x2x7mm resolution, 10s breathold, 21 phases per cycle, which is a standard Siemens product sequence.

fig 1b





Results

High quality cine images were shown with the centric approach, which demonstrate reduced sensitivity to off-resonance effects (see figure at left, showing conventional method left column, and centric-radial method right column as a function of frequency offset), and do not suffer from flow related artefacts. High quality images were obtained for short and long axis views.

Discussion & Conclusions

Centric-radial SSFP has the benefits of reduced off-resonance effects, and residual off-resonance artefacts will not be as severe with the radial acquisition. The disadvantage of this approach is that more phase-encoding steps are required as radii are not an efficient way of filling k-space, and consequently breath-holds are longer or resolution is reduced. This method has further implications for specific absorption rate (SAR) heating, as the reduced TR allowed increases the SAR. To compensate for these effects some or all of the time that has been saved can be used to extend the duration of the RF pulse (and hence decrease its SAR for the same flip angle). Consequently, the radial centric approach provides a shortening of the acquisition component of the sequence which can be used either to decrease the TR (and hence the off-resonance effects) or to extend the RF pulse and hence to reduce the SAR effects, either or both of these features may be used (as was performed in these experiments). Effects due to the flow of blood are not a source of artefact, and sources of artefact due to differential gradient timing can be managed in reconstruction. It is expected that this approach will also have applications for vessel imaging.

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References:
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