Cardiac Cine 3d trueFISP Parallel Imaging using Auto-calibrating 2d-TSENSE

P. Kellman[1], A. C. Larson[1], Q. Zhang[2], O. P. Simonetti[2], A. E. Arai[1], E. R. McVeigh[1]
[1]Laboratory of Cardiac Energetics, National Heart Lung and Blood Institute, NIH, DHHS, Bethesda, Maryland 20892 USA
[2]Siemens Medical Solutions, USA, Chicago, IL, United States

INTRODUCTION

Cardiac cine 3d imaging offers the potential for full heart coverage in a single, segmented breath-held acquisition. A single acquisition eliminates breath-hold registration errors between slices that may occur in conventional 2d multi-slice imaging requiring multiple breath-holds. A trueFISP sequence combined with parallel imaging is used to achieve spatial resolution of 2.5 x 2.6 x 5 mm^3 and approximately 40 ms temporal resolution within a single 20 heartbeat breath-hold. Parallel imaging uses 2d-TSENSE at acceleration rate 8 with a custom 32-element surface coil array.

METHODS

Cardiac cine 3d imaging was implemented on a state-of-the-art 32 channel Siemens Avanto 1.5T scanner using a gated, segmented trueFISP sequence. Parallel imaging using 2d SENSE [1] was used to reduce the breath-hold duration. Doubly oblique imaging was used with the partition encode along the long axis of the heart. The phase encode and frequency readout directions were in the short axis plane with the frequency readout along the longer dimension of the body after in-plane rotation was applied. The graphical prescription is shown in Fig. 1. The acquisition used rate R=4x2=8 undersampling, with rate 4 undersampling in the phase encode dimension and rate 2 undersampling in the partition encode direction.

The B1-maps were estimated using the auto-calibrating TSENSE method [2]. The k-space undersampling varied cyclically with complete k-space acquired in 8 phases as illustrated in Fig. 2. The complete dataset was integrated to reconstruct B1-maps for calculating SENSE unmixing coefficients. Temporal filtering was not applied to the TSENSE reconstructed images. Since it is important to have artifact free in vivo reference images for B1-map estimates, 25% slice oversampling was used in the partition encode dimension to reduce wrap. The acquisition matrix was 128x104x20 with 4 slices discarded after reconstruction. The example shown used a FOV of 320x270x80 mm^3 providing a spatial resolution of 2.5x2.6x5 mm^3. The actual number of lines acquired were 104/4=26 phase encodes x 20/2=10 partition encodes. The sequence parameters were: bandwidth = 1400 Hz/pixel, TR=2.84 ms, 50° readout flip angle. There were 13 views per segment providing 13x2.84 ms=37 ms temporal resolution. The total breath-hold duration was (104/4)x(20/2)/13 = 20 heart beats. Typical imaging parameters are summarized in Table 1.

A custom 32-element cardiac phased array (Rapid Biomedical, Würzburg, Germany) was used, consisting of two 16-element gapped 2d arrays with 1 array positioned on the chest, and the second array positioned on the back of the patient. The coverage of the array was approximately 40 cm in the left-right direction and 30 cm in the superior-inferior direction. SENSE g-factors [3] were estimated from the prescan noise and the B1-maps.

Table 1. Typical Imaging Parameters

pulse sequence:	true FISP
k-space acquisition:	ECG gated, segmented
resolution:	2.5 x 2.6 x 5 mm^3
Matrix	128 x 104 x 16*
TE/TR:	1.4/2.8 ms
bandwidth:	1400 Hz/pixel
RF flip angle:	50°
views per segment:	13
temporal resolution:	37 ms
breath-hold duration:	20 heart beats

* slice oversampling was 25%, with 20 partition encodes actually acquired

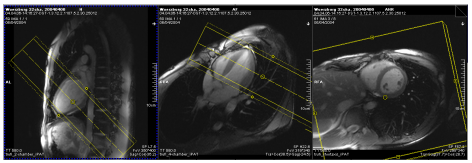

Figure 1. Graphical prescription for cine3d doubly oblique imaging. The partition encode is along the long axis of the heart. The phase encode and frequency readout directions were in the short axis plane with the frequency readout along the longer dimension of the body after in-plane rotation was applied.

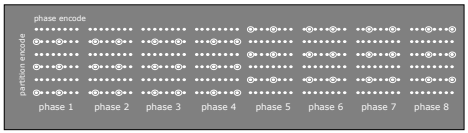

Figure 2. k-space acquisition order for R = 4 x 2 = 8 2D TSENSE example with under-sampling by 4 in the phase encode direction and undersampling by 2 in the partition encode direction. Complete k-space is acquired in 8 phases.

RESULTS

Example images for systolic and diastolic cardiac phases are shown in Figure 3 for a normal volunteer. The mean g-factor is estimated to be approximately 2.0 in the heart region. A histogram of estimated g-factor values for approximately 16000 pixels in the heart region is shown in Fig. 4.

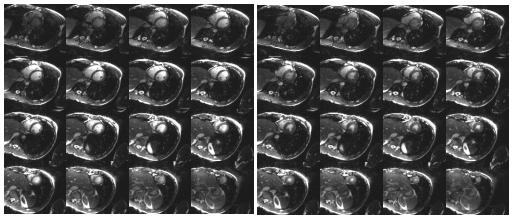

Figure 3. Example cardiac cine3d images using 2d TSENSE with rate 4x2=8 with 16 slices and approx 40 ms temporal resolution acquired in a single 20 sec breath-hold. Images shown at (a) diastolic and (b) systolic phases.

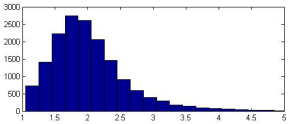

Figure 4. Distribution of estimated g-factor values in heart region, with mean value approximately 2.0, 90% less than 2.8, 95% less than 3.2, and 99%<4.2.

CONCLUSIONS

Cardiac 3d cine MRI using 2d parallel imaging was demonstrated for single breath-hold acquisition. Scan time may be further reduced by using elliptical scanning and using a faster RF pulse for reduced TR. Despite relatively high g-factors for rate 8, the SNR and artifact suppression were quite good using 3d imaging. At higher accelerations, it may be possible to approach isotropic resolution and thereby display both short and long axis views from a single acquisition.

REFERENCES

1. Weiger M, et al. Magma. 2002; 14(1):10-19.
2. Kellman P, et al. MRM. 2001; 45(5): 846-52.
3. Pruessmann, et al. MRM. 1999; 42(5): 952-62.

Acknowledgement

The authors gratefully acknowledge the tremendous effort by Mark Griswold, Univ Würzburg, and Stephan Kannengiesser, Siemens Medical, in acquiring data using the Siemens Avanto and prototype 32 channel array from Rapid Biomedical. The authors also acknowledge Titus Lanz, Rapid Biomedical for design and development of the prototype 32 channel array.