Single Breath-hold 3D Cine Cardiac Imaging of the Entire Heart with 32 Channel Parallel Imaging

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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 1.8x2.4x7 mm^3 and approximately 30 ms temporal resolution within a single 18 heartbeat breath-hold. Parallel imaging used 2d-TSENSE at various acceleration factors up to rate 12 with a prototype 32-element surface coil array.

METHODS

Cardiac cine 3d imaging was implemented on a 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 various rates 4x2=8, 4x3=12, and 6x2=12 undersampling, with rate 4 or 6 undersampling in the phase encode dimension and rate 2 or 3 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 R phases (R is the undersampling rate) as illustrated in Fig. 2 for rate 4x3=12 example. 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, approx. 25% slice oversampling was used in the partition encode dimension to reduce wrap. The acquisition matrix was 192x108x18 with 4 slices discarded after reconstruction. The example shown used a FOV of 340x255x98 mm^3 providing a spatial resolution of 1.8x2.4x7 mm^3. At rate 4x3=12, the actual number of lines acquired were 108/4=27 phase encodes x 18/3=6 partition encodes. The sequence parameters were: bandwidth = 1400 Hz/pixel, TR=3.08 ms, 50° readout flip angle. There were 9 views per segment providing 9x3.08=27.7 ms temporal resolution. The total breath-hold duration was (108/4)x(18/3)/9 = 18 heart beats. Typical imaging parameters are summarized in Table 1.

A prototype 32-element cardiac phased array (Invivo) 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 35 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:	1.8 x 2.4 x 7 mm^3
SENSE acceleration, R	4 x 3 = 12
Matrix	192 x 108 x 18 (full) 192 x 27 x 6 (undersampled)
TE/TR:	1.5/3.1 ms
bandwidth:	1400 Hz/pixel
RF flip angle:	50°
views per segment:	9
temporal resolution:	28 ms
breath-hold duration:	18 heart beats

* 4 slices discarded, slice oversampling was 25%

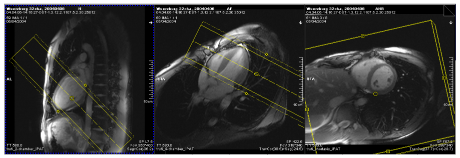


Figure 1. Graphical prescription for cine3d doubly oblique imaging. The partition encode is along the long axis of the heart. The phase encode and frequency readout directions were in the short axis plane with the frequency readout along the longer dimension of the body after in-plane rotation was applied.

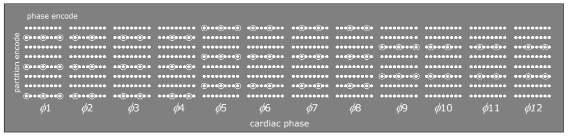


Figure 2. k-space acquisition order for R = 4 x 3 = 12 2D TSENSE example with under-sampling by 4 in the phase encode direction and under-sampling by 3 in the partition encode direction. Complete k-space is acquired in R=12 phases.

RESULTS

Example images for rate 4x3=12 are shown in Fig. 3 for a normal volunteer subject. The measured g-factor values for which 95% of the pixels in the heart region fall below were 5.2 for rate 4x3=12, 6.7 for rate 6x2=12, and 2.9 for rate 4x2=8. A histogram of the g-factor for pixels in the heart region is shown in Fig. 4 for rate 4x3=12.

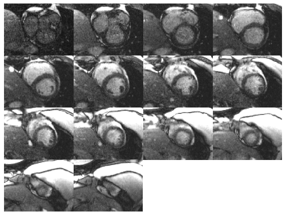
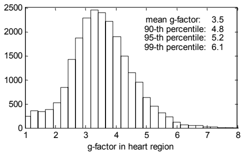


Figure 3. Example cardiac cine3d images using 2d TSENSE with rate 4x3=12 with 14 slices and approx 30 ms temporal resolution acquired in a single 18 sec breath-hold. Images shown at (a) diastolic and (b) systolic phases.

Figure 4. Distribution of estimated g-factor values in heart region, with mean value approximately 3.5, 90% less than 4.8, 95% less than 5.2, and 99%<6.1.



CONCLUSIONS

Performance of a 32-element array for cardiac 3d cine MRI using 2d parallel imaging was measured at high acceleration rates. Single breath-hold acquisition of a complete functional scan with good quality is possible. Performance may be further improved using an optimized RF pulse for either improved slab selectivity or reduced TR. Despite relatively high g-factors, 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

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2. Kellman P, et al. MRM. 2001; 45(5): 846-52.
3. Pruessmann, et al. MRM. 1999; 42(5): 952-62.