ANALYSIS OF ENDOCARDIAL BORDER SHARPNESS OF ACCELERATED 2D CINE SSFP: IMPLICATIONS FOR LEFT VENTRICULAR FUNCTION ASSESSMENT

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Introduction

In current clinical practice CINE imaging for the assessment of left ventricular (LV) function is limited by the competing constraints of scan time, signal-to-noise ratio (SNR), spatial and temporal resolution. Acceleration techniques like k-t BLAST (1,2) afford scan time reduction through k-space undersampling and hence promise to extend the capabilities of CINE imaging from a single to multiple slices per breath-hold or even to single breath-hold, whole heart coverage CINE acquisitions (3,4). K-t BLAST exploits spatio-temporal signal correlations from low-spatial resolution training data to resolve aliasing in dynamic, undersampled k-space data (k-t space). With increasing acceleration factors more signals have to be packed in the reciprocal x-f space which can cause blurring and residual aliasing and hence might be detrimental for accurate assessment of LV function. Consequently, myocardial border sharpness remains a concern despite the clear imaging speed advantage of the k-t approach. For all of those reasons, this study examines endocardial border sharpness (EBS) of 2D CINE k-t acquisitions. For this purpose, an algorithm is proposed which supports the quantitative assessment of EBS through an objective measure of acutance.

Methods

2D CINE imaging was conducted in 12 healthy adult volunteers (mean=35 ± 5 years) at 1.5 Tesla (Philips, Best, Netherlands) with a 5-element cardiac phased array coil. An ECG-gated 2D SSFP pulse sequence (TE=1.85 ms, TR=3.7 ms, α=60°, FOV = (35x35) cm^2, slice thickness=8 mm, matrix =192×192 (reconstructed 384x384), cardiac phases=25) was used. Spatial resolution was (1.9 x 1.9) mm^2 for data acquisition and (0.9 x 0.9) mm^2 for image reconstruction. Accelerated breath-held (BH) CINE imaging was conducted using three different strategies: (i) SENSE (R=2.5, 3 slices/BH), (ii) k-t BLAST (R=5, 3 slices/BH) and (iii) k-t BLAST (R=8, 4 slices/BH). For comparison conventional 2D CINE SSFP imaging (single slice/BH) was carried out. End-diastolic and end-systolic volume (EDV, ESV), stroke volume (SV), ejection fraction (EF), and left ventricular mass (LVM) were quantified. For EBS assessment left ventricular myocardium was segmented into 72 radial sections. In each segment, endocardial borders and local signal intensity values of myocardium (SI_{myo}) and ventricular blood (SI_{LV}) were automatically determined. For each segment, the transitional border zone between ventricular blood and myocardium depends on the local signal intensities of myocardium and left ventricle and was defined as area within the limits from $SI_{myo}+1/3*(SI_{LV}-SI_{myo})$ to $SI_{myo}+2/3*(SI_{LV}-SI_{myo})$. Therefore EBS is a measure of acutance and describes the width of the blurred edge. It is given by the mean value of numbers of pixels within the transitional border zone as illustrated in Figure 1. EBS was estimated for each cardiac phase in each segment. Systolic/diastolic border sharpness is given by the mean border sharpness of 72 segments at systole/diastole. Mean EBS was calculated from the averaged border sharpness of all 72 segments over the entire cardiac cycle.

Results

Conventional, 2.5-fold SENSE and 5-fold k-t BLAST 2D CINE SSFP allowed sufficiently high (effective) temporal resolution for well delineated myocardial borders as shown in Figure 2**.** Mean EBS derived from conventional 2D CINE SSFP was found to be 1.4± 0.2 pixels over the entire cardiac cycle. For comparison, the mean EBS over the cardiac cycle was 1.4±0.2 pixels and 1.4±0.3 pixels with 2.5-fold SENSE and 5-fold k-t BLAST acceleration respectively. A degeneration of EBS was found for 8-fold k-t accelerations (Figure 3), which exhibited a mean value of EBS=1.7±0.5 pixel over the entire cardiac cycle. A closer examination showed an EBS=1.4 pixel for the cardiac rest period as shown in Figure 4. Conversely, deterioration of EBS was pronounced during cardiac phases of contraction and relaxation, which both provided an EBS of 2.8 pixels as illustrated in Figure 4. This EBS diminishment resulted in mis-segmentation of endo- and epicardial borders leading to an apparent increase in the myocardial wall thickness at systole. For 8-fold k-t BLAST accelerated 2D SSFP CINE global cardiac function parameter were statistically different from those obtained for the conventional 2D CINE approach (EDV 150±11 ml vs. 158±14 ml, ESV: 67±5 ml vs. 62±6 ml, EF: 54±3 % vs. 60±4 %).The difference between 5-fold accelerated k-t BLAST and conventional 2D CINE SSFP was considered to be clinically irrelevant (EDV: 153±13 ml vs. 158±14 ml, ESV: 64±5 ml vs. 62±6 ml, EF: 56±3 % vs. 60±4 %). 2.5-fold SENSE accelerated 2D CINE SSFP revealed LV function parameter of EDV=155±13 ml, ESV=61±5 ml, EF=60±3%.

Discussion and Conclusions

An objective measure of acutance has been implemented to analyze the effect of parallel imaging on endocardial border sharpness. The EBS analysis demonstrated that 2.5-fold accelerated SENSE and 5-fold accelerated k-t BLAST using a five-element cardiac coil array do not impair the accuracy of global cardiac function assessment. Limitations in the effective temporal resolution dictate that a fairly rapid degeneration of endocardial border sharpness at k-t accelerations of R=8 and larger may be inevitable. In conclusion, the imaging speed advantage of k-t BLAST over the conventional 2D CINE SSFP approach should be carefully balanced against the endocardial border sharpness deterioration. Therefore, an acceleration factor of R<8 is advised for clinical routine LV function assessment. This approach still provides sufficient acceleration to extend the capabilities of breath-hold CINE imaging from a single slice to 3-4 slices per breath-hold without adverse effects on image quality.

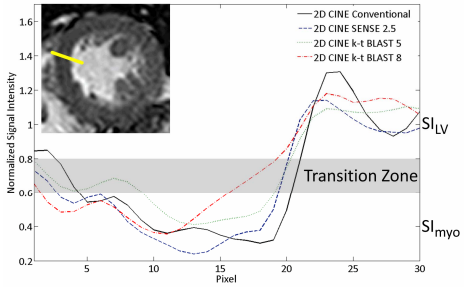

Figure 1: Signal intensities (SI) across the myocardium/blood interface (marked with bold yellow bar in the short axis view) obtained for conventional (black line), SENSE accelerated (R=2.5, blue line) and k-t BLAST accelerated (R=5 green line, R=8 red line) 2D CINE SSFP. SIs are normalized using the mean SI of the left ventricle. The transition zone is marked in grey.

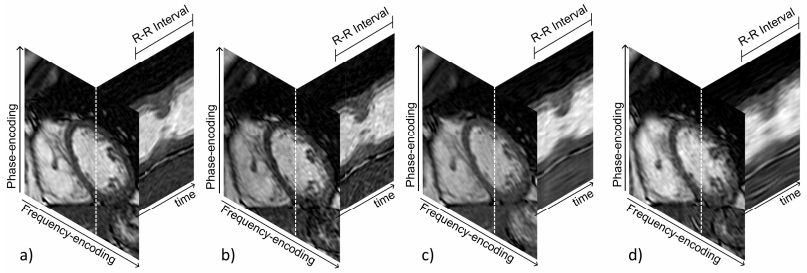

Figure 2: Short axis views of the heart obtained at 1.5 T using **a)** conventional **b)** 2.5 fold accelerated SENSE, c) 5-fold and d) 8-fold accelerated k-t BLAST 2D CINE SSFP together with 1D projections along dotted lines through the short axis views covering the entire R-R interval. Please note, that the temporal profile of 8-fold accelerated k-t BLAST shows blurring.

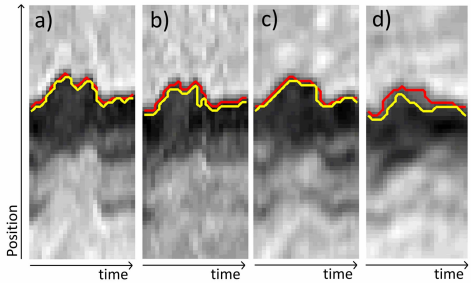

Figure 3: Whole R-R interval temporal profile of one-dimensional projections obtained for one out of 72 myocardial segments derived from **a)** conventional, **b)** 2.5-fold SENSE accelerated, **c)** 5-fold and **d)** 8-fold k-t BLAST accelerated 2D CINE SSFP data sets. The endocardial border width (marked with yellow and red lines) is significantly increased for 8-fold accelerated k-t BLAST as shown in **d)**.

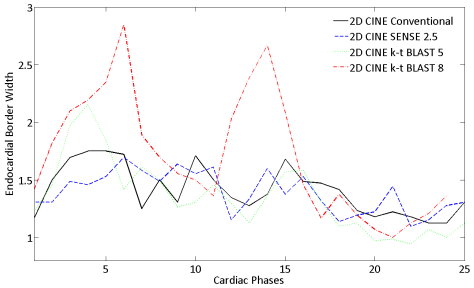

Figure 4: Tracking of the mean endocardial border width of all 72 myocardial segments over the entire cardiac cycle. For 8-fold accelerated k-t BLAST severe degeneration of EBS occured during contraction and relaxation while the EBS obtained at diastole matches that of conventional 2D CINE SSFP.

References: 1) Tsao, J. et.al. Magn Reson Med 50:1031-1042 (2003), 2) Tsao, J. et.al. Magn Reson Med 53:1372-1382 (2005), 3) Greil, G.F. J et.al. Magn Reson Imag 27:510-515 (2008). 4) Huber S. et.al. Magn Reson Imag 26:727-738 (2008).