Fast Imaging of Cardiac Strain Using Partial k-Space HARP in Mice

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Introduction

Characterization of myocardial deformation in genetically manipulated mouse models with MR tagging provides new opportunities for elucidating the molecular mechanisms of cardiac function. However, tagging on murine hearts presents additional challenge because of the requirement for high tagging and imaging resolution. The high heart rate of mice renders EPI or segmented k-space sampling impractical. As a result, typical acquisition time for mice is much longer than that for humans. One direct consequence of long acquisition time is that more hemodynamic variations might occur during imaging acquisition that could potentially compromise image quality and complicate data interpretation.

Recently, an ultra-fast acquisition method was developed based on Harmonic Phase (HARP) technique [1]. Tagged image is composed of multiple spectral peaks in the Fourier domain (Figure 1, left). The phase image of the inverse Fourier transformed off-center peaks directly encodes the motion of the underlying tissue [2]. Based on this property, ultra-fast HARP method was proposed to sample only the off-center spectral peaks. However, direct reconstruction of HARP image from the k-space data of a single off-center peak suffers from inaccuracies in phase correction. Phase correction is further complicated by the use of surface coil and high imaging/tagging gradients in small animal imaging to maximize signal-to-noise ratio and achieve high spatial and temporal resolution.

Here we propose a partial k-space sampling approach for imaging mouse heart. Such an approach samples all the spectral peaks in the low-frequency part of the k-space. HARP analysis is based on the reconstructed magnitude images so that phase correction is not necessary. Validation was performed in the current study on four mice. The results exhibited excellent correlations with the full k-space sampling method.

Methods

Tagged images of 9 months old mice (n=4) were acquired on a 4.7T Varian Associates INOVA system. A 2.5 cm surface coil was fabricated for image acquisition. Animals were anesthetized with 1% isoflurane by nose cone and placed into the coil in the prone position. Electrodes were attached to front paws and right leg for ECG gating and vital monitoring.

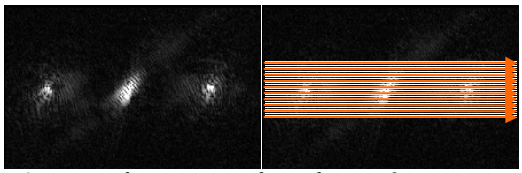

Figure 1. Left: Fourier transform of a tagged image. Right: partial k-space sampling.

The sequence consisted of a gated multi-frame gradient-echo sequence. Tags were generated using a SPAMM-1-1 sequence with the tagging gradient applied in the read-out direction. The modified sequence acquired only 40 phase-encoding lines centered around the low frequency part of the k-space. A depiction of the k-space trajectory was shown in Figure 1 (right). The imaging plane was then rotated by 90 degrees and images with tags in the other direction were acquired using the same scheme. Full k-space sampling was also performed for data comparison. Three short-axis images were acquired at basal, midventricular and apical levels with the following parameters: TR, R-R interval; TE, 3 ms; field of view, 4 cm×4 cm; data matrix, 256×40 for partial k-space sampling and 256×128 for full k-space sampling; tag resolution, 0.5 mm; slice thickness, 1 mm. Fifteen frames were acquired per cardiac cycle.

Images were transferred to a PC for data processing. The partial k-space data were zero filled into 512×512 data matrix. Images were reconstructed by inverse Fourier transform. Myocardial contours were interactively traced using B-spline interpolation with 8 control points. Pixel-wise 2D strain tensor was calculated directly from the HARP images [2]. The two eigenvalues of the strain tensor were calculated to yield maximum stretching and maximum shortening. Primary angle was defined as the angle between the radial direction and the direction of maximum stretching.

Results

Image acquisition time for partial k-space sampling approach was approximately 3 minutes for each slice, which was only one third of the traditional method. By visual inspection, images reconstructed from partially sampled k-space data exhibited no discernable differences in image quality from that reconstructed from full k-space data (Figure 2, left). Tag lines traces from the $\pi/2$ isophase contours of the reconstructed phase images were also similar (Figure 2, right). Data analysis from partial k-space sampling method demonstrated excellent correlation with that from full k-space approach (Figure 3). The correlation coefficients for maximum stretching, maximum shortening, and primary angle between the two approaches were 0.95, 0.97, and 0.93 respectively ($p<0.001$). Quantitatively, average differences between the two methods were $(-9.4\pm8.2)\times10^{-3}$ for maximum stretching, $(0.7\pm3.5)\times10^{-3}$ for maximum shortening, and $0.27\pm1.03°$ for primary angle (p=NS).

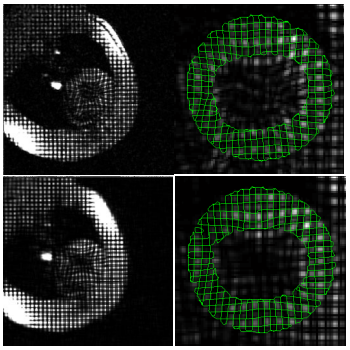

Figure 2. Top: image acquired with full k-space sampling. Bottom: image acquired with partial k-space sampling.

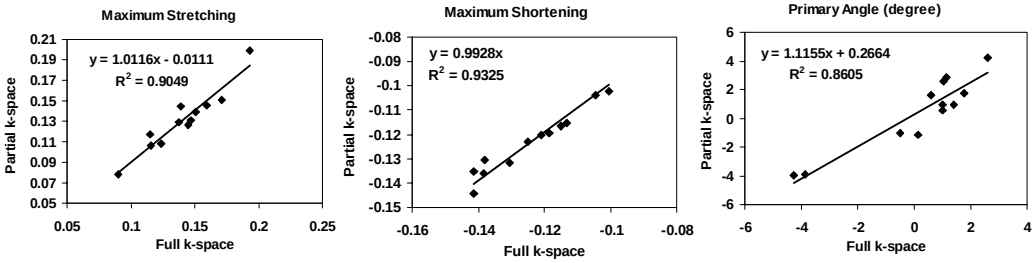

Figure 3. Correlations between partial k-space sampling and full k-space sampling.

Conclusion

A HARP-based partial k-space sampling approach was developed for fast measurement of the cardiac strain field in mice. The method greatly reduced image acquisition time without compromise image quality. The comparable image quality is probably attributable to less hemodynamic variations during image acquisition. Validation study exhibited strong correlation with traditional full k-space sampling method. This method provides a practical approach for fast imaging of myocardial strain in small animals.

References

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2. Osman NF, McVeigh ER, Prince JL, Imaging heart motion using harmonic phase MRI. IEEE Trans Med Imaging., 2000;19:186-202.