A New Spiral K-Space Sampled Time-Resolved MR Optimization Approach for 4D MR Renography

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Introduction

Time-resolved k-space undersampling techniques for contrast-enhanced 3D MRI have many clinical applications such as cancer imaging and functional studies, including MR renography. Increases in temporal resolution of 4D data can improve the precision of quantified perfusion metrics by more accurately reflecting the dynamics of the perfusion process. However, there are trade-offs among high temporal resolution, high spatial resolution, and image artifacts that occur with k-space undersampling. We explore the optimization of acquisition parameter settings using a computer simulated 4D renal phantom.

Methods

By varying signal intensities (SI) in aorta, cortex, medulla and collecting system according to patient data, the 4D renal perfusion phantom (true voxel size 1.8x1.8x1.8mm with matrix 100x160x40 after cropping) was designed to reflect the results of a 4ml bolus of Gd-DTPA injected intravenously over 2sec, followed by a 20ml saline flush [1]. Without time-resolved technology, baseline acquisition time (TA) was 9 sec. A new time-resolved spiral k-space undersampling scheme [2] was used in phase-encoding plane (Fig. 1), with k-space points reordered and sampled by their radial distances and angles. K-space is separated into two regions: *A* (lower spatial frequency) and *B* (higher spatial frequency), where *pA (percentage of A)* can be defined as *kc/kmax* (or as the percentage of k-space area sampled). Region *B* is undersampled with respected to *A* and represented by N trajectories: *Bi* (*i = 1, 2, 3, …*), each trajectory spanning the whole *B* region. *pB (percentage of B)* can be defined as *1/N,* or sampling density, in region *B*. The order of sampling is then AB_1, AB_2, AB_3…, AB_1, AB_2, AB_3…. Theoretically, the inverse relation of k-space voxel size and image voxel size guides selection of *pA(=kc/kmax)* which should be at least *Dvoxelsize/Dvesselsize* where *Dvesselsize* is diameter of key structures such as renal artery or renal cortex. For example, if the key structures to be analyzed quantitatively and dynamically, in this case the aorta and renal cortex, span at least 3 voxels, we infer that *pA* can be *0.33*.Given a reasonable *pA*, *pB* needs to be optimized based on the trade off between fast temporal resolution and ringing artifacts caused by losing higher frequency information in k-space. To find global optimal parameters, both *pA* and *pB* were varied: *pA = 0.50, 0.33, 0.25, 0.20 (or 50%, 31%, 21%, and 13% of entire rectangular phase encoding k-space area); pB = 1/2, 1/4, 1/6, 1/8.* Temporal accuracy was evaluated by calculating errors from averaged signal intensity aortic enhancement curve estimation. In order to assess image ringing artifacts caused by k-space undersampling, differences between reconstructed and true images, normalized by true image SI, were calculated. Total error index was calculated as the sum of these two errors.

Results

Fig. 2 shows a 3-D surface plot of total error index. The minimum error for our MR renography simulation corresponded to *pA=0.33* and *pB=1/8*. With optimized parameters, estimated enhancement curves in different tissues are shown in Fig. 3, where peak aortic enhancement was underestimated by 2.36%. (5) Fig. 4 shows images (left) and subtraction of images from truth (right) for a range of pA and pB (acquisition times, TA, shown) for peak aortic enhancement. Ringing artifacts increase, both in the aorta and renal cortex during rapid changes in signal, as *pB* decreases.

Conclusions

For a new undersampled k-space time-resolved acquisition, the degree of undersampling of the center of k-space, *pA* can be optimized by considering spatial resolution constraints on quantification of enhancement kinetics and *pB* by considering both temporal performance and artifact tolerance. Simulation provides a useful tool for optimizing parameter selection for dynamic time-resolved contrast-enhanced 3D imaging.

References [1] J.H. Maki et al. JMRI, 6:642, 1996. [2]R. Kroeker et al. Siemens Application Document on Time Resolved Contrast-enhanced MRA: TWIST.

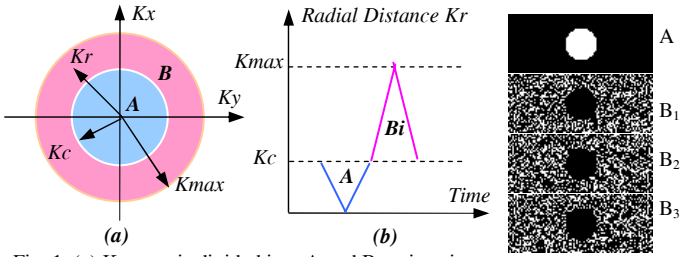

Fig. 1. (a) K-space is divided into A and B regions in phase encoding plane. (b) Acquisition order.

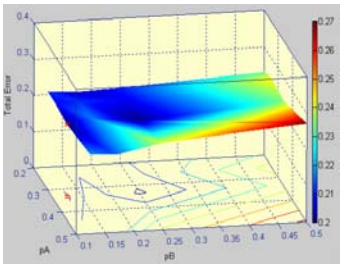

Fig 2 Total error index vs pA, pB.

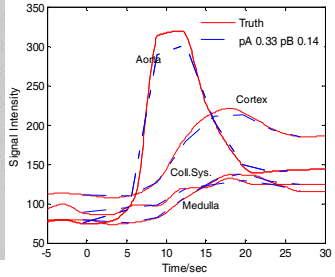

Fig. 3. SI enhancement curves.

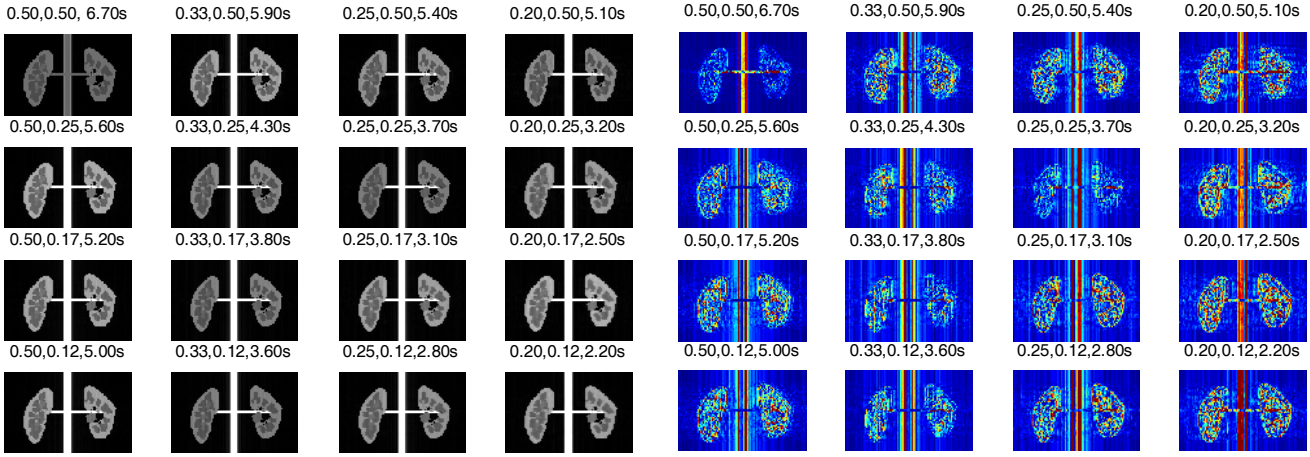

Fig. 4. Left: Middle slices of reconstructed images titled pA, pB and TA. Right: normalized differences between reconstructed and truth image.