Contrast-Enhanced MR Angiography using Time-Resolved Interleaved Projection sampling along the 3D Cartesian Phase and Slice encodings (TRIPPS)

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INTRODUCTION

Contrast-enhanced three-dimensional (3D) magnetic resonance angiography (MRA) has emerged as a useful noninvasive method for evaluating the vasculature of most organs in humans (1-7). Timing of data acquisition to contrast arrival is critical in generating high quality arterial phase images. The sparse bright vessel signals in 3D MRA are largely located at k-space center (5). A more frequent update of the small portion of central k-space data allows improved temporal resolution, as is used in 3D Cartesian key-hole and TRICKS techniques. Radial k-space sampling provides oversampling of k-space center, and allows undersampling of the periphery of k-space to improve temporal resolution. While a variety of projection reconstruction (PR) type techniques have been proposed with both high spatial and temporal resolution (2-5), their clinical application is still limited since projection reconstruction is sensitive to gradient errors, eddy currents and off-resonance effects. The combination of 3D Cartesian encoding with PR acquisition in the phase and slice encoding plane has recently been shown to double the spatial resolution with minimal artifact (7). Here we report a novel Time Resolved Interleaved Projection sampling along the 3D Cartesian Phase and Slice encodings (TRIPPS), which combines the robustness of Cartesian imaging and efficiency of undersampled PR acquisition.

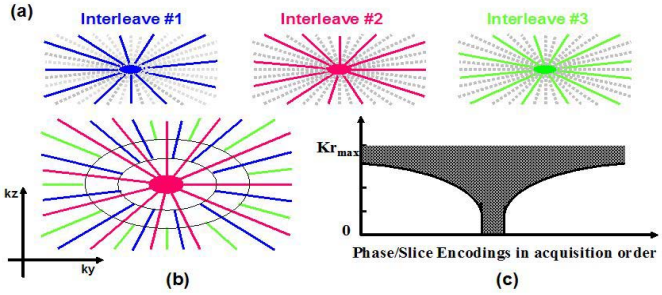

Fig 1 *TRIPPS data acquisition and reconstruction: (a) k-space is partitioned into half projections in the ky-kz plane which are interleaved into multiple groups with each group sparsely but uniformly covering k-space. (b) High frequency phase and slice encoding data from neighbor interleaves is shared to reduce undersampling artifact. (c) A sliding window reconstruction algorithm is used to generate high temporal resolution images.*

MATERIALS AND METHODS

The TRIPPS technique is based on a clinical 3D spoiled gradient echo sequence, where only these phase and slice encodings located within the predefined radial trajectories are sampled, as shown in Figure 1a. The whole set of half projections is divided into 12 to 16 interleaves. Each interleave has an odd number of half projection (such as 15 or 29), creating an asymmetric radial sampling of ky-kz space for improved streak artifact reduction (7). The central phase/slice encodings (such as 100) are always sampled for each interleave, regardless of the pre-defined radial trajectories for improved artifact control (7). High frequency phase and slice encoding data are shared among the neighbor interleaves (Figure 1b), similar to the view sharing strategy used in PR dynamic imaging (3-5). This filter is slid forward to reconstruct each dynamic frame (Figure 1c). The TRIPPS technique was applied to both pulmonary and renal CE-MRA in 6 volunteers. Typical acquisition parameters included: FOV of 32 cm, 32 slices, 2 to 4 mm slice thickness, TR = 3.6 ms, TE = 1.4 ms, flip angle = 30°, bandwidth = ±125 kHz, readout = 256, scan time = 24 to 32 seconds. 30 ml of Gd-based contrast agent was injected at a rate of 3 ml/sec followed by 30 ml of saline at the same rate.

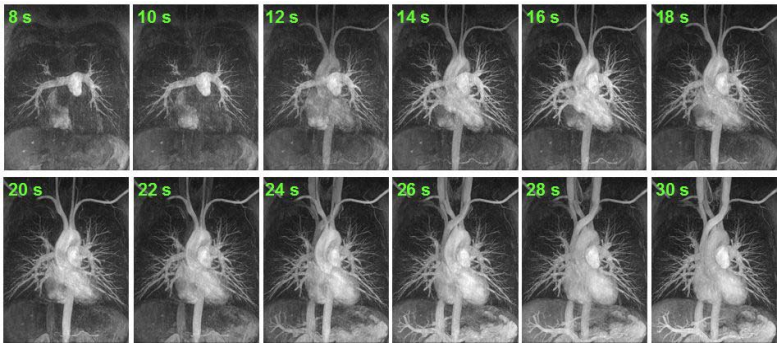

Fig 2 *TRIPPS imaging of the pulmonary vasculature of a 35 year old volunteer provides excellent depiction of the contrast dynamics in pulmonary arterial and venous segmental and subsegmental branches with a high temporal resolution of 2 seconds per frame.*

RESULTS AND DISCUSSION

Figure 2 shows coronal maximal intensity projection (MIP) dynamic images of the pulmonary of a 35 year old volunteer, which provide excellent depiction of the pulmonary arterial and venous vasculature with a spatial resolution of 1.25×1.25×4.0 mm^3 and frame rate of 2 seconds per frame. Figure 3 shows coronal MIP of renal dynamics of a 63 year old volunteer. The arterial and venous phases are well separated with a high temporal resolution of 2 seconds per frame and spatial resolution of 1.25×1.25×2.0 mm^3. Compared to TRICKS, TRIPPS is more flexible and more efficient in updating the k-space center, allowing higher temporal resolution. TRIPPS is much more robust than PR type techniques since it is basically a Cartesian type of acquisition. The sliding window view sharing reconstruction algorithm provides minimal streak artifact while maintaining contrast dynamics.

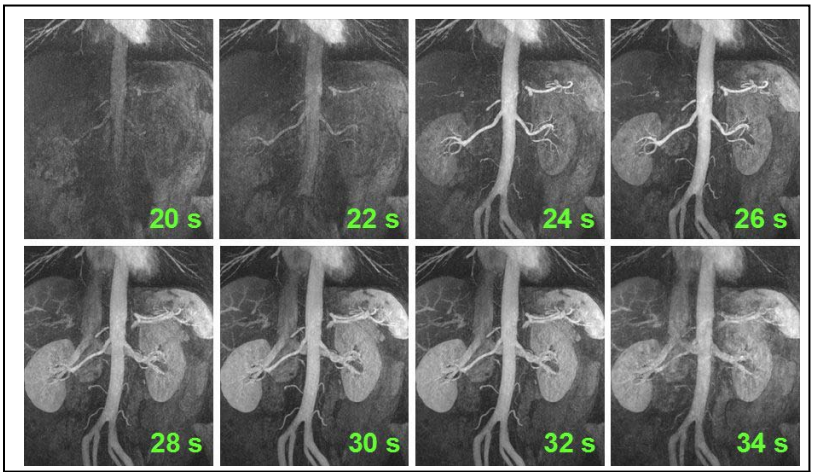

Fig 3 *TRIPPS imaging of the renal vasculature of a 63 year old volunteer provides excellent depiction of the contrast dynamics, including arterial and venous phase with a high temporal resolution of 2 seconds per frame.*

CONCLUSIONS

TRIPPS is able to provide high spatial and temporal resolution 3D CE-MRA with minimal artifact. The preliminary study on pulmonary and renal angiography show high clinical potential.

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