Phase Contrast Stack of Stars Imaging

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INTRODUCTION

Phase contrast MR Angiography (PC MRA) can provide anatomical and functional information on vascular territories. With concerns rising over the safety of contrast agents, it also provides an alternate imaging method for patients at risk for nephrogenic systemic fibrosis. However its clinical use has been hindered by extensive imaging times for 3D flow encoding and unfavorable artifacts from cardiac pulsatility and intravoxel dephasing. PC MRA with 2D [1] or 3D [2] radial trajectories is well suited for high degrees of radial undersampling because of the sparse data sets obtained by the inherent subtraction of signal from stationary tissues. With such an approach, imaging times can be reduced and higher spatial and temporal resolutions can be obtained, thereby overcoming the limitations of standard 3D PC MRA. Here we introduce the implementation of a hybrid 3D PC MRA radial "stack of stars" (SOS) acquisition that is well suited for vascular territories that require larger in-plane coverage than slab thickness. This acquisition also allows for the use of parallel imaging techniques in the slice encoding direction which are highly simplified for Cartesian encoding.

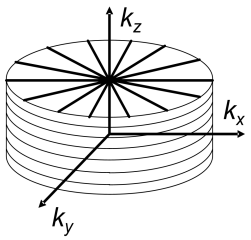

Figure 1. K-space trajectory for a stack of stars sequence.

METHODS

In a SOS sequence, k-space data are acquired as radial lines in the xy-plane, while conventional phase encoding is used in the z-direction (Fig. 1). The acquisition is arranged such that velocity encoding is performed in all three directions before incrementing the projection angle by 'the Golden Angle' (137.51°) and all projections for a given phase encode are acquired before increasing the phase encoding gradient. The distributed nature and low frequency over sampling of this pattern reduces cardiac pulsatility artifacts. Although spatial resolution in the z direction is limited by the number of phase encodes, spatial resolution in the xy-plane is determined only by the readout resolution. Since phase subtraction eliminates the stationary background, scan time can be reduced by limiting the number of k-space projections in the xy-plane without the appearance of intense streak artifacts as seen in conventional imaging.

All experiments were performed on a clinical 3T scanner with an 8-channel head coil (Excite HD, GE Healthcare, Waukesha, WI). Image quality comparisons were made for intracranial MRA as compared to the standard 3D Cartesian phase contrast sequence on healthy volunteers without the use of contrast agent. Cartesian PC images were obtained with FOV = 220x165x96mm, resolution = 0.86x0.86x1.5mm, 32 kHz readout bandwidth, TR=14ms,TE=5.7ms, α=10°, scan time = 11:28. In each volunteer, two sets of SOS images were acquired, one with matched readout parameters and one with more optimized parameters which could not be achieved on the Cartesian scan due to implementation issues. Parameters for the matched sequence were FOV =220x220x96mm, 0.86x0.86x1.5mm, 32 kHz readout bandwidth, TR=14ms,TE=3.9ms, α=10°, 128 projections per phase encode, scan time =7:39. For the optimized sequence the parameters were FOV=220x220x96mm, resolution= 0.86x0.86x1.5mm, 62Khz readout bandwidth, TR=9.8ms,TE=3.9ms, α=7°, 128 projections per phase encode, scan time =5:21. Both PC SOS sequences had a 20s gradient calibration acquired immediately following acquisition to correct for errors from eddy currents and gradient timing errors[3]. Optimized PC SOS scans were further decimated to simulate higher acceleration factors. Complex difference images were analyzed for vessel conspicuity and artifact prevalence.

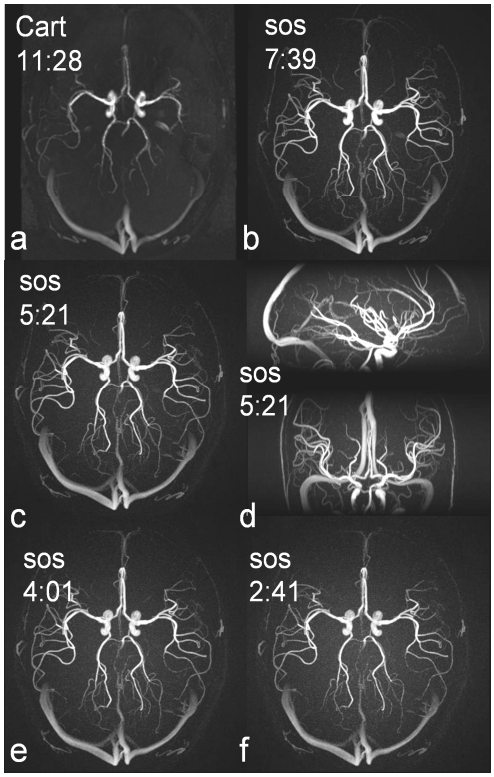

Figure 2. Representative MIP images.

RESULTS

MIPs from the complex difference images are shown in Figure 2 along with the acquisition times. Figure 2 a,b shows the result from the PC Cartesian acquisition along with the undersampled PC SOS acquisition with matched parameters. Notice that finer vessel detail is present in the images acquired with the SOS sequence. Figure 2 c,d shows the results from the optimized sequence with 128 projections per phase encode, while figures 2 e,f show the optimized sequence with 96 and 64 projections per phase encode. Although noise becomes more apparent as the undersampling increases in the PC SOS studies, it does not obscure the finer vessel detail that the more fully sampled PC SOS sequence provides over the Cartesian sequence.

DISCUSSION

In this feasibility study, we demonstrated the successful application of radially undersampled PC SOS MRA. Even with an angular undersampling factor more than six relative to the Nyquist criterion, the reduction of pulsatile artifacts in SOS produced more detailed images than the fully sampled Cartesian sequence acquired at identical resolution. While the truly 3D radial PC VIPR acquisition offers higher degrees of undersampling for cubic imaging volumes, this approach is beneficial for the imaging of vascular territories with a smaller slab thickness than FOV, e.g. the circle of Willis, CSF flow, and other applications. In addition, parallel imaging [4] can be added in the slice encoding direction for further reduction in scan time in a straight forward matter with proper coil alignment. We are currently investigating such strategies [5] Besides providing anatomical information on the vasculature, PC MRA also allows for the functional analysis of the velocity vectors over a 3D volume and derived parameters such as flow, wall shear stress and trans-stenotic pressure gradients [6], especially with cardiac gating. The current results encourage further studies with evaluations in volunteers and patients. In addition to providing anatomical and hemodynamic information, this approach also provides a MRA alternative for patients that are contra-indicated for the administration of Gadolinium based contrast agents.

REFERENCES

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