Diffusion Imaging Of Head And Neck At High Angular And Spatial Resolution Using Multi-Shot Spirals

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TARGET AUDIENCE: Researchers interested in high-resolution diffusion imaging of the brain, especially of brain regions severely affected by susceptibility artifacts. Applications include the study of micro-structural connectivity in regions such as the cerebellum, pons etc. in the lower brain and connections ensuing thereof such as spinothalamic and cerebellothalamic fiber tracts.

PURPOSE: Diffusion imaging in brain regions such as the cervical spine are highly desirable in clinical diagnosis of conditions such as cervical spondylotic myelopathy or spinal cord injury[1]. However, diffusion imaging of lower brain regions including the cerebellum, pons, and cervical spine are challenging due to the presence of air-tissue and tissue-bone interfaces producing susceptibility artifacts. These regions are also affected by involuntary motions such as blood and cerebrospinal fluid (CSF) pulsation, breathing and other kinds of motions such as swallowing[1,2], making diffusion imaging inherently difficult. Since the sizes of the structures of interest are small in these regions, high spatial resolution is desired. Conventional single-shot imaging schemes are ineffective in these regions due to the low SNR and field inhomogeneities. Multi-shot diffusion imaging coupled with parallel imaging techniques can offer enhanced image quality for such applications. The use of radial or spiral acquisitions can achieve higher SNR while trajectories with small readout durations minimize T2* artifacts. However, the main drawback of the above scheme is the sensitivity of the multi-shot imaging to motion artifacts. Recently, we proposed a fast motion-compensated multi-shot diffusion imaging acquisition and reconstruction scheme[3,4], where the k-space sampling is performed using multi-shot variable density spirals that efficiently under-samples the combined k-space and q-space of diffusion imaging. We show that the proposed imaging scheme is highly suitable for obtaining high angular resolution diffusion images (HARDI) at high spatial resolution from these challenging regions.

METHODS: Whole brain diffusion data was collected on a Siemens 3T scanner (45 mT/m, 200T/m/s gradient) using a combined 12-channel head coil and 4-channel neck coil providing coverage from the top of the head to C2. A variable density spiral sequence was designed with 25 spatial interleaves, $\alpha = 10$ and readout duration of 13.5ms, to cover FOV = 20cm using a192x192 matrix to achieve an in-plane spatial resolution of 1.04 x 1.04 mm^2. 54 axial slices with slice thickness of 2.5 mm were acquired. One fully sampled b_0 image and 30 k-q under-sampled (x5) diffusion-weighted images (DWIs) were collected at b= 1000 s/mm^2 using TE/TR = 76/3000 ms. The total acquisition time was under 18 minutes. An iterative reconstruction imposing total-variation (TV) regularization on the DWIs and sparsity on the number of diffusion components were used to recover the images using the equation: $\hat{v} = \arg\min_{v} \|\mathbf{E}(v) - \mathbf{y}\|^2 + \lambda_1 \|\mathbf{A}(v)\|_{TV} + \lambda_2 \|v\|_1$ where $\|\mathbf{A}(v)\|_{TV} = \left\| \sqrt{(\nabla_x \mathbf{A}(v))^2 + (\nabla_y \mathbf{A}(v))^2} \right\|_1$ where **y** is the k-space data, **A**(*v*) are the DWIs and **E**(*v*) is the motion-compensated forward model operator that enforces data consistency[3]. A T2 weighted sequence as well as a single-shot EPI diffusion sequence with a single b_0 image and 30 DWIs at b=1000 s/mm^2 were also collected for comparison. The single shot EPI was collected with a matrix size of 128 x 128 providing an in-plane spatial resolution of 1.6 x 1.6mm^2.

RESULTS: Figure 1 shows the comparison of the axial b_0 images obtained from the single-shot EPI and multi-shot spiral sequence as compared to the acquired T2-weighted image for the same slices. The single-shot EPI suffers from significantly greater geometric distortions and signal dropouts as compared to multi-shot spiral imaging. Since each shot of spiral k-space trajectory has shorter readout durations, it is robust to T2* artifacts. Also, the joint k-q under-sampling scheme enables the acquisition of high angular and spatial resolution diffusion images in a reasonable scan time. The high density of sampling at the center of k-space as well as the lower TE possible with the spiral sampling enables imaging at improved SNR from these regions compared to single-shot EPI scans.

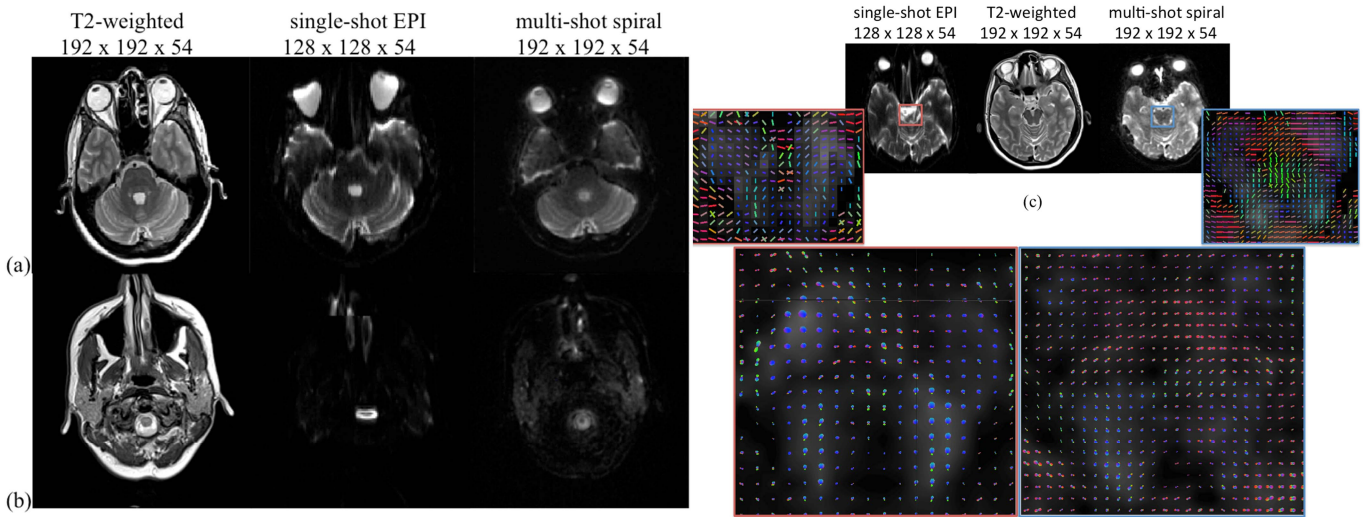

Figure 1: Comparison of multi-shot spiral and single-shot EPI axial diffusion images in brain regions that are affected by susceptibility artifacts. (a) & (b) shows the T2-weighted image, Single-shot EPI and Multi-shot spiral images of the same slices in the cerebellum and cervical spine respectively. The geometric distortions in the single-shot EPI even for moderate resolutions are significant. Multi-shot spiral imaging provides better quality images in these regions. (c) shows an axial slice from the region of the pons and the color coded primary diffusion directions from the boxed region. In the bottom row, the diffusion ODFs from the region are shown for the single-shot EPI and multi-shot spiral. At the higher resolution obtained using the multi-shot spiral imaging, the complex neuronal fiber orientations such as the transverse pontine fibers can be observed in greater detail. This region suffers from significant artifacts using single-shot EPI.

DISCUSSION and CONCLUSION: The HARDI data obtained from the above acquisition enables the reconstruction of diffusion orientation distribution function (ODF) at high angular and spatial resolution. The proposed scheme can provide improved depiction of white matter connections in many of the above-mentioned challenging regions, which in turn enables the study of brain connectivity of these regions, which were unattainable with single-shot imaging.

REFERENCES: (1) Vedantam et al, Neurosurgery, 2014, 74(1):1-8; (2) Vertinksy et al, Neuroimaging Clin N Am. 2007, 17(1): 117–136; (3) Mani et al, MRM, Jan, 2014 (4) Mani et al MRM, Oct 2014.