# High Resolution Radial Diffusion-Weighted Imaging at 7T

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**Introduction:**

Diffusion tensor imaging (DTI) has been established as an extremely useful technique for probing the microstructure of tissue organization in both humans and animals [1]. The most common application of acquiring diffusion-weighted images (DWI) on both human and animal imagers use single shot or interleave echo planar imaging methods [2,3]. While these methods are fast and robust to motion, they are inherently limited in spatial resolution and are extremely sensitive to changes in the magnetic field (i.e. susceptibility). These problems can be severe at the high fields used for small animal imaging. With the increasing use of animal models in imaging studies of structure and physiology, DTI has become an important tool in quantifying, validating, and ultimately understanding microstructural changes in tissues in these animal models, and thus the development of a robust and efficient high field DTI sequence is critical.

High spatial resolution without susceptiblity artifacts can be acheived by imaging with a multi-shot spin-echo acquisition method. However, small motions and system instabilities introduce phase and data shift errors when diffusion weighting (DW) is implemented in multi-shot sequences. DW Radial MRI, where data are acquired along radial lines of Fourier space, has been demonstrated as an imaging method that is insensitive to motion, system instabilitity, and susceptibility [4-9]. This study presents the implementation of radial acquisition techniques to obtain high resolution DWI on a GE 7 T animal scanner. Results are shown in an excised fixed normal rat brain, and an excised rabbit heart.

**Methods:**

Data were acquired on a 7 T GE echospeed EXCITE scanner equipped with 75 mT/m, 250 mT/m/ms gradient system located at the UC San Diego Center for Functional MRI. The pulse sequence has a standard spin echo (SE) diffusion preparation. Data acquisition occurs on a set of radial lines passing through the origin of k-space so that the sampled data form a polar grid. Following the selective excitation, two gradients are applied to pre-position the trajectory in k-space. The gradients in the x and y directions have the same pulse width but are scaled by $G_x=G_o\cos\theta$ and $G_y=G_o\sin\theta$. The readout gradients have the same amplitude as the corresponding positioning gradient but are of opposite polarity.

For data collected on a polar grid, an image can be reconstructed via filtered back projection reconstruction (FBPR). In theory, when implementing radial MRI, the complex data point obtained at the center of k-space should be the same from on acquisition to the next, where the peak signal should occur in the center of the acquisition window. With DWI, small translational motion (physiological or vibrations) will produce large deviations in the phase from one radial line to the next and possible shifts in the k-space trajectory due to diffusion gradient induced eddy currents. These errors can be partially compensated for by modifying the radial lines of Fourier data prior to FBPR. The correction scheme makes the following assumption: The object is a positive real quantity and therefore each projection of the object should be a positive real quantity [4,6]. This assumption is true for a stationary object in ideal circumstances. However, motion related errors cause the projection data becomes complex. Utilizing the above assumption, we can obtain a motion corrected projection by taking the magnitude of the signal following a 1DFT.

**Results:**

Coronal images of a fixed normal rat brain were acquired with the following parameters: voxel size 210 μm × 210μm × 210μm, BW = 16 kHZ, TR = 2.8 sec, TE = 24 ms, 128 complex points in the readout direction along 128 projections angles, and NEX = 40. With b ≈ 5000 s/mm$^2$, gradients were applied along 6 diffusion directions [10]. Axial rabbit heart images were acquired with the following parameters: voxel size 125μm × 125μm × 1mm, BW = 16 kHZ, TR = 1.5 sec, TE = 25 ms, 256 complex points in the readout direction along 402 projections angles, and NEX = 4. With b ≈ 1600 s/mm$^2$, gradients were applied along 24 diffusion directions. Diffusion images were reconstructed from raw data using a magnitude FBPR reconstruction method. Representative diffusion images for the rat brain showing the strong white matter contrast are shown in Figure 1. In Figure 2 are shown results in an excised rabbit heart.

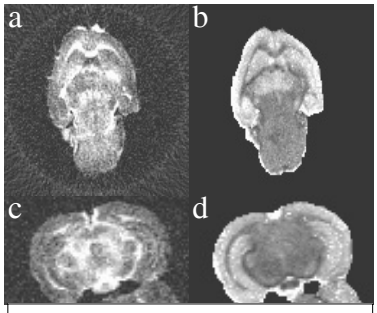


**Figure 1**. (a,c) DW images of a fixed rat brain with b ~ 5000 s/mm$^2$ along a single diffusion direction. (b,d) ADC maps derived from diffusion data collected with 6 diffusion encoding directions.

**Conclusion:**

The acquisition of high resolution DTI data at high fields in small animal imaging systems is of great importance to a wide variety of studies that employ animal models of tissue. The ability of MRI to allow longitudinal studies on genetically altered animals has dramatically increased the number of studies that involve DTI as a probe for tissue structure. DTI data has the potential to provide a variety of information, including tissue integrity and local fiber orientation. However, the accuracy of these measurements is predicated on the DW images of minimal distortion. This is particularly a problem at high fields due to large susceptibility effects. In addition, small animals have elevated heart rates and thus there can be increased motion artifacts that distort DW images. We have developed a sequence that we have demonstrated can acquire high-resolution diffusion-weighted images on a 7T with greatly reduced susceptibility artifacts. This sequence also has the reduced motion effects inherent to radial acquisitions since we are able to utilize a modified FBPR reconstruction technique which compensate for phase errors produced by bulk translational motion and shift errors produced by eddy current. This offers the possibility of improved accuracy of the diffusion measurements at high fields.

Recent work has shown that high angular resolution diffusion (HARD) measurements can provide information that goes beyond what is described by the diffusion tensor [11,12]. By employing HARD encoding along with radial acquisition techniques to obtain high resolution DWI that are insensitive to susceptibility artifacts, one can improve the accuracy and sensitivity of the diffusion anisotropy measure. Future work will include implementing HARD encoding along with a fast spin-echo (FSE) acquisition method to improve acquisition time. (Research supported by 5 R01 MH64729-03)

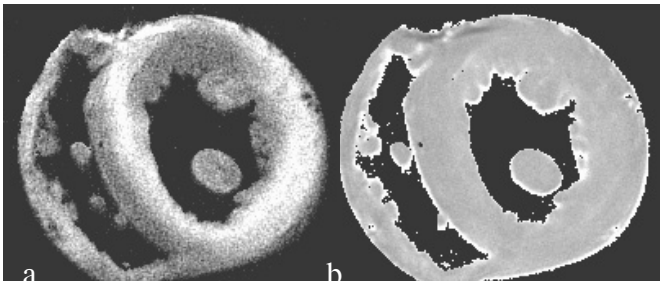


**Figure 2**. (a) Axial DW images of a fixed rabbit heart with b ~ 1600 s/mm$^2$ along a single diffusion direction. (b) ADC map derived from diffusion data collected with 24 diffusion encoding directions.

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