High-Resolution 3D Diffusion Tensor Imaging of an excised animal heart using COmposite Diffusion Encoding (CODE) at 3T

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INTRODUCTION: Singleshot diffusion weighted echo-planar imaging (ss-DWEPI) has proven to be a powerful method for examining neurological diseases in the brain. However, there is substantial image distortion due to the magnetic susceptibility when using a conventional ss-DWEPI, which subsequently limits the spatial resolution. Diffusion prepared (DP) imaging has been used to reduce the distortion and the motion artifacts as an alternative acquisition technique to ss-DWEPI. DWI with DP requires two separate acquisitions with the transmit phase of their tipup RF pulses shifted by 90 degrees.[1,2] A new technique, COposite Diffusion Encoding (CODE) EPI, was developed using 3D EPI to simultaneously acquire both quadrature components of the diffusion encoded magnetization, which gives several important advantages over the conventional DP technique.

MATERIALS AND METHODS: A Stejskal-Tanner DW waveform was incorporated into 3D segmented EPI on a Siemens 3T system. CODE-EPI, shown in Fig. 1, acquires two DW images, in which the phase error of the magnetization in each voxel is transformed to the amplitude of each component by separating the signal into (1) diffusion weighted (DW: $M(\mathbf{r})\cdot\cos\varphi_{err}(\mathbf{r})$) and (2) diffusion prepared (DP: $M(\mathbf{r})\cdot\sin\varphi_{err}(\mathbf{r})$) magnetizations. A pair of crusher gradients denoted as A_c was applied to selectively crush the T_1 recovered magnetization, as well as to eliminate the effects of the transmit phase of the excite/tipup RF. The sequence was applied to DTI measurements of (a) a uniform agar phantom, and (b) an excised dog heart with $(1.0\ \text{mm})^3$ isotropic resolution. B values were 0 and 400 sec/mm^2 along 7 directions for the heart. A Siemens wrist coil was used with ETL of 9.

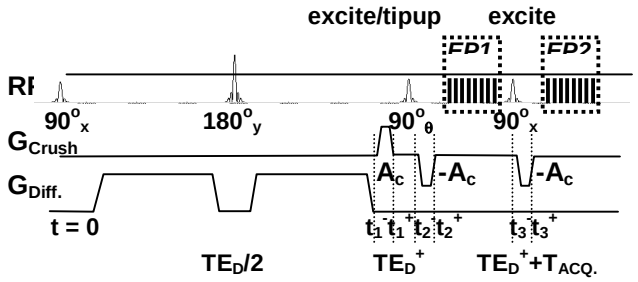

Figure 1. *CODE-EPI with crusher gradient. The resultant DWI is independent of the phase between the excite/tipup RF pulse and the DW prepared magnetization. The 0th moment A_c of the crusher must be large enough to cause of phase difference of at least 2π in the spins across an imaging voxel. This scheme effectively spoils any non-DW magnetization for both the EP 1 and EP 2 images.*

RESULTS: 3D DW images of a uniform phantom are compared to that of ss-DWEPI in Fig. 2. The uniformity and the accuracy of the ADC values measured by 3D DTI measurement are comparable to those of ss-DWEPI. The DTI data were diagonalized, and a RGB color map was constructed for the principal eigenvector and is displayed in Fig. 3 in (a) short and (b, c) long axis planar views. The vector plots of the principal eigenvector are overlaid for selected regions enclosed in dotted boxes in Fig. 3(d-f). The resultant DTI measurements reveal the helical structure of the cardiac muscle, and agree well with previously reported results.[3]

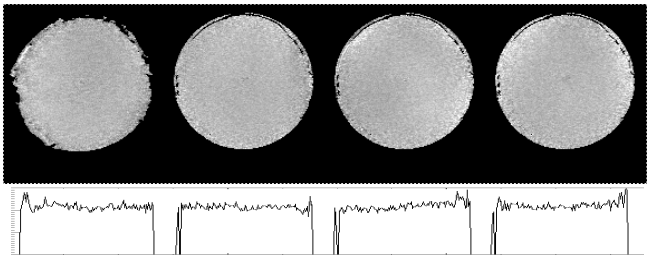

Figure 2. *ADC maps of 2D ss-DWEPI along (AP+SI) direction (a) and 3D DWEPI along 3 directions (RL+AP, RL-AP,AP+SI) (b-d). ADC values across the phantom in the images were plotted on the bottom graphs*

DISCUSSION: CODE-EPI reduces the imaging time by ½ for the same SNR compared to conventional DP imaging. Moreover, the two quadrature signals are acquired simultaneously (one immediately after the other after a single DP period), eliminating phase errors between DW and DP magnetization components for each k-space line in the SRSS technique. In contrast, conventional DP techniques may lead to misregistration between the two quadrature images, because they are acquired by two separate acquisitions.

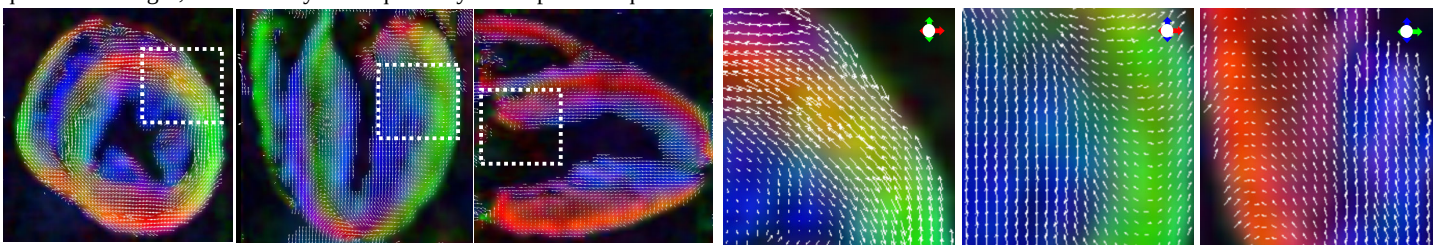

Figure 3. *RGB fiber maps of the principal eigenvector of 3D CODE-EPI. The colors represent **R**: left-right and **G**: up-down on the short axis plane, **B**: in-out along the long axis, and mixed colors for muscle fiber running obliquely. Exploded views of selected boxes are shown in (d-f).*

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