Improvement of DTI measurement using the Composite Gradient Systems on a Clinical 3T MRI System: DTI study of ex vivo Dog's Heart

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INTRODUCTION: Diffusion Tensor Imaging (DTI) techniques have improved due to increased magnetic field strength and improved RF and gradient coil performance. Further improvement in gradient performance could be used to shorten the echotrain duration or increase the number of echoes in the same duration and thereby be of substantial benefit for high resolution DTI acquisition. Although, insert gradient coils can improve gradient performance for the benefit of EPI, diffusion and short TE imaging[1,2], their use typically requires that the insert gradients replace the body gradients, which is a logistically difficult process. The ideal MRI system may allow insert gradients to be used in concert with the whole-body gradients so that the best qualities of each gradient system can be dynamically selected for each acquisition. We have implemented hardware on our research 3T MRI scanner to allow simultaneous operation of two gradient systems. To test the potential utility of this system for DTI measurement, we have acquired diffusion weighted images of phantoms, tissue samples, and an excised dog heart using a combination of local insert and standard whole body gradients. Here, we report on the results of DTI of the excised dog heart.

METHODS: The insert gradient coil was developed for head and neck imaging and details of gradient insert coil construction can be found in reference 3. All MRI scans were performed on the Siemens 3Tesla TIM Trio scanner (Siemens Health Care AG, Erlangen Germany). The standard system was augmented with three additional gradient amplifiers and master/slave configured computers capable of controlling extra gradient channels. The control hardware and software were developed and provided by Siemens. Pulse sequences were implemented to control both gradient coils synchronously. A separate pulse sequence was used to operate each gradient set. For our experiments, the master computer was used to 1) maintain all computer controlled shims, including the first order gradient shims obtained using the standard body gradients, 2) control RF excitation and reception, 3) control standard whole body imaging gradients to allow any combination of x, y, z be on or off, and 4) synchronously trigger the slave computer. The slave computer executed a pulse sequence controlling the gradient insert to allow any combination of x, y, z to be on or off. DW images of the excised dog heart were acquired using 2D ss-rFOV-DWEPI[4] and composite gradients with the following parameters: FOV=128x40mm, matrix=128x32, slice thickness=2 mm, TR=3s, TE=82ms, 12 magnitude averages. Diffusion gradients were applied along 12 directions using b-values of 0 and 500 s/mm^2. Standard gradient system was only used to apply the diffusion sensitized gradient. The resultant in-plane resolution of DWI was 0.5x0.5 mm^2. To obtain the same in-plane resolution of DWI used in composite system, the imaging matrix used in the body-gradient-only acquisition was increased to 256x64 and TE was increased to 135ms. DW images were post-processed using DTI analysis software written in IDL (Research Systems Inc., Boulder, CO) to calculate ADC maps, the six independent diffusion tensor components, eigenvalues and eigenvectors, fractional anisotropy (FA), and to visualize the results using an RGB representation of the principal eigenvector and fiber map.

RESULTS: To obtain DW images with reduced susceptibility artifact the inferior region in the excised heart (dotted line in Fig 1) was imaged. Figure 2 displays the DTI measurements obtained using the body gradients (a) as well as the composite gradients (b), The vector map of the principal eigenvector of slice 4 in Fig. 2b is projected onto the short axis plane in Fig2-c. The corresponding fiber tracts are shown in Fig 2-d. Detailed structure of the myocardial muscle is well presented in both the vector map and fiber map. DTI result obtained using only the standard gradient showed distortion artifacts due to the long readout duration (Fig 2-a).

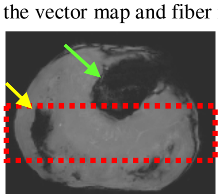
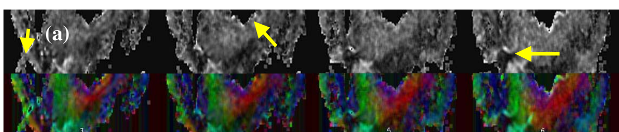


Fig 1: Region used for DWI of dog's heart is indicated by red dotted line. Arrows point to the left (green) and right (yellow) ventricles.



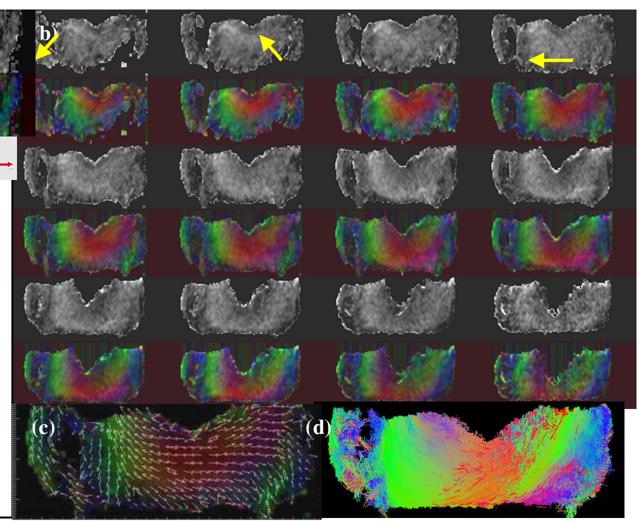


Fig 2: FA map obtained using the three eigenvectors and the RGB map of principal eigenvector map obtained using body gradients (a) and composite gradients (b). The colors represent the directions: vertical (Red), horizontal (Green), in-out (Blue). Projected vector map of tensor principal component (c) and fiber tracts (d) obtained using DTI data from composite gradients for slice 4. DTI of only the first 4 slices obtained using the standard gradients are shown in (a). Because of the longer readout duration, DTI using only the standard gradient shows more distortion artifact (indicated by yellow arrows in (a)) than DTI by using composite gradient (corresponding arrows in (b)).

DISCUSSION: The results presented here are very important because this composite gradient system that we are investigating is designed to function in studies of the human brain in vivo. This composite system has the distinct advantage that both gradient systems can be operated simultaneously and/or independently. With simultaneous acquisition, the gradient strength available from either system alone can be increased. Although there are many challenges associated with simultaneous operation, we have successfully demonstrated that this is possible, and that this can have a substantial effect on improving image quality in EPI sequences, such as DTI.

In conventional systems, spatial resolution and SNR in DWI techniques have been improved with multiple shots and averages. However, multi-shot DWI in human applications usually suffers from artifact induced by phase error between each shot. Further, the long scan time can result in additional motion problems. As we have demonstrated in this study, the composite gradient system can acquire better DTI measurements with less artifact in human studies than can be obtained with insert or body gradient coils alone. This system can also provide high resolution fMRI datasets with better imaging quality compared to data obtained using the standard gradient system.

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