Reduced Susceptibility Artifacts in Diffusion Weighted Brain Imaging Using Specialized RF and Gradient Hardware

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INTRODUCTION: Diffusion Weighted Imaging (DWI) techniques have improved due to increased magnetic field strength and improved Radio Frequency (RF) and gradient coil performance[1]. Improved gradient performance is used to shorten the echotrain duration and increase the number of echoes in the same duration, thereby reducing susceptibility artifacts[2,3]. In this study, we combine a home-built insert gradient with the body gradient (BG) on our research 3T MRI scanner to create a composite gradient (CG) system with increased gradient performance (Figure 1). Because the body RF coil does not penetrate strongly through the RF shield of the insert gradient, we have developed a shielded high pass birdcage coil for use with our CG system (Figure 2). Due to the birdcage's small size it has high SNR when compared with the body RF coil, and it deposits much less SAR over the entire body such that the patient experiences much less RF heating. To test the potential utility of this system for DWI measurement, we compare diffusion weighted images obtained using only the BG coils and using the CG system.

METHODS: The insert gradient was developed for head and neck imaging. Details of its construction can be found in [4]. All MRI scans were performed on a Siemens 3 Tesla TIM Trio MRI scanner (Siemens Health Care AG, Erlangen, Germany) that has been 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. The maximum gradient strength of the BG is 40mT/m and CG is 120 mT/m.

The birdcage coil has 16 rungs and is shielded so that it is useable both within and without the insert gradient. Due to the close proximity of the birdcage RF shield, we used a highpass design to increase capacitor values and to simplify tuning. The attached endcap [5] extends the imaging region to the endcap of the birdcage. In order to reduce resonant frequency shifts when inserted into the insert gradient, the shield is attached to the endcap. The shield and endcap of the birdcage coil are slotted to reduce gradient frequency eddy currents and the slots bridged with 15000 pF capacitors to create RF shorts.

DW images of a human brain were acquired using a 2D single shot EPI sequence with our RF birdcage and CG coils. The imaging parameters were: FOV=166x166mm, matrix=160x160, slice thickness=2 mm, TR=5s. The TE was 111ms with the BG and 86ms with the CG system. The ESP reduced from 1.03ms with the BG system to 0.52ms with the CG system. The CG was operated at triple the BG gradient strength. Diffusion gradients were applied along the slice direction using b-values of 0 and 1000 s/mm^2. The resultant in-plane DWI resolution was 1x1 mm^2. DW images were post-processed using DWI analysis software written in IDL (Research Systems Inc., Boulder, CO) to calculate ADC maps.

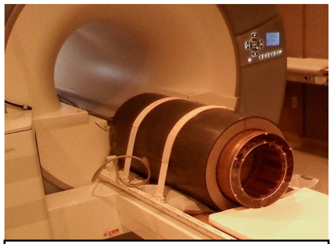

Fig 1: Birdcage RF coil inside of the insert gradient prior to entering the magnetic bore.

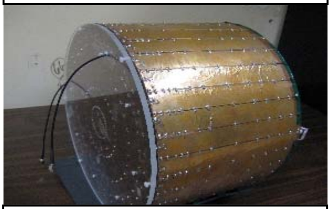

Fig 2: Highpass birdcage RF coil with attached shield and endcap visible.

RESULTS: To obtain DW data with reduced susceptibility artifact we imaged a human brain. Figures 3 and 4 display DWI measurements obtained using the BG as well as the CG with the local transmit/receive coil. The bandwidth of the phase encoding direction was increased from 6.25 Hz using the BG to 12.2 Hz using the CG system. With just the BG, large areas of the images are either distorted or dark in the ADC images. Using the CG system eliminates most of these effects, as shown by the lack of dark patches in the CG images. There is some aliasing due to imperfections in the insert gradient.

DISCUSSION: These results are important because the CG system is designed to function in studies of the human brain *in vivo*. The CG 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 substantial benefits in image quality can be obtained in EPI sequences, such as DWI.

In conventional MRI 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 CG system can acquire better DWI measurements with less artifact in human studies than can be obtained with the insert or BG coils alone. This system can also provide high resolution fMRI datasets with better imaging quality compared to data obtained using the BG system.

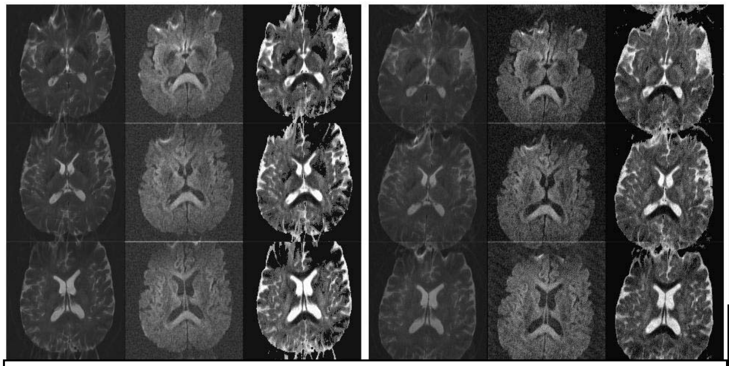

Fig 3: Three different slices (separated vertically) of DWEPI images using the (a) body gradient and the (b) composite gradient system. Three images are shown in each set, from left to right: b=0, b=1000, and ADC. Large dark spots and significant distortion that are seen in the final ADC body gradient images are reduced in the composite gradient system.

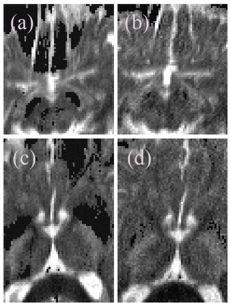

Fig 4: Closer view of some DWEPI images with the body (a,c) and composite (b,d) gradients. (a) and (b) are the same region, and (c) and (d) are the same region.

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