Assessment of Concomitant Gradient Blurring in Spiral In-Vivo scans at 1.5 T

C. T. Sica[1], and C. H. Meyer[2]

[1]Engineering Physics, University of Virginia, Charlottesville, VA, United States, [2]Biomedical Engineering, University of Virginia, Charlottesville, VA, United States

Introduction: Off-resonance phase in spiral scans can lead to undesirable blurring artifacts. The most commonly considered sources of such off-resonance phase are chemical shift and static B_0 field inhomogeneities, such as magnet imperfections and susceptibility effects. A less commonly considered but still important source of off-resonance phase is concomitant gradients. Concomitant gradients, also known as Maxwell terms (1), arise because the combination of a static main field and linear gradients do not satisfy Maxwell's equations of electrodynamics. In this abstract, we demonstrate the severity of the concomitant gradient artifact in spiral in-vivo scans at 1.5T. The main goal is to determine, for a variety of scan plane orientations, the distance from isocenter at which concomitant blurring starts to become significant.

Theory: A version of the concomitant gradient equation used in oblique spiral scans is given in [1], and was first derived in (2).

$$f_c(X,Y,Z,t) = \frac{\gamma\sqrt{G_X(t)^2 + G_Y(t)^2}}{8\pi B_0}(F_1X^2 + F_2Y^2 + F_3Z^2 + F_4YZ + F_5XZ + F_6XY) \qquad [1]$$

The coefficients F_1 through F_6 are calculated from the rotation matrix that rotates the gradients and scan plane coordinates from the logical coordinate system to the physical one. The X,Y,Z coordinates in [1] are specified in the logical coordinate system. $G_X(t)$ and $G_Y(t)$ are the logical readout gradients. It should be noted that altering the resolution in a spiral scan will change $G_X(t)$ and $G_Y(t)$, which leads to a change in the concomitant blurring pattern (3). Examining [1], there are a number of ways concomitant gradients can be a problem: significant spatial offsets, a double oblique orientation where F_1 through F_6 will be non-zero, strong readout gradients, or any combination of these parameters.

Methods: Image data was collected on phantoms and patients with a 1.5 T Siemens Avanto using spiral sequences. A variety of scan plan orientations and offsets were utilized in the collection to observe concomitant gradient blurring. Image reconstruction was performed in 2 ways, the first a standard gridding operation followed by FFT, the other a time segmented reconstruction scheme (4) to remove concomitant gradient artifacts. The concomitant field map was calculated from theory for a given scan plan orientation, scan plane offset, and gradient design. Image blurring was evaluated qualitatively before and after concomitant gradient correction to determine if significant blurring was present.

The images in Fig. 1 have the following common parameters: 8192 points per interleave with 2 us dwell time and a 5 mm slice thickness. The heart images were acquired with a 360x360 mm FOV, 16 interleaves, double oblique orientation, a 32 channel surface coil, and scan plane offset of 1.53 cm in sagittal direction, -5.46 cm in coronal direction, and 0.257 cm in transverse direction. The brain images were acquired with a 350x350 mm FOV, 20 interleaves, sagittal orientation, 4 channel head coil, and scan plane offset of -1.32 cm in coronal direction, and -4.16 cm in transverse direction.

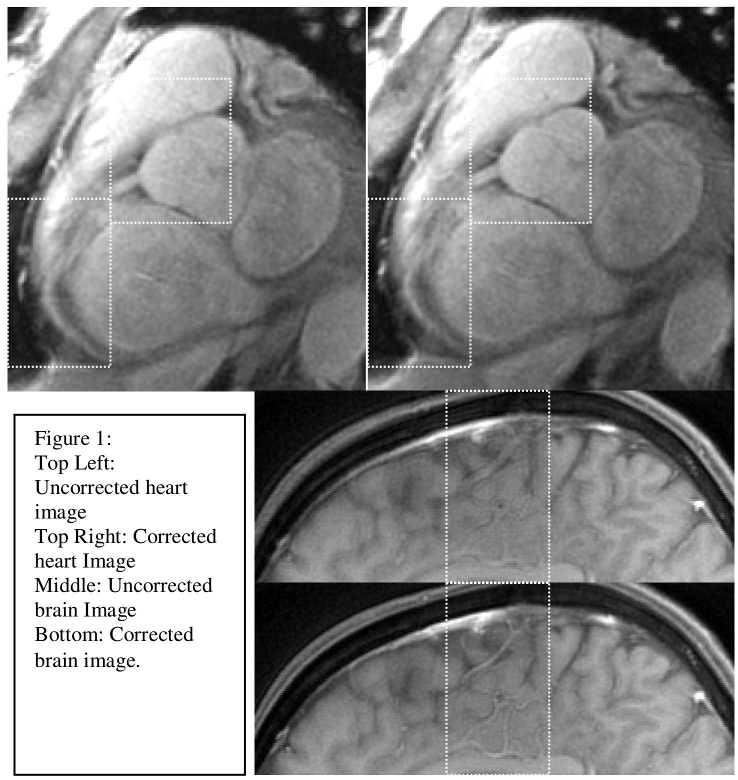

Figure 1:
Top Left: Uncorrected heart image
Top Right: Corrected heart Image
Middle: Uncorrected brain Image
Bottom: Corrected brain image.

Results: Images from a heart and brain scan are shown in Fig. 1. The images displayed are a crop of the full image. On the top right is a heart image corrected for concomitant gradients by time-segmented reconstruction, and on the top left is an uncorrected image. The middle image is an uncorrected brain image, and the bottom image is a brain image corrected for concomitant gradients by time-segmented reconstruction. The white dashed regions indicate areas where the correction has improved the image. It should be noted that the scan plane offsets in the images are typical and were not chosen to accentuate blurring. The sagittal brain image has an offset of -4.16 cm in the z direction, which means the top of the displayed crop is at 7.46 cm in z, and the bottom of the crop is at 3.56 cm in z. Within the lower left box in the heart images, on the far left side, the heavily blurred artery is located just 5.9 cm from isocenter.

Discussion: Based on these results and others obtained to date, concomitant gradient blurring starts to becomes an issue around 6-7.5 centimeters from isocenter in the z direction, across a multitude of scan plane orientations. Significant blurring can also occur in oblique orientations with a z offset less than 6 cm if there are offsets on the x and y-axes. An example of blurring due to offsets on all 3 axes is the heavily blurred artery in the lower box in the heart images, which has spatial offsets of 4.68 cm in z, -2.91 cm in y, and -2 cm in x from isocenter. Spiral scans that contain an anatomical feature of interest within these spatial ranges, or even farther out, should use concomitant gradient correction. Overall, concomitant gradients are a significant source of blurring in spiral scanning at 1.5T and a robust spiral image reconstruction program must correct for concomitant gradients.

An additional observation concerned the effect of using a higher scan resolution. The higher resolution scans appear to suffer less from concomitant gradient blurring than the lower resolution scans. High resolution scans use more spiral interleaves, which allows the trajectory to reach a given radius in k-space more rapidly. This occurs because the trajectory turns more gradually and thus has a higher radial component of k-space velocity. The concomitant phase accrued at a given radius is thus reduced, and so the amount of blurring of a structure of a given size is reduced. Increasing the number of interleaves typically also increases the average k-space velocity along the trajectory, because more gradient slew can be devoted to increasing the gradient amplitude early in the scan. This further reduces the time over which the phase can accrue, although it increases the rate of concomitant phase accrual. In a typical spiral gradient design, the net effect of increasing the number of interleaves is to decrease the blurring of an object of a given size.

A final point that should be noted is that after correction most of an image is deblurred, but some parts get worse. Within regions where the off-resonance phase of concomitant gradients and B_0 inhomogeneity are of opposing sign, they cancel one another out. Hence there will be reduced blurring in those regions in an uncorrected image. Removing the concomitant phase leaves a net B_0 inhomogeneity phase, which causes those regions to get worse after correction. Such a region can be seen by comparing the lower right corner of the two heart images. In order to solve this problem, a combined correction scheme is needed that simultaneously corrects for B_0 inhomogeneity and concomitant gradients.

References: (1) Norris et al. Proc., 4th SMRM, 1037 (1985) (2) King et al. MRM 41: 103 (1999) (3) Bornert et al. MAGMA 9: 29 (1999) (4) Noll et al. IEEE Trans. Med. Imaging 10: 629 (1991)