Reduction of FSE Cusp Artifact Using Slice Tilting

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Introduction With specific combinations of B_0-field, B_1-field, and gradient field, peripheral signals outside the prescribed field of view (FOV) can fold back onto the image, resulting in a bright spot, a series of spots, a band, or a "feather-like" artifact along the phase encoding direction. In a fast spin echo (FSE) image, this type of artifact has been termed as cusp artifact [1,2], annefact, fold-over artifact, feather artifact, and other names. It is most commonly seen on sagittal (or coronal) spine or knee images. With the present trend of short magnets in whole-body scanner designs, the problem of the FSE cusp artifact becomes increasingly important. Current approaches to attack this problem involve substantial hardware modification [3], sophisticated image reconstruction [4-5], or use of metal shields which may cause localized RF power deposition. These approaches, while effective, may not be easily implementable on all MRI scanners. We propose a technique to reduce the FSE cusp artifact by a simple pulse sequence modification.

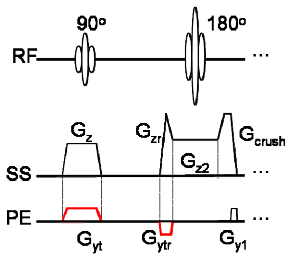

Figure 1: A segment of the modified FSE pulse sequence illustrating the slice-tilting gradient G_{yt} and its rewinder G_{ytr} (red lines).

Materials and Methods A commercial FSE sequence (GE Healthcare, Waukesha, WI) was modified to introduce a very small "slice-selection" gradient (G_{yt}) along a non-slice selection axis during RF excitation (Fig. 1). With this gradient, the slice selected by the excitation RF pulse (90°) is tilted by $\theta=\arctan(G_{yt}/G_z)$ from the prescribed slice orientation. Due to the tilt, spins excited by the 90° pulse do not overlap completely with those selected by the RF refocusing pulses. With an optimally selected tilt angle for a specific slice thickness, signal contributions from the artifact-producing regions beyond the FOV can be reduced while the signals within the prescribed FOV are minimally affected. For a given protocol, the optimal tilt angle was experimentally obtained and a linear relationship between the optimal tilt angle and the slice thickness was established (r = 0.9963). To further suppress the artifact, the image intensity values over a narrow width of the remaining artifact (~3 pixels or less) were zeroed out along a column in the phase-encoding direction. The pixel intensities were then determined by a one-dimensional linear interpolation based on the neighboring pixels. The artifact strength was evaluated at each step as the ratio of mean artifact intensity in a region of interest (ROI; ~100 pixels) over the signal intensity of a uniform ROI selected from the object.

All experimental studies were carried out on a 3.0 T GE Signa HDx scanner (GE Healthcare, Waukesha, WI). A water phantom was used to obtain the optimal tilt angle at slice thickness ranging from 2 to 10 mm, and to evaluate the performance of the technique using several clinical protocols. For example, an FSE sagittal cervical spine protocol was used on a four-channel neurovascular coil with TR = 2000ms, TE = 10ms, ETL = 8, bandwidth = ±62.5kHz, matrix = 256×256, NEX = 2, FOV = 24cm, slice thickness = 5mm, and tilt = 2°. To demonstrate the performance on human subjects, an FSE T1-weighted sagittal foot scan was performed on a healthy female volunteer under an approved IRB protocol. The imaging parameters were: TR = 600ms, TE = 20ms, ETL = 8, matrix = 256×256, NEX = 4, FOV = 26cm, slice thickness = 5mm, and tilt = 2°.

Results Figure 2 demonstrates the performance of this technique on a spherical phantom. With a tilt of 2°, the cusp artifact was considerably reduced, with the artifact strength decreasing from 12.4% (Fig. 2a) to 5.2% (Fig. 2b). Additionally, slice tilting restricted the "feather-like" artifact to a narrow band of ~3 pixels in width, which could be reduced further by the interpolation technique (Fig. 2c; artifact strength = 1.9%).

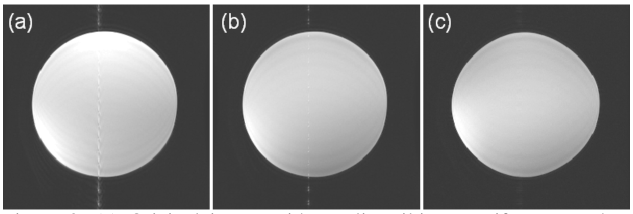

Figure 2: (a) Original image without slice tilting , artifact strength = 12.4%. (b) Image with tilt angle = 2°, artifact strength = 5.2%. (c) Image with tilt angle = 2°, after post-processing, artifact strength = 1.9%

Figure 3 shows a pair of images before (Fig. 3a) and after (Fig. 3b) applying the slice tilting technique on the left foot of the human volunteer. The window and level of the images were adjusted to highlight the artifact which was reduced from 2.1% in Fig. 3a to ~0.4% in Fig. 3b.

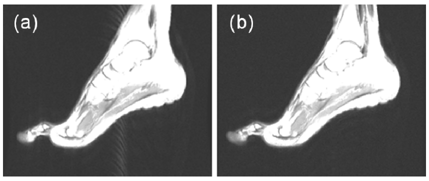

Figure 3: An image of human foot (a) without slice tilting (artifact strength = 2.1%), and (b) with slice tilting of 2° (artifact strength = 0.4%).

Discussion and Conclusions A very small tilt (e.g., 2°) in the slice has substantially reduced the intensity of the FSE cusp artifact. The advantages of this technique include: (a) only a small change in the pulse sequence is necessary; (b) post-processing steps, if needed, are easy to implement; and (c) no modifications are required in the system hardware, patient handling, and image reconstruction. A drawback of the proposed method is reduction in signal away from the slice center. For a FOV of 24cm with 5mm slice thickness and a tilt angle of 2°, the theoretically calculated signal at the edge of the FOV reduces to approximately 16% of its original value, assuming an ideal gradient linearity. However, the reduced gradient strength (i.e., due to non-linearity) at the edge of the FOV can result in an increase in the actual overlap between the nominal and the tilted slice profiles, leading to an elevated signal, which offsets the signal reduction due to tilting. Another drawback is that this technique may affect spins from the neighboring slices in multi-slice imaging. To reduce this effect, the slice spacing was increased slightly. The minimum slice spacing required can be calculated as $sp = \tan\theta \times FOV/2 + (\sec\theta - 1)\times th/2$ where *sp* is the slice gap, *th* is slice thickness, and θ is the tilt angle. For the clinical protocols we have evaluated, a slice gap of ~3-4mm effectively avoided the problem. If a smaller gap is needed, a scrambled slice ordering scheme can be used [6]. Slice tilting does not have an impact along the line where $dB_{eff}/dz = 0$ (B_{eff} is the combination of B_0 and gradient fields). A very thin line can remain as shown in Fig. 2b, although the artifact intensity is considerably reduced. A simple interpolation has been found sufficient to remove the residual artifact.

In conclusion, introducing a small tilt in the selected slice can substantially decrease the FSE cusp artifact. This simple approach results in images in near-final form at the end of the scan. With an additional processing step, the resultant images can be further improved.

References (1) Steckner MC, *et al.*, ISMRM Abstracts, 1995, p.756. (2) Kim JK, *et al.*, ISMRM Abstracts, 1999, p.1033. (3) Frederick P and Johnson J, US Patent No. 6134465, 2000. (4) Larkman D, *et al.*, JMRI, 2000, 12: 795-797. (5) King K, Hinks R, US Patent No. 7250762, 2007. (6) Oh CH, *et al.*, MRM, 1992, Dec, 28: 290-29.