A simple method for cusp artifact removal by gradient optimization

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Purpose

Cusp artifact，also learn as annefact artifact, is when the spin signal outside the imaging field of view (FOV) folds into the FOV and severely reduce the diagnostic value of MR exams. It differs from the traditional wrap-around artifacts that signal fold over take place close to image center and varies in form in different scan scenarios. Several groups of methods have been proposed to tackle the issue of cusp artifact utilizing gradient design modification[1], parallel imaging based signal processing technique[2] or receiver coil arrays[3]. However, these methods are rather difficult to implement on commercial scanners due to their complicated post-processing. In this article we report an easy-to-implement method to eliminate the cusp artifact by optimizing the pulse sequence design in Fast Spin Echo sequence (FSE). It requires no additional post-processing and hardware modification.

Methods

Cusp artifact is ultimately caused by magnet field's (B0) non-uniformity and gradient field's (Gz) non-linearity, so that the spins outside the imaging FOV are excited simultaneously with the spins inside the FOV along the direction of the main magnet field (z axis). An easy way to get around this issue in FSE is to employ gradients with opposite polarities for the excitation and refocusing radio frequency (RF). As in this way, the spins excited by the two gradients reside at two ends of the magnet bore, so they will not form an echo and consequentially no cusp artifact is produced (Fig.1). Unfortunately, this quick fix is blocked by the field inhomogeneity (Bs) which always exists in practice (Fig.2). The frequencies (f in eq.[1], eq.[2]) of excitation and refocusing RF pulses are calculated based on B0 and Gz. The effect of field inhomogeneity is to shift the position of excited spin (Z_{shift} in eq.[3]).

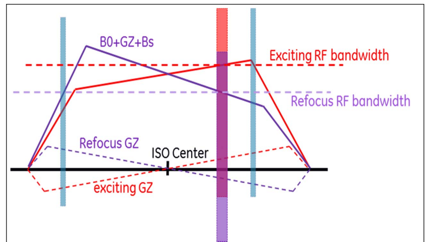

Fig.1. Opposite polarity gradient for exciting and refocus RF pulses to remove cusp artifact.

In conventional cases, it is acceptable as both spins excited by the excitation and refocusing gradients are shifted toward the same direction. But if the polarities of the gradients are flipped, the shift will be in opposite directions. It would cause signal drop when the gap of shift (ΔZ in eq.[4]) is comparable with slice thickness.

$$f = (B_0 + G * Z_0) * \gamma \quad [1]$$
$$f = (B_0 + B_s + G * Z_1) * \gamma \quad [2]$$
$$Z_{shift} = Z_1 - Z_0 = -B_s/G \quad [3]$$
$$\Delta Z = Z_{shift\_ex} - Z_{shift\_ref} = B_s/G_{ref} - B_s/G_{ex} \quad [4]$$

We adapt another way to get around with this issue. The polarities of the two types of gradient remain the same. However, change their amplitude to eliminate the effects of cusp artifact. Specially, the amplitudes of excitation and refocusing gradients are optimized individually so that the location shift of excited spins by the two RF is minimized, whereas the annefact regions correspond to the two RF are separated. The former ensures no signal drop takes place. The latter ensures no cusp artifact is formed.

The distribution of B0 and Gz is known from magnet and gradient coil designer. Slice selection location and cusp region can be calculated with its band width of a designed excitation RF pulses (Fig.3). The calculation steps are given as below.

1. Calculate excitation gradient amplitude (G_{ex}) with slice thickness and RF bandwidth.
2. Calculate location of excitation cusp region with overall magnet field.
3. Define the location of refocusing cusp region to separate it with excitation cusp region.
4. Calculate refocusing gradient amplitude (G_{ref}) with the location of refocusing cusp region.

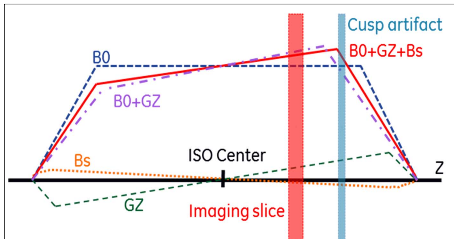

Fig.2. Total magnetic field distributes along Z axis for B0, Gz and B0 inhomogeneity Bs. The location of imaging slice (Red block) and cusp artifact source (blue block) along Z axis are shown.

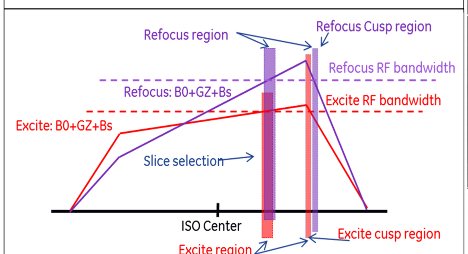

Fig.3. Optimize amplitudes of excitation and refocusing slice selection gradients to avoid cusp artifact and signal drop.

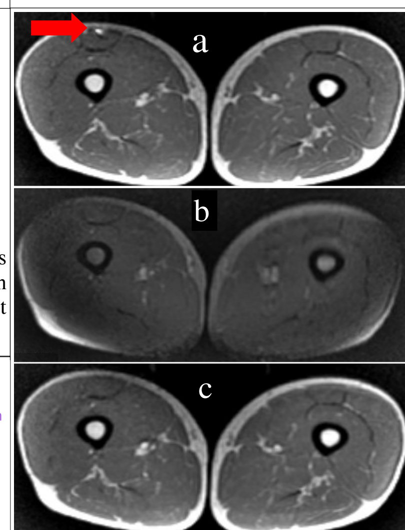

Fig.4. Images acquired with different excitation and refocusing slice selection gradient. a). Same amplitude gradient. Cusp artifact is seen. b). Opposite polarity gradient. SNR is reduced 40%. c). Optimized amplitude gradient. Avoid cusp artifact and signal drop issue together.

Experiments and Results

The proposed method was implemented on 1.5T GE MR360 system. In-vivo experiments of a volunteer's legs using 2D FSE with excitation and refocusing gradient of a) same amplitude and polarity, b) opposite polarity and c) same polarity but optimized amplitudes as above were performed. The results are summarized in Fig4. It is seen that in Fig4.a the cusp artifact is obviously seen, in Fig4.b the cusp artifact is removed but there is significant signal drop, in Fig4.c the cusp artifact is eliminated and similar level of SNR is maintained.

Discussion

A novel method for optimizing slice selection gradient amplitude to remove cusp artifact in FSE is proposed. This method is easy to implement and requires no post-processing. A single slice example is illustrated, but this optimization may be really applied to multi-slice setup, which would lead to different amplitudes being used for different slices. A potential drawback for this case is the reduction of fat signal due to chemical shift for the excitation and refocusing pulses. This impact has been tested to be clinical acceptable.

References

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