

Virtual Frequency Encoding: Achieving Symmetry in K-space

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INTRODUCTION: Distortion of 2DFT MR images by off-resonance such as chemical shift and field inhomogeneity results from the time dependence in the readout direction in k-space. Swapping phase and readout directions rotates the resulting distortion by 90° in the image. Modification of the imaging pulse sequence to add a time-dependence in the phase encoding direction (Figure 1) makes it also sensitive to off-resonance distortion resulting in a virtual frequency encoding direction that is rotated away from the readout direction. When the virtual frequency encoding axis is at 45°, the phase and readout axes can be swapped without the distortion artifacts rotating to follow the readout axis. One application of such a method is to eliminate the off-resonance sensitivity of previously reported methods that swap these axes for averaging or reduction of motion artifacts [1,2].

METHODS: All experiments were performed using a clinical 1.5 Tesla MR scanner (GE Signa, Milwaukee, WI) equipped with 1.0 mT/m gradients. Images were acquired using the spin echo pulse sequence in Figure 2 in which a variable k_y -dependent time shift was introduced to both the readout gradient and data acquisition window (TR/TE = 500/25, 5mm slice, readout bandwidth 31.25 KHz or 122 Hz/pixel). Images were acquired of a water-fat phantom to demonstrate the effect of chemical shift artifact. Images were acquired of a grid phantom in the presence of severe field inhomogeneity to demonstrate the effect of B_0 non-uniformity with this method. In each case comparison images were acquired with and

without per-view echo shifting and with swapped phase and frequency directions.

RESULTS: In the conventional sequence the spatial distortion due to off-resonance (Chemical shift or B_0 inhomogeneity) was strictly in the readout direction, as expected. Using the view-dependent echo shifting method presented here, the resulting distortion occurred in a diagonal direction and was identical when the phase and readout directions were swapped. The most striking example, caused by intentionally degraded homogeneity, is shown in Figs. 2 & 3.

DISCUSSION: The addition of a k_y -dependent echo shift establishes a virtual frequency encoding axis that is rotated relative to the readout axis. At a rotation of 45°, phase and readout axes can be swapped with no change in the encoded image, thereby improving previously reported methods that swap these axes for averaging or reduction of motion artifacts.

REFERENCES

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Fig. 2,3: Conventional (2) and Virtual Frequency Encoding (3) imaging sequences. Phase and readout directions are swapped in (a) and (b).

Fig. 1: Virtual Frequency Encoding pulse sequence.

