Improved Slice Excitation for Ultra-short TE Imaging with B0 and Linear Eddy Current Correction

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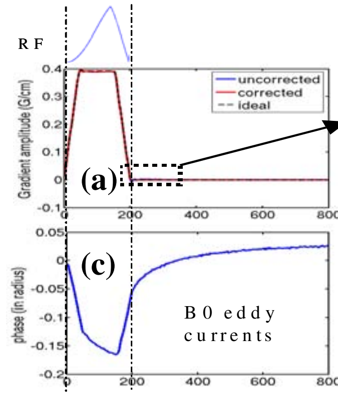
INTRODUCTION

MR imaging with ultra short echo times (UTEs) are of increasing interest to visualize tissues with short T2 or T2*, such as cartilage and ligaments, or monitoring the temperature during cryosurgery [1]. To achieve ultra-short TEs, a self-refocused half RF is usually used for excitation [2]. However, eddy currents induced by the selective gradient can result in undesirable slice profile and therefore limit the applications of this technique. Though several techniques have been proposed to compensate for eddy currents [1,3], a robust approach is still needed. Here we present an effective method to compensate for both B0 eddy currents and linear eddy currents, and our results demonstrate significantly improvement in slice selectivity.

MATERIALS AND METHODS

The half-RF pulse excitation approach acquires k-space data twice with opposite slice selective gradient polarity, these two acquisitions are then combined to generate signal from the desired slice. B0 eddy currents resultant from the selective gradients causes a constant phase difference between the two acquisitions, while the linear eddy currents distort the traversed k-space trajectory.

To compensate for both effects, B0 eddy currents and linear eddy currents are first measured. This is achieved by linearly fitting the phases of signals obtained using Duyn's method with various gradient amplitudes at several off-isocenter positions [4]. At each time point, signal phases from the same slice are first linearly fit with respect to gradient amplitude. The linear coefficients are then fit with respect to the slice position. The resultant constant terms now correspond to the phases accumulated by B0 eddy currents, while the linear coefficients corresponds to k-space trajectory traversed by the applied gradient and linear eddy currents, respectively, both normalized by the selective gradient amplitude.



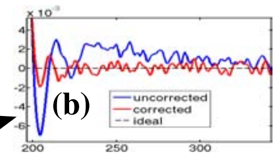


Fig. 1 a) Ideal, measured gradients before and after correction. b) A enlarged portion of a). c) Measured phase due to B0 eddy currents.

The phase accumulated by B0 eddy currents and the measured linear gradients with typical amplitude are shown in figure 1a and 1b. Both exhibits slow decay (~2-3 ms) in this case and therefore extend to data acquisition. To compensate for the linear eddy currents, the non-zero "tail" of the measured gradient is inverted and attached to the ideal gradient as the compensated selective gradient. The corresponding B0 eddy currents and linear eddy currents are again measured. As shown in Figure 1b, the slowly decaying tail of the gradient is nearly removed, though oscillation that may come from the noise of the measurement is still seen. The half RF pulse is then designed to pre-compensate for the linear eddy currents. B0 eddy current effects during excitation are compensated by dynamically varying the RF phase accordingly. The "tail" of B0 eddy current extending to data acquisition can be corrected by fitting it to decaying exponentials, which can then be used to correct the phase of the acquired signal on a per data point basis before adding the two acquisitions.

RESULTS AND DISCUSSION

Experiments were performed on a 0.5T GE Signa open scanner. Using the half-RF pulse with radial acquisition, a TE of 100µs was achieved. The free-induction-decay signals (FIDs) in Fig. 2a were obtained from a ball phantom filled with dopped water (long T2). Severe distortion is observed due to eddy currents, while a nice exponential decay as expected is obtained after the proposed compensation. The effectiveness of the proposed method for improving the slice profile is demonstrated in Fig. 3. The object to be imaged is illustrated in Fig. 3a, which consists a phantom with several short T2 components, a cylinder and a ball phantom. A slice close to the edge of the ball (vertical line) was scanned. For comparison, Fig. 3b was acquired with a regular RF pulse. Fig. 3c-f were acquired with half RF excitation. Without any eddy current compensation, Fig. 3c shows significant out-slice signal from the cylinder (arrow). The out-slice signal is greatly reduced but still noticeable in Fig. 3d (arrow) with linear eddy current correction. With both B0 and linear eddy current correction, a much better slice selection is achieved in Fig. 3e, and the out-slice signal is hardly visible. The knee image (Fig. 3f) demonstrates good slice selectivity with eddy current correction.

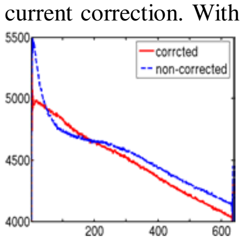


Fig. 2 FIDs of a slice from a uniform ball phantom (long T2) with and without eddy current correction.

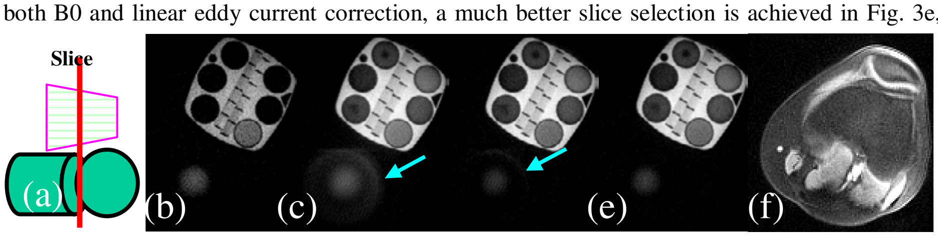


Figure 3. phantom images shows significant improvement in slice selectivity with eddy current correction. a) phantom setup. b) regular full RF acquisition c) without any eddy current correction d) with linear eddy current correction. e) with both linear and B0 eddy current correction. f) knee image show good slice selection.

CONCLUSIONS

An effective approach to correct for both B0 and linear eddy current for half-RF pulse excitation is presented based on the measured actual B0 and linear eddy currents. This method has been shown capable of significantly refining the selected slice profile. In potential, this technique can be of great interest for applications where ultra short TE is preferred, especially when image quantification is needed.

REFERENCE

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