Slice Excitation for Ultrashort TE Imaging

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Introduction

MR imaging of short T2 species has been a topic of continuous research [1]. Short T2 components appear in highly ordered tissues such as tendons, ligaments, cartilage and bone, i.e., tissues that exhibit low signal contents in conventional imaging sequences. To image short T2 species, sequences employing ultrashort echo times (UTE) are required. In this work, slice excitation using self-refocused half-sinc RF pulses for UTE imaging is investigated.

Theory and Methods

To achieve ultrashort echo times, half-sinc RF excitation pulses are used, limiting the echo time to only the hardware switching time [2,3]. For a proper slice definition, two subsequent excitations with slice-selection gradients of opposite sign are applied (Fig.1), and their MR signals (S_+, S_-) are added to form the signal of the desired slice. The half-sinc pulse is inherently self-refocused [2] and is applied also during the rising and falling slopes of the slice-selection gradient.

However, the half-sinc excitation approach suffers from sensitivities to gradient imperfections [4]. B0 eddy currents cause a spatially invariant phase shift, and short-time-constant eddy currents result in a distortion of the applied gradient waveform. The effect of B0 eddy currents is compensated by adding the signals from the two excitations using a phase offset Φ:

$$S(\mathbf{r}) = S_+(\mathbf{r}) + S_-(\mathbf{r}) \cdot e^{i\Phi}. \quad (1)$$

The gradient waveform distortion is compensated assuming that the real (distorted) gradient waveform resembles the original waveform convolved with an $e^{-t/\tau}$-system impulse response.

$$G_{\text{real}}(t) = G_{\text{ideal}}(t) \otimes e^{-t/\tau}. \quad (2)$$

Different compensation approaches are then feasible. One possibility is to compute a *pre-compensated gradient waveform* such that the actual gradient waveform resembles the ideal gradient:

$$G_{\text{comp}}(t) = F^{-1}\{F\{\, G_{\text{ideal}}(t)\} \,/\, F\{\, e^{-t/\tau}\}\} \quad (3)$$

As an alternative, rather than pre-compensating the gradient, a *pre-compensated RF waveform* can be determined using the real gradient waveform:

$$B_{1\text{comp}}(t) = \text{sinc}(k_{\text{real}}(t)) \cdot G_{\text{real}}(t) \quad (4)$$

The resulting waveforms of the two compensation schemes are shown in Fig.1.

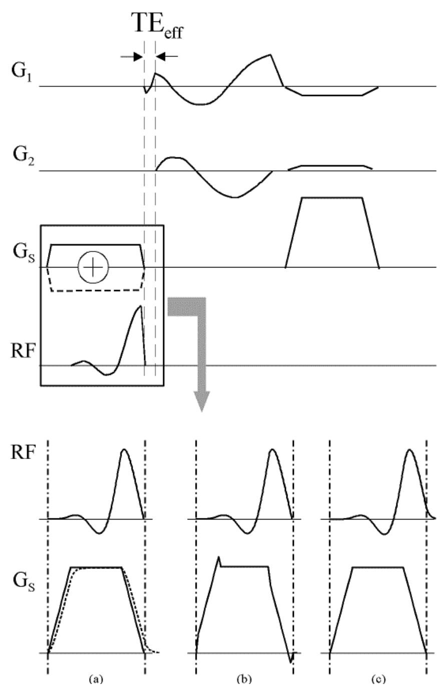

Figure 1: Top: Ultrashort TE imaging sequence using spiral read-out. To compensate for the non-ideal gradient waveform (bottom (a)), the gradient waveform is either pre-compensated (b), or the RF waveform is computed according to the real gradient shape (c).

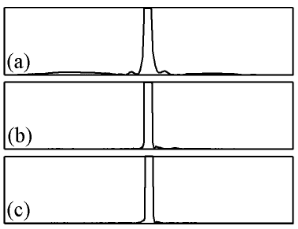

Figure 2: Slice profile (maximum is clipped); (a) normal half-sinc pulse, (b) pre-compensated gradient, (c) pre-compensated RF waveform.

Results and Discussion

Experiments were performed on a Philips 3T whole body scanner using a local Tx/Rx coil with a switching time of 60 μs or a Tx/Rx body coil with a switching time of 55 μs. To characterize the effects of B0 eddy currents and the gradient distortions, the 1D slice profile was measured in preparation scans as a function of the phase offset between the signals from the two excitations and the time offset between RF and gradient waveform. The optimum phase offset was found to be system and orientation dependent and, thus, must be determined before each scan. Measured slice profiles are shown in Fig.2 for the different eddy current models. Good slice profiles were obtained with both compensation schemes (Fig.2(b) and (c)) using a time constant of $\tau = 40\mu$s.

Fig.3 shows multi-slice images of a phantom for an echo time of TE = 160 μs. The pre-compensated RF waveform (Fig.1(c)) was used, yielding a good slice definition with negligible cross talk between the slices. Fig.4 shows in vivo images of the ankle for different echo times (TE = 1000 μs, 280 μs, 160 μs). The pre-compensated RF waveform was employed. For all results, the UTE imaging sequence was used in combination with a spiral/TwiRL read-out [3].

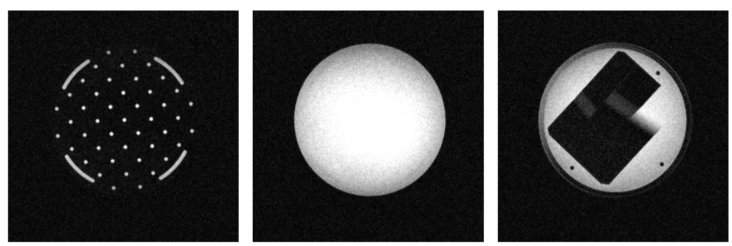

Figure 3: Multi-slice excitation using the pre-compensated RF waveform: phantom images. Proper slice excitation is obtained with minimum cross talk between the slices times (TE = 160μs, TR = 300 ms, a = 10°, 256 interleaves, 256 matrix).

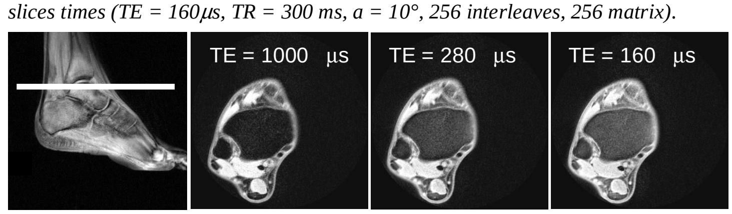

Figure 4: Fat suppressed in vivo UTE images. Slice through the foot for different echo times (TR = 300 ms, a = 10°, 256 interleaves, 256 matrix, SPIR fat suppression).

Conclusion

By compensating B0 eddy current effects and gradient waveform distortions, a very good slice definition, for single and multi-slice images, was obtained. The pre-compensation of the gradient or RF waveform (Fig.1(b) and (c)) yield similar results. However, for practical applications, the gradient pre-compensation (Fig.1(b)) is advantageous, because the excitation pulse is shorter. However, RF compensation could be applied additionally to compensate residual eddy current effects. The in vivo images show the effect of ultrashort echo times: enhanced signal appears from the bone structures when shortening the echo time.

References

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