MRI with Zero Echo Time: Hard versus Sweep Pulse Excitation

M. Weiger[1,2], K. P. Pruessmann[2], and F. Hennel[3]
[1]Bruker BioSpin AG, Faellanden, Switzerland, [2]Institute for Biomedical Engineering, University and ETH Zurich, Zurich, Switzerland, [3]Bruker BioSpin MRI GmbH, Ettlingen, Germany

Introduction The echo time (TE) of an MRI sequence is considered zero when the generation of the transverse magnetisation coincides with the start of spatial encoding. This feature is characteristic for three-dimensional (3D) radial techniques in which the readout gradient is already on during excitation. For the latter either a hard RF pulse [1-4] can be used or a pulse with a frequency sweep as in the SWIFT technique [5]. A key advantage of sweep pulses lies in their ability to create the large bandwidths required for measuring samples with very short T2 at limited RF amplitude [6]. However, a complication of this kind of excitation is that it requires quasi-simultaneous data acquisition, which has been achieved by rapid periodical switching between send and receive operation [5]. In view of these distinct characteristics the present work aims to compare zero TE MRI with hard and sweep pulse excitation with a focus on T2 sensitivity and signal-to-noise-ratio (SNR).

Methods Both techniques were implemented according to the schemes in Fig. 1 on a Bruker BioSpec MRI system at 4.7 T and compared for identical parameters including bandwidth BW, flip angle α, and acquisition oversampling [7, 8]. Hard pulse data were acquired after an inevitable initial gap Δ composed of RF pulse, T/R switching, and a digital filter delay. From these data, one-dimensional (1D) projections were obtained by algebraic reconstruction [7]. The sweep pulse counterpart was performed with acquisition during and after the pulse [8] and periodical gaps Δ, and image reconstruction was again algebraic, now also incorporating the encoding properties of the sweep pulse [9]. From a suitable number of 1D projections a 3D image was obtained by a standard gridding procedure. For both techniques the resulting SNR was determined from the images as well as calculated on a pixel-by-pixel basis as $I_i/\sqrt{x_{ii}}$, where I_i denotes the reconstructed intensity of the pixel i and x_{ii} is the corresponding diagonal element of the noise covariance matrix $\mathbf{X} = \mathbf{F}\,\mathbf{\Psi}\,\mathbf{F}^H$, $\mathbf{F}$ denoting the linear mapping used for reconstruction and $\mathbf{\Psi}$ the noise covariance of the raw data [10].

Results The images in Fig. 1 show one and the same slice taken from different 3D data sets acquired from a stack of pieces of rubber with T2* ≈ 400 µs. At BW = 42 kHz the images acquired with hard and sweep pulses exhibit identical blurring due to apodisation caused by T2* decay [11]. This effect is greatly reduced at BW = 83 kHz for both methods, resulting in a sharper depiction of the object. However, the hard pulse image exhibits a subtle SNR advantage, which can be made more visible by reducing the flip angle as shown in the third column. This impression is confirmed by the SNR determined from the data, which was twice as high for hard pulses as for sweep pulses at this bandwidth. Finally, a hard pulse image was acquired at 156 kHz, showing a further improvement in sharpness. Sweep pulse acquisition was not possible at this bandwidth because the gap required by the system exceeded the sampling interval δ, which is equal to the inverse of the bandwidth. The theoretical SNR analysis for the hard pulse mode yields a gradual SNR loss for increasing Δ (Fig. 2), which corresponds to the findings in Ref. [7] and is due to increasingly ill conditioning of algebraic reconstruction as more and more initial signal is lost. A similar mechanism affects the SNR in gapped sweep pulse MRI. However, in addition it suffers from a gradual decrease in effective acquisition time as increasing bandwidth requires an ever larger time fraction for gapping. For the shown experiments at 83 kHz this resulted in a 1.8-fold SNR advantage for the hard pulse mode (circles in Fig. 2), which is in good agreement with the value derived from the data.

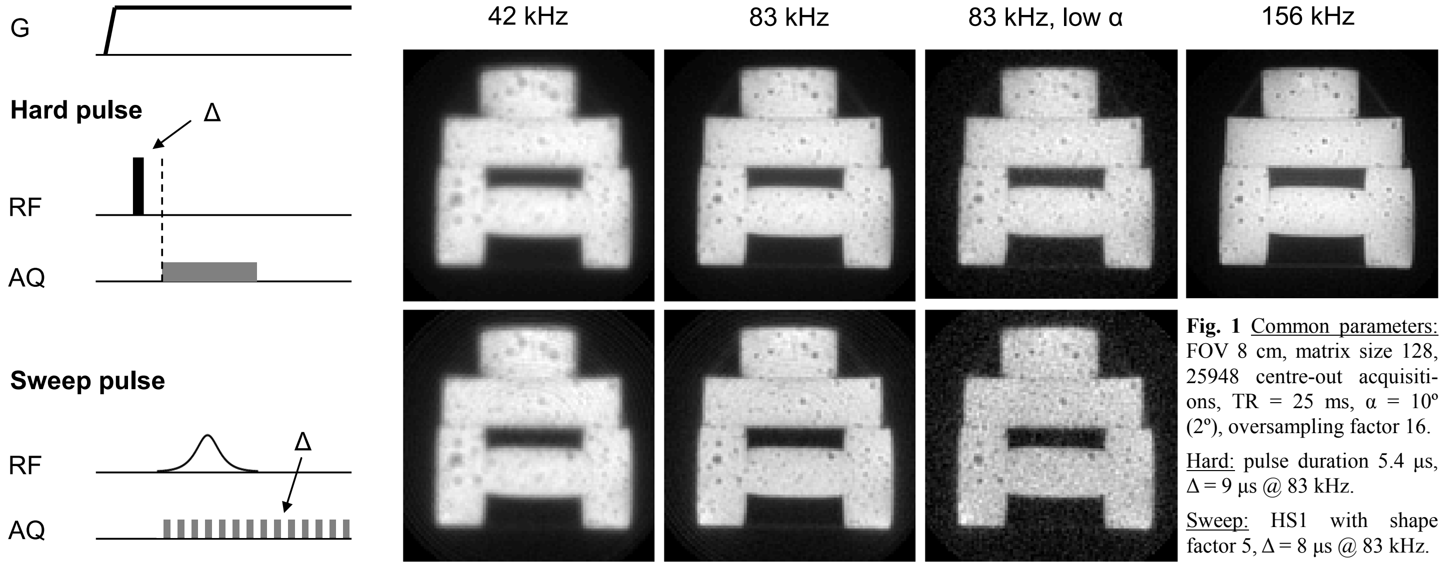

Fig. 1 Common parameters: FOV 8 cm, matrix size 128, 25948 centre-out acquisitions, TR = 25 ms, α = 10º (2º), oversampling factor 16.

Hard: pulse duration 5.4 µs, Δ = 9 µs @ 83 kHz.

Sweep: HS1 with shape factor 5, Δ = 8 µs @ 83 kHz.

Conclusions

- Zero TE MRI with hard and sweep pulse excitation is equivalent in terms of T2 sensitivity and SNR as long as no T/R switching and RF amplitude limitations apply. Both techniques share the agreeable properties of being silent and fast.
- With T/R switching of finite duration hard pulse excitation yields higher SNR than gapped sweep pulse excitation. Truly simultaneous excitation and acquisition would remove this discrepancy.
- For limited RF amplitude and given bandwidth sweep pulses enable larger flip angles. However this benefit is typically more than compensated for by SNR loss due to acquisition gapping.
- Zero TE imaging with hard pulse excitation is less demanding in terms of RF hardware requirements, implementation issues, and reconstruction effort.

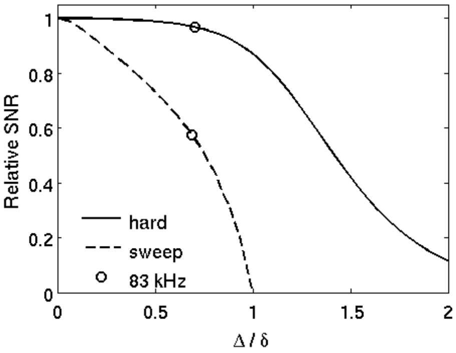

Fig. 2 SNR loss with increasing gap size.

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