General time-encoding description and improved RASER imaging

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Introduction

Rapid acquisition by sequential excitation and refocusing (RASER) is a new ultrafast MRI technique (1). It provides single-shot images that are purely T_2-weighted, so there are no artifacts due to T_2^* effects that plague EPI. RASER shows promise for fMRI studies in areas of the brain that are difficult to image with EPI (2, 3). The basis of RASER is time-encoding, which uses a frequency-swept excitation pulse to encode one dimension of the image (1, 4, 5). All previously reported versions of time-encoding use a chirp pulse, which has a poor slab-selection profile. In this work, we provide a general description of time-encoding for any excitation pulse with frequency and gradient modulation, along with an analysis of the SNR possible with time-encoding, and a comparison of the time-encoded signal produced by chirp, HS20, and HS40 pulses.

Theory

A general time-encoded sequence consists of an excitation pulse with a frequency modulation, $f(t)$, and a gradient modulation, $G(t)$, and then an acquisition time during a gradient waveform, $G_A(t)$. The underlying assumption is that an isochromat will be excited instantaneously when $f(t)$ is equal to its Larmor frequency. The magnitude of the signal acquired in a time-encoding sequence is an approximation of the spin density of the object. Using this general description, a series of equations that describe the constraints on the gradient and frequency modulations are derived. The general signal equation can be used to show that the signal energy of a time-encoded image will be reduced by a factor of R/N_p, where R is the product of the bandwidth of the pulse and the duration of the pulse, and N_p is the number of points acquired. The value of R/N_p must be ~17 to obtain the point-spread function (PSF) suitable for imaging; as a result, the SNR of a time-encoded image is reduced by a factor of 4.1 compared to an ideal frequency-encoded image.

Methods

MRI experiments were performed at 4 T using a TEM head coil and a cylindrical water phantom. The images were acquired using RASER with a chirp, HS20, or HS40 pulse. The parameters for all experiments were: pulse length = 60 ms; TE = 125 ms; matrix = 64 x 74; acquisition bandwidth = 150 kHz; FOV = 25 cm x 12.5 cm; acquisition time = 185 ms.

Results and Discussion

In order to give regularly spaced pixels with a constant echo time, the frequency sweep of the excitation pulse should be linear and the gradient modulation should be constant. A chirp pulse satisfies these requirements, but it has a poor excitation profile that results in a wide point-spread function for the early and late pixels in the time-encoded direction. The RASER image with a chirp excitation pulse is shown in Fig. 1. HS20 and HS40 pulses have an approximately linear frequency sweep with a better excitation profile. This results in more accurate image edges, as shown in Fig. 2, which is the plot of the center line of the chirp, HS20 and HS40 images. Since the phantom has a uniform proton density, the plot should be level. Since the first few pixels of the chirp pulse image will have a broad PSF, the values are increased. This is removed using an HS20 or HS40 pulse.

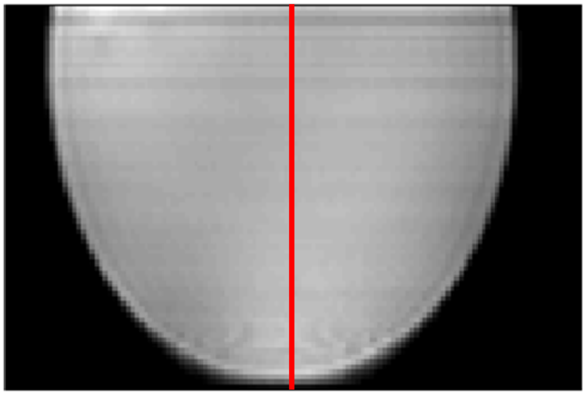

Figure 1 – RASER image using a chirp pulse. Red line indicates position of profile for Fig. 2

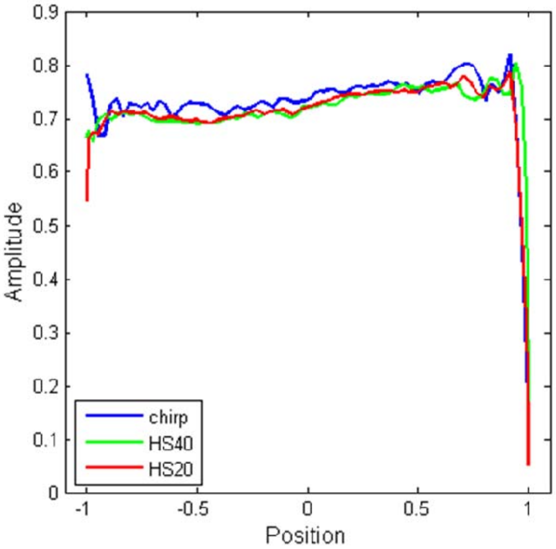

Figure 2 – Profiles of images using chirp, HS20, and HS40 excitation pulses. The elevated level of the far left pixel in the chirp profile is an artifact caused by the poor excitation profile of the chirp pulse. This is removed using an HS20 or HS40 pulse.

References

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