Investigation of multiple-echo spin-echo signal acquisition under distant dipole-dipole interactions

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Synopsis

MR signals formed under the influence of distant dipolar field (DDF), or intermolecular multiple-quantum coherence (iMQC), exhibit a number of potentially unique and useful properties. However, the signal is small in most tissues, primarily due to transverse relaxation. Multiecho acquisitions such as echo-planar or fast spin-echo imaging, combined with the unique time dependence of iMQC signal formation, have the potential of providing increased signal-to-noise ratio. Here we investigate the influence of closely spaced π pulses on the DDF during signal formation and the implications for practical multi-echo acquisitions.

Introduction

Multiecho acquisitions such as those applied in echo planar (EPI) and fast spin-echo (FSE) imaging allow for fast imaging, or alternatively, can be used to increase the signal-to-noise ratio by providing greater signal averaging. Low signal-to-noise ratio is the primary difficulty associated with measuring signals formed in the presence of a distant (long-range) dipolar field (DDF), also called intermolecular multiple-quantum coherence (iMQC) (1-2). These signals are typically 5% (or less) of conventional NMR signals in biological tissues. Thus, in generating iMQC images, we sometimes apply multiecho acquisitions to increase signal averaging rather than decrease iDQC image time (3).

The effect of magnetic susceptibility heterogeneity, i.e. the BOLD effect, on iDQC images is established during the evolution period and then stored as longitudinal magnetization (the DDF) during the detection period. To make optimal use of the unique BOLD properties of the iDQC signal we must minimize contributions from conventional BOLD effects during the detection period, such as those which would be introduced by an EPI or spiral acquisition scheme. Therefore a FSE acquisition, which refocuses susceptibility effects during detection period, appears to be preferable for iDQC brain fMRI studies or BOLD-based tumor oxygenation studies.

An echo train in which the π pulses are much shorter than the echo spacing is not expected to have any influence on the long-range dipole-dipole interactions which lead to formation of the iDQC signal because transverse magnetization and the DDF are inverted simultaneously and the modulation continues unattenuated. However, in a typical FSE imaging acquisition the slice selective refocusing pulses constitute a significant fraction of the inter-echo delay. During the time the pulse is applied transverse magnetization and longitudinal DDF are mixed. Here we investigate the effects of finite refocusing pulse duration on iDQC spin-echo acquisitions, and consider optimal phase modulation of π pulse trains.

Methods

The CRAZED-based multiecho pulse sequence shown in Fig. 1 was used at 14 Tesla. N is the number of π pulses, 2τ is the echo spacing, 2τN is the duration of the echo train, and δ is the π pulse duration. As δ increases, the power is reduced to maintain a constant flip angle. The final π pulse was a slice selective sinc pulse (st = 4 mm) with fixed duration 1 ms and is shifted by τ_{ev} to properly refocus background gradients. A read-out gradient was applied during signal acquisition (FOV = 20 mm). Correlation length d_c = 150 μm, τ_{ev}=1.5 ms. The phase of the pulses in the echo train were alternated by π every pulse with the first pulse having the same phase as the β pulse. The sample was water in a 5 mm NMR tube.

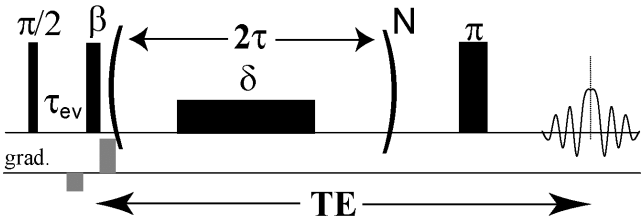


Figure 1)

Results

The influence of π pulse duration, δ, on the formation of iDQC signal in a multiecho acquisition is shown in Figure 2. The multi-echo signal forms approximately normally (compared to N = 1 and 2τ = TE) when δ is small. However, as δ increases (constant τ) formation of the signal is attenuated. As shown in Figure 3, the signal attenuation is approximately linear with respect to δ/2τ for a fixed number of echoes. Signal formed before or after the echo train is **not** affected by δ, i.e. there is no attenuation or loss of this signal. Shifting the π pulse phase by π for every other pulse is important to correct the effect of pulse errors to **both** the xy-magnetization and the DDF. A constant π/2 phase CPMG corrects only xy-magnetization errors.

Figure 2)
iDQC image intensity as a function of echo train length, 2τN, at various π pulse widths, δ.

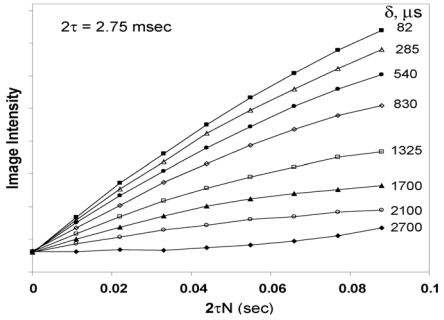
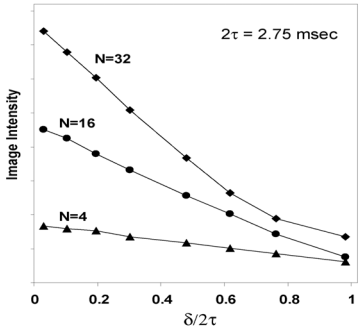


Figure 3)
iDQC image intensity as a function of π pulse width, δ, at various echo train lengths, 2τN.



Discussion

These results demonstrate that pulse power and duration must be carefully considered when multiple spin-echo acquisitions are applied in iDQC imaging. Typical clinical fast spin-echo parameters include echo spacings of 7-9 ms and π pulses of 2-3 ms (1-2 ms for the main lobe). By reference to Figure 3, we might expect a 20% signal loss due to DDF mixing. When T_2 relaxation process is omitted, iDQC image intensity is almost proportional to 2τN(1-δ/2τ). However, if the start of the echo train is delayed until the iDQC signal is near maximum, then very little signal is lost. Nonetheless, it may be advantageous to consider acquisition schemes which reduce the number of π pulses, such as GRASE, yet maintain susceptibility refocusing properties. In any case, alternation of pulse phases in the echo train are required to prevent huge loses due to flip angle errors.

References

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