Optimum Inter-Echo Spacing for the GESFIDE Pulse Sequence in the Simultaneous Measurement of R2 and R2'

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Introduction

The measurement of the reversible and irreversible transverse relaxation rates, R_2' (=$1/T_2'$) and R_2 (=$1/T_2$), respectively, plays a vital role in various areas of research, including studies that involve brain iron, integrity of trabecular bone, and iron-overloading diseases. Both relaxation parameters are often desired, and two parameters could be measured simultaneously with the GESFIDE (Gradient-Echo Sampling of Free Induction Decay and Echo) pulse sequence [1]. Although optimizing the imaging parameters for a single exponential decay has been widely investigated [2,3], there is no report of such optimization in sequences such as GESFIDE in which two exponential decays are simultaneously measured to obtain both R_2 and R_2'. In this work, the measurement errors in R_2 and R_2' as a function of several imaging parameters, including the inter-echo spacing, are systemically studied, and a means to optimize the parameters is presented.

Methods

The GESFIDE pulse sequence is illustrated in **Fig. 1**. Following the 90° excitation pulse, a train of gradient echoes is acquired, which decays exponentially with the rate constant R_2^* (=$1/T_2^*$). The error in the computed R_2^* could be expressed as [2]

$$\sigma_{R2^*} = SNR_0^{-1}\sqrt{\sum w_n \Big/ \left(\sum w_n \sum w_n n^2\tau^2 - \left[\sum w_n n\tau\right]^2\right)} \qquad [1]$$

where τ is the inter-echo spacing, n is echo number, SNR_0 is the SNR of the first echo, and $w_n = exp(-2n\tau R_2^*)$. Following the 180° refocusing pulse, a second train of gradient echoes is acquired, which evolve exponentially with R_2^-. The error in R_2^-, σ_{R2-}, could also be represented by Eq.[1] simply by replacing R_2^* with R_2^- and SNR_0 with that of the first image of the second echo train: ,

$$SNR_0' = SNR_0 \exp[-(N-1)\tau R_2^* - \tfrac{1}{2}T_p(R_2^* + R_2^-)] \qquad [2]$$

in which T_p (= 10 ms used in this work) is the separation between the last echo of the first echo train and the first echo of the second. Because $R_2 = (R_2^* + R_2^-)/2$ and $R_2' = (R_2^* - R_2^-)/2$, the error for both is expressed as $\sigma_{R2} = \frac{1}{2}\sqrt{\sigma_{R2^*}^2 + \sigma_{R2-}^2}$, and σ_{R2} could be minimized either numerically or by solving $\partial\sigma_{R2}/\partial\tau = 0$.

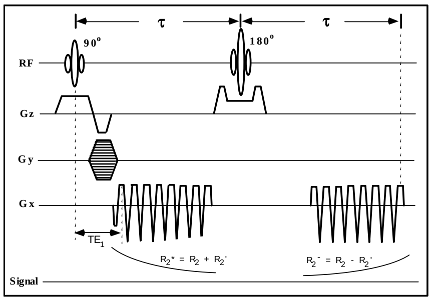

Fig. 1. GESFIDE pulse sequence.

Results and discussion

If only a single decay R_2^* is considered, by setting $\partial\sigma_{R2^*}/\partial\tau = 0$ one can show that the ratio τ_o/T_2^* is a constant for a given number of echoes N in the echo train, where τ_o is the optimum inter echo spacing. **Fig. 2** shows the relationship between γ [= $(N-1)\tau/T_2^*$], which is the total data acquisition time relative to T_2^*, and the number of acquired echoes. The plot also implies that for a given number of echoes, the optimum echo spacing is a function of T_2^* but is independent of the image SNR. Although SNR will affect the error in the measurement of R_2^* according to Eq. [1], the optimum echo spacing is not affected by the noise levels. According to the plot, a good rule of thumb for the total data collection time is twice the relaxation period T_2^*.

Fig. 3 plots the results for the GESFIDE sequence showing the relationship between the optimum inter-echo spacing and R_2 for several values of R_2^* for N=5. The plot indicates that for a fixed R_2^*, the optimum echo spacing τ_o is a function of R_2, with higher R_2 requiring shorter τ_o. A plot of γ vs. R_2 is presented in **Fig. 4,** showing that in GESFIDE, the optimum data acquisition period for each echo train ranges approximately from $0.7T_2^*$ to $2T_2^*$. These findings make intuitive sense since reduced length of the first echo train would preserve more signal for the second. Similar plots using larger N result in nearly identical results as shown in **Fig. 4**, although for smaller N, γ decreases slightly similar to that observed in **Fig. 2**.

Conclusion

While the optimum data acquisition time for the measurement of a simple R_2^* decay is $2T_2^*$, that of the GESFIDE sequence is dependent on R_2 and R_2' and ranges from $0.7T_2^*$ to $2T_2^*$.

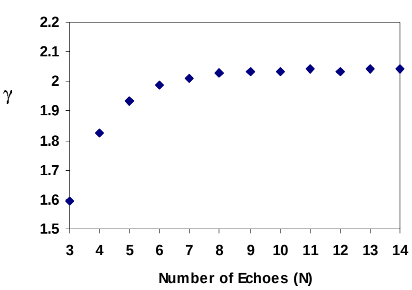

Fig. 2 The ratio of the total data acquisition time to T_2^* [$\gamma = (N-1)*\tau/T_2^*$] as a function of number of echoes acquired for a single exponential decay.

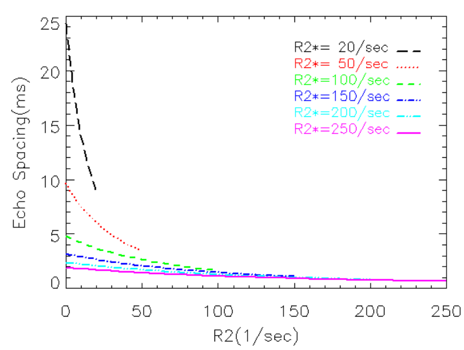

Fig. 3 Optimum inter-echo spacing vs. R_2 for various values of R_2^*. Some of the curves are cut off since $R_2 \leq R_2^*$. N=5.

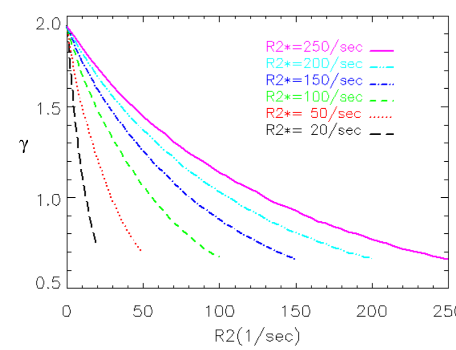

Fig. 4 γ vs. R_2 for a given values of R_2^*. The plots are nearly the same for different values of N.

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References [1] Ma J, Wehrli FW, J. Magn. Reson. **B111**:61-69 (1996). [2] Hardy PA, Yue G, J. App. Physiol. **83**:904-909(1997) [3] Majumdar S, *et. al.* J. Magn. Reson. **3,** 397-417 & 562-574(1986)