Maximizing T2 Signal Weighting Generated by RF Excitation

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Introduction: Traditionally, T_2 weighting in MR is controlled by varying the sequence echo time (*TE*). Alternatively, T_2 contrast can be generated from the RF pulse itself (e.g. TELEX pulses [1]). In this work we study ways to maximize T_2 weighting generated by this mechanism. The absolute contrast between two tissues I and II with different T_2s, which we will call ΔS, is given by:

$$\Delta S \equiv S^{I} - S^{II} \approx \left(\frac{\partial S}{\partial T_2}\right)\Delta T_2 = \left(\frac{\partial S}{\partial \ln T_2}\right)\left(\frac{\Delta T_2}{T_2}\right) \equiv W\left(\frac{\Delta T_2}{T_2}\right) \qquad \text{with} \qquad W \equiv \left(\frac{\partial S}{\partial \ln T_2}\right) \qquad (1)$$

where the sequence weighting *W* is evaluated at the average T_2 of the two tissues.

Single RF Pulse: For a single hard RF pulse of field strength B_1 ($\omega_1 = \gamma B_1$) and duration τ the signals in the presence of T_2 relaxation is given by Eq.2 [1] and the weighting *W* is given by Eq.3, where $\kappa \equiv \tau / T_2$ and $\theta = \gamma B_1 \tau$ is the nominal flip angle.

$$S = S_0 \frac{\omega_1}{\sqrt{\omega_1^2 - \frac{1}{4T_2^2}}} \exp\left(-\frac{\tau}{2T_2}\right) \sin\left(\sqrt{\omega_1^2 - \frac{1}{4T_2^2}}\,\tau\right) = S_0 \frac{\theta}{\sqrt{\theta^2 - \frac{\kappa^2}{4}}} \exp\left(-\frac{\kappa}{2}\right) \sin\left(\sqrt{\theta^2 - \frac{\kappa^2}{4}}\right) \qquad (2)$$

$$W = S_0 \frac{\theta \exp\left(-\frac{\kappa}{2}\right)}{4\kappa\left(\frac{\theta^2}{\kappa^2} - \frac{1}{4}\right)^{3/2}} \left\{\left[2\kappa\left(\frac{\theta^2}{\kappa^2} - \frac{1}{4}\right) - 1\right] \sin\left(\sqrt{\theta^2 - \frac{\kappa^2}{4}}\right) + \sqrt{\theta^2 - \frac{\kappa^2}{4}} \cos\left(\sqrt{\theta^2 - \frac{\kappa^2}{4}}\right)\right\} \qquad (3)$$

The fact that τ and T_2 always occur in a ratio (κ) implies that, for any given flip angle θ, the RF pulse duration τ controls the weighting in an analogous way to conventional T_2 weighting, where *TE* controls the conventional weighting function. Plots of signal (Eq.2) and weighting (Eq.3) as a function of logT_2 for different values of nominal flip angles and fixed τ are shown in Fig.1. The maximum weighting is largely independent of flip angle, which confirms that the RF duration effectively controls the contrast. The values of κ for which the weighting is maximized are displayed in Table I for selected values of θ:

θ	0° → 90°	180°	270°	360°
κ	1.79 → 1.71	2.72	2.11	2.10
W	0 → 0.28	0.08	0.38	0.03

Table I: Values of κ that maximize weighing for selected θ. The absolute maximum weighting occurs at 90° and 270° since they exhibit the largest total change in signal (Fig.1a). For typical excitation flip angles, the optimal RF duration is around 1.7-1.8 times the T_2, however at higher flip angles the behavior is not straightforward.

Spoiled RF Pulse Train: The previous analysis considered the case of a single RF pulse with fully relaxed spins ($M_z = M_0$), which is equivalent to $TR \gg T_1$. In practice, the longitudinal magnetization usually does not re-grow to its equilibrium value M_0, so we now consider the case of a spoiled hard RF pulse train acquisition. Using a mathematical induction argument [2], the steady state magnetization can be shown to be given by Eq .4 and is plotted in Fig.2a.

$$S = S_0 \frac{\theta(1 - E_1)\exp\left(-\frac{\kappa}{2}\right)\sin\left(\sqrt{\theta^2 - \frac{\kappa^2}{4}}\right)}{\sqrt{\theta^2 - \frac{\kappa^2}{4}}\left\{1 - E_1 \exp\left(-\frac{\kappa}{2}\right)\left[\cos\left(\sqrt{\theta^2 - \frac{\kappa^2}{4}}\right) + \frac{1}{2\sqrt{\frac{\theta^2}{\kappa^2} - \frac{1}{4}}}\sin\left(\sqrt{\theta^2 - \frac{\kappa^2}{4}}\right)\right]\right\}} \qquad (4)$$

As before, the weighting may be calculated using Eq.1 and is plotted in Fig.2b vs. logT_2. The T_2 at which *W* is a maximum is again largely independent of the flip angle, however now the value of κ depends on TR/T_1. Surprisingly, the maximum for *W* occurs at the classical Ernst angle, since it exhibits the largest total change in signal (Fig.2a). A plot of the optimal κ with θ at the Ernst angle is shown versus TR/T_1 in Fig.3. Note that κ approaches 1.71 for high values of TR/T_1 (i.e. Ernst angle → 90°), as expected from Table I.

Conclusion: The purpose of this study was to maximize contrast generated by hard RF pulses for tissues with different T_2 values. The following guidelines apply:
<u>Single RF pulse:</u> Use a flip angle of $\theta = 90°$ and pulse duration $\tau = 1.71 \cdot T_2$ to shift the peak of *W* to the mean T_2 of the tissues.
<u>SPGR RF pulse train:</u> Use the classical Ernst angle for the T_1 and *TR* of interest and a pulse duration $\tau = \kappa \cdot T_2$ (κ shown in Fig.3).

References: [1] M. S. Sussman et. al, MRM 40:890-899 (1998) [2] M. A. Bernstein, *Handbook of MRI Pulse Sequences* (2004).

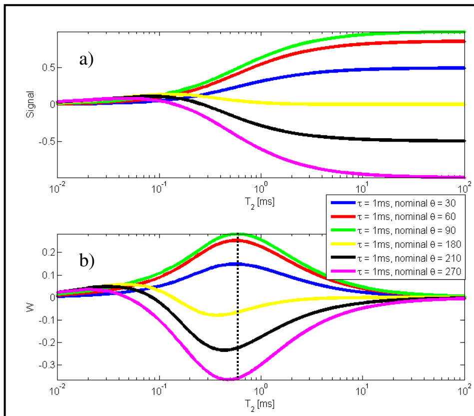

Fig.1: a) MR signal vs. logT_2 for different flip angles using a fixed value of τ = 1ms.
b) Corresponding signal weighting vs. logT_2.

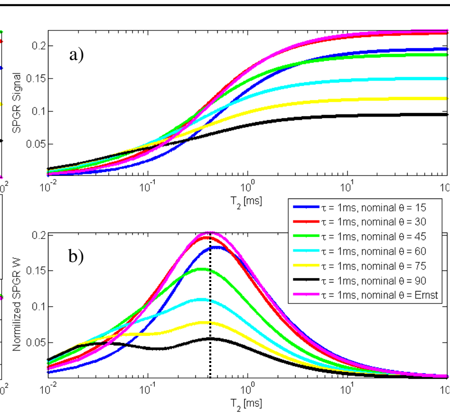

Fig.2: a) SPGR MR signal vs. logT_2 for different flip angles using a fixed value of τ = 1ms and TR/T_1 = 0.1.
b) Corresponding signal weighting vs. logT_2.

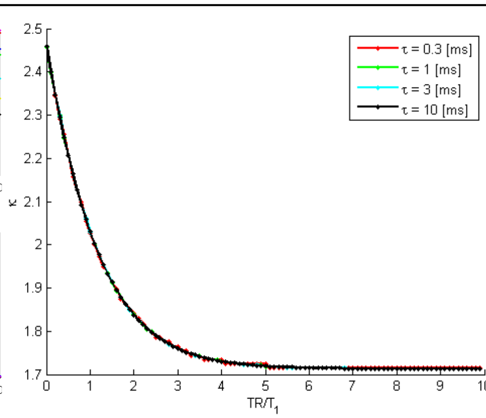

Fig.3: Optimum values of κ as a function of TR/T_1.