Automatic Flip Angle Calculation for Consistent Contrast

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Introduction

Spoiled Gradient Echo (SPGR) sequences are used to rapidly acquire T1-weighted images for a wide range of clinical applications. In such sequences the two parameters which determine contrast, repetition time (TR) and flip angle (α), interact in a non-linear manner which is often difficult to intuit. When flip angle is fixed by protocol, variation in TR due to changes in prescription parameters such as number of slices, resolution, or bandwidth can have an unintended effect on contrast.

Image contrast appearance may be characterized by plotting signal as a function of T1. If the curve is relatively flat, the image has weak T1 contrast, while if the curve is steep, the image has strong T1 contrast. Changing TR or α changes the shape of this curve. Here we demonstrate a means to calculate α such that when TR is changed, signal scales equally in all tissues, independently of T1. The shape of the signal-vs-T1 curve is preserved and thus image contrast appearance does not change.

Methods

Figure 1a shows how the shape of the signal vs. T1 curve varies if TR is changed, but α is kept constant. As TR changes, signal does not scale independently of T1; the shape as well as the amplitude of the curve changes.

Instantaneous contrast around a given T1 is defined as the derivative of signal with respect to T1:

$$C = \frac{dS}{dT1} = \frac{-TR\ \sin(\alpha)\exp(-TR/T1)\left(1-\cos(\alpha)\right)}{T1^2\left(1-\cos(\alpha)\exp(-TR/T1)\right)^2} \quad [1]$$

For a given application, one may wish to optimize contrast about some particular T1. This choice of which T1 to optimize for (call it $T1_{opt}$) may be considered a control parameter. The flip angle, α, which maximizes contrast about this $T1_{opt}$ is (1,2)

$$\alpha = \cos^{-1}\left(\frac{2\exp(-TR/T1_{opt})-1}{2-\exp(-TR/T1_{opt})}\right) \quad [2]$$

Suppose we choose α such that $T1_{opt}$ is maintained for any TR. That is, match some new (TR′,α′) to a baseline (TR,α)

$$T1_{opt} = TR/\log\left(\frac{2+\cos\alpha}{1+2\cos\alpha}\right) = TR'/\log\left(\frac{2+\cos\alpha'}{1+2\cos\alpha'}\right) \quad [3]$$

Solving this expression, the new flip angle, α′, may be calculated for the new TR′ as:

$$\alpha' = \cos^{-1}\left(-1/2+3/\left(-2+4\left(\frac{2+\cos\alpha}{1+2\cos\alpha}\right)^{\frac{TR'}{TR}}\right)\right) \quad [4]$$

Figure 1b shows the signal-vs-T1 curves for this case. Now it appears that signal does scale independently of T1. Normalizing the curves by dividing by $\sqrt{TR}$, as shown in Figure 1c, confirms this. The curves all lie on top of each other, suggesting that images generated using these sets of (TR, α) will have identical contrast appearance and only vary in SNR.

To validate this method of maintaining contrast equivalence, an experiment was performed on a phantom containing standards with various T1 values. 3D SPGR images were acquired with (a) a baseline of TR=6ms, α=15°, (b) TR doubled but α kept the same, and (c) TR doubled and α=21.1° in order to maintain $T1_{opt}$ of the baseline case. Image intensity in all cases was normalized such that signal in one particular standard was the same for all cases. Difference images were then computed to better visualize any change in relative contrast.

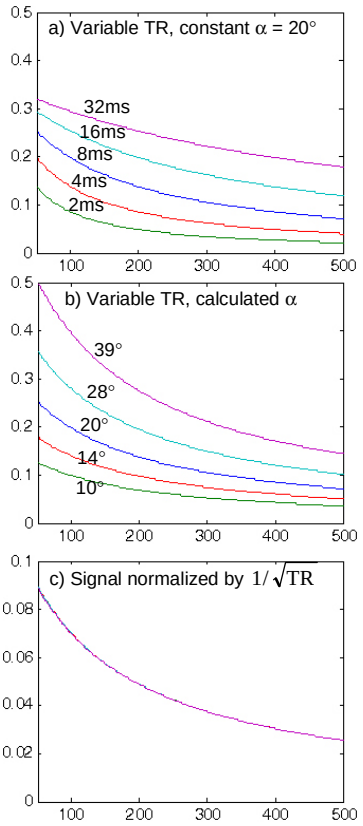

Figure 1: Signal vs. T1 curves

Results

Figure 2a shows a difference image between cases (a) and (b). When flip angle is not adjusted, relative contrast is not maintained – in this instance it is reduced. Figure 2b shows a difference image between (a) and (c). Here relative contrast is maintained as evidenced by very little normalized signal difference in standards of all T1 values.

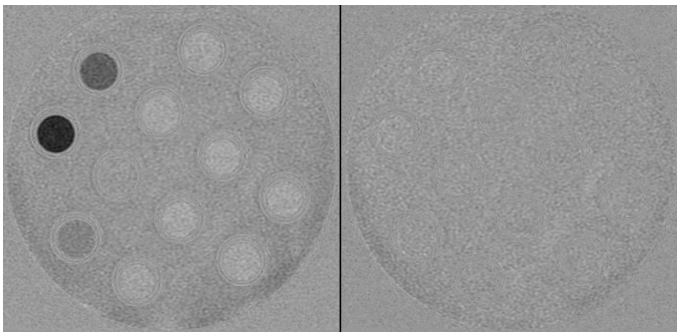

Figure 2: Difference images showing contrast consistency

Discussion

We have demonstrated that, for SPGR sequences, the flip angle may be calculated such that signal scales independently of T1 and proportionally to $\sqrt{TR}$. Relative contrast, the shape of the signal-vs-T1 curve, may therefore be controlled by a single parameter, $T1_{opt}$. $T1_{opt}$ might be chosen based on theoretical considerations (choosing $T1_{opt}$ to lie between the T1 values of tissues one wishes to discriminate), it might be established by trial and error, or it might be calculated based on the TR and α of a well accepted protocol.

In any case, once $T1_{opt}$ is selected, TR is free to vary to accommodate a range of sequence parameters such as resolution and bandwidth without impacting relative contrast. Protocols already optimized with particular TR and α values may have their contrast performance "translated" to any other TR without having to re-optimize flip angle through trial and error.

We have also investigated other single-parameter options to control contrast such as a $T1_{Ernst}$ (analogous to $T1_{opt}$, but based on signal rather than contrast maximization) and an "Effective TR" method proposed by Dixon et al. (3). We found the proposed method more accurately maintains contrast equivalence over a wider range of baseline TR and α values – contrast equivalence only begins to break down for T1≤TR. As a control parameter, $T1_{opt}$ is more useful than α because it is TR-independent and relates directly to tissue relaxation parameters. Further work may be done to determine $T1_{opt}$ values best suited for various clinical applications.

References

(1) Edelstein WA, Bottomly PA, Hart HR, Smith LS, *J Comp Assist Tomog*. 7:391 (1983), (2) Pelc NJ, *Magn Reson Med*. 29:695 (1993), (3) Dixon WT, Blezek DJ, Dhawale PJ, Harisinghani MG, *Proc Soc Molecular Img* (2002)