I. Introduction

MR fluoroscopy (1), used for interactive examination of dynamic processes, has typically been based on gradient-echo, EPI or spiral sequences. Within this context of real-time interactive imaging, it would be desirable for some applications to have the benefits of spin-echo imaging, in particular reduced susceptibility to off-resonance, high-SNR, and T2-weighting.

While a single-shot fast spin-echo sequence (2) could possibly meet these criteria, two factors have limited its implementation for real-time T2 imaging. First, the period required for many materials to recover in order to achieve T2-weighting is long, limiting temporal resolution. Second, transverse magnetization decay during the long readout train limits spatial resolution.

In this work we address these challenges by: (i) designing a pulse sequence using driven equilibrium magnetization realignment (3) to enhance the signal from fluids and thus shorten the required recovery time, and (ii) applying Wiener demodulation (4) prior to reconstruction to offset T2-decay effects while constraining noise. We show that the real-time interactive imaging technique can be applied clinically to dynamic pelvic imaging and interactive obstetric imaging.

II. Methods

Transverse magnetization remaining at the end of the echo train is realigned with the principal field by a 90° RF pulse, producing the driven equilibrium (DE) condition. We show that for single-shot fast spin-echo imaging, DE improves signal levels according to

\[ \text{Gain} = \frac{1}{1 - e^{-T_{\text{read}}/T_1}} \]  

where \( T_{\text{read}} \) is the length of the readout train and \( T_{\text{read}} = TR - T_{\text{read}} \) is the quiescent recovery period after the realigning RF pulse. From this equation, it is clear that species with \( T_2 \) values much shorter than \( T_{\text{read}} \) or \( T_1 \) values much shorter than \( T_{\text{read}} \) will not be affected by driven equilibrium. For single shot imaging with \( T_{\text{read}} \) typically on the order of 400 ms, fluids are expected to be significantly enhanced when \( TR < T_1 \).

Experiments were performed to determine the signal enhancement produced by driven equilibrium in water, gel, and oil at various TR values, and simulations were performed to determine how contrast is affected by the TR and \( T_{\text{read}} \) values.

Wiener demodulation is a method, applied in the k-space domain, which combines simple deconvolution with Wiener noise filtering. The technique is applied in an attempt to reverse the effects of \( T_2 \) decay, which is manifest in fast-spin-echo imaging as a modulation in the \( k_z \) direction. Given a \( k_z \)-dependent modulation transfer function, \( m(u, k_z) \), and an estimate of the noise variance, \( \Gamma \), the Wiener demodulation function becomes

\[ w(k_z) = \frac{m(u, k_z)}{[m(u, k_z)]^2 + \Gamma} \]

Experiments were performed to determine the effect of Wiener demodulation on phantom and in-vivo image data.

The methods have been implemented for real-time imaging and applied to several clinical tasks including dynamic pelvic floor imaging and interactive fetal imaging. In both cases, the desired contrast is dependent on adequate recovery of fluids, and thus both benefit from DE. Tomographic plane position and orientation as well as TR and TE values, which determine contrast could be altered interactively while continuously collecting and reconstructing images at rates of one image every one to two seconds.

III. Results

Figure 1 compares the signal attained for water and oil when using driven equilibrium to that when using a conventional SPFSE sequence. For a fixed TR, driven equilibrium improves signal in fluids and thus allows stronger T2-weighting which is compromised with shorter TR's. For a fixed amount of contrast, the TR may be reduced by approximately 1000 ms by using driven equilibrium, allowing higher temporal resolution for real-time dynamic imaging.

IV. Conclusions

Diagnostic quality T2-weighted images may be acquired in an interactive, real-time paradigm using a single shot fast spin echo pulse sequence. Driven equilibrium enhances fluid recovery and thus allows T2 contrast at a 0.5 - 1.0 Hz frame rate. Wiener demodulation reduces blurring caused by \( T_2 \)-decay through the course of a single-shot acquisition. Applied clinically, the technique has promising utility.

V. References