Optimized, Unequal Pulse Spacing in Multiple Echo Sequences Improves Refocusing in Magnetic Resonance

W. S. Warren[1], and R. T. Branca[2]
[1]Chemistry/CMBI, Duke University, Durham, NC, United States, [2]Chemistry, Duke University, Durham, NC, United States

Recently, an astonishing prediction from the quantum computing community[1]-that multiple echo sequences can be improved by using unequal spacing-was demonstrated to be correct for reducing dephasing of optically trapped ions[2]. The optimal delays in Figure 1 (called a "UDD sequence" and analytically derived in ref. 1, but for a model that was stated there to be irrelevant to MR) did a better job than the approach universally used in MR since the 1950s (Carr-Purcell-Meiboom-Gill (CPMG) sequences with equally spaced echo pulses). Here we show that, in fact, optimal UDD sequences produce different T_2-weighted contrast in magnetic resonance than do CPMG sequences with substantial gains in most regions. Figure 2 shows one such example, a relaxation map from a mouse abdominal slice.

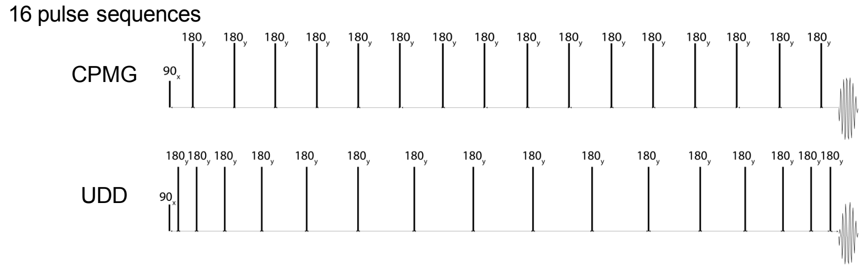

Figure 1. Comparison of the conventional multiple echo sequence (CPMG) with the newly proposed "UDD" sequences for 16 pulses.

The key is understanding that in MRI of structured materials such as tissue, diffusion in compartmentalized and microstructured environments with susceptibility gradients leads to fluctuating fields on a range of different timescales. The UDD sequence can be shown to do the best possible job of suppressing effects of very low frequency fluctuations, and thus can outperform the conventional multiple echo sequences. We have shown that, both in excised tissue and in a live mouse tumor model, optimal UDD sequences produce different contrast than do CPMG sequences with the same number of pulses and total delay, with substantial enhancements in most regions (signal gains typically were 20-70%)[3].

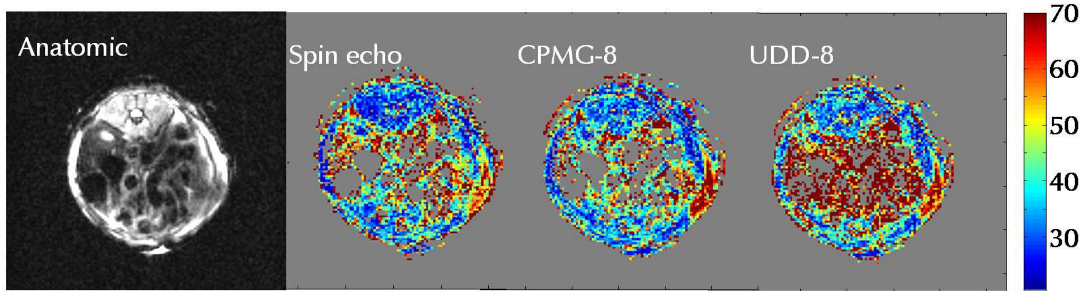

Figure 2: Left: anatomic image (mouse abdomen, 7T). Right: relaxation time maps for a simple two-pulse spin echo, an eight-pulse CPMG sequence, and an eight-pulse UDD sequence (T_2 plotted in ms). The UDD sequence dramatically lengthens the coherence lifetimes in many regions, and contrast is different than in any conventional images.

This new source of endogenous contrast has potential applications in human MR (particularly at lower fields, where power dissipation is not an issue), because varying the length of the UDD sequence effectively maps out the spectral density function. This is expected to be highly sensitive to the microenvironment (including vascularity, oxygenation, and perfusion). It can also improve sequences which are limited by T_2 relaxation, such as intermolecular multiple-quantum coherence experiments[4]. Issues associated with pulse imperfections and stimulated echoes will be discussed, as will the effects these results have on $T_{1\rho}$ and $T_{2\rho}$ measurements.

References

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