A Comparative Study of the Uhrig Dynamic Decoupling (UDD) and CPMG Pulse Sequences

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Target Audience. MR Physicists with an interest in novel pulse sequence design and application.

Purpose. UDD is a pulse sequence originally introduced to extend the coherence lifetime of qubits in quantum computing [1]. It differs from the familiar CPMG sequence only in the timing of the 180° refocusing pulses. The uniform pulse spacing in CPMG was shown to be suboptimal in [1] and UDD improves this by changing the spacing of the refocusing pulses to render the system more robust with regard to resonance frequency fluctuations $\Delta\omega(t)$. Specifically, the pulse spacings are chosen such that for n refocusing pulses the first n–1 derivatives of $Y(\omega)$ at ω =0 vanish, where $Y(\omega)$ is the Fourier transform of the switching function $y(t)$. $y(t)$ is initially 1 and changes sign with every refocusing pulse. Neglecting imperfections, the average toggling frame Hamiltonian is $H=\hbar\omega(t)y(t)I_z$, where I_z is the z-angular momentum operator, and the signal dephasing is proportional to: $\lambda = \int_{-\infty}^{\infty} d\omega |G(\omega)|^2 |Y(\omega)|^2$, where $|G(\omega)|^2$ is the spectral density of the resonance frequency fluctuations. Assuming low-frequency fluctuations dominate as is the case for many microscopic processes in biological systems, minimizing the power spectrum of the modulation function around ω=0 by making as many derivatives of $y(\omega)$ as possible vanish decreases λ and thus dephasing. In [2,3] it was suggested that different tissue microstructures would likely produce different signals in response to a UDD sequence, resulting in contrast enhancement, reduced RF-power dissipation by requiring fewer refocusing pulses and even enabling spectral density characterization of different tissues. In particular it was suggested that UDD was better at refocusing inhomogeneous tissue signals while CPMG appeared better at refocusing free water signals. To validate these claims and better understand the potential benefits and drawbacks of UDD, we performed phantom studies.

Methods. The UDD*n* and CPMG*n* (*n* even) pulse sequences were implemented on the Siemens IDEA pulse-programming platform and executed on a *Magnetom Skyra* 3T scanner (Siemens, Erlangen, Germany) with a 7 cm diameter loop coil (Fig. 1) and a 32-channel head coil (Fig. 2). Studies were performed using a variety of phantoms including water, oil, colloidal dispersions and animal tissue (lamb liver). A variety of T_R and T_E values were used in many phantom studies but we focus on just a few examples here.

Results. Results were analysed in MATLAB (The Mathworks, Inc.). Fig. 1 displays CPMG4 and UDD4 acquisitions of a coronal slice of a cylindrical water tube and a small oil capsule at T_E =30 ms and T_R= 100 – 7000 ms as indicated. Yellower regions indicate a larger signal. For very short T_R, banding due to the steady state effect is seen in both CPMG and UDD-acquired images. On increasing T_R the banding remains for much longer T_R in the UDD images than for CPMG. Furthermore, the local field inhomogeneity near the oil capsule manifests as a susceptibility artifact in the UDD images which can be clearly seen at T_R =7000 ms. The contrast between the oil and water is much greater for large T_R in the UDD image than its CPMG counterpart.

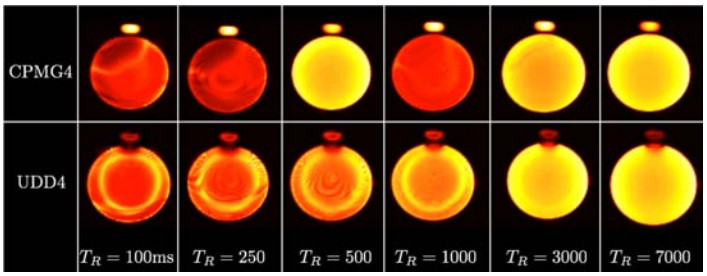

Figure 1: Coronal CPMG4 and UDD4 acquisitions of a water vial and a small oil capsule (top of images) at T_E =30 ms.

Fig. 2 displays UDD4 and CPMG4 acquired images of cut lamb liver in (a) and (b) (photograph in (c)) and a whole liver in (d) and (e). Banding due to local field inhomogeneities caused by the air-tissue interface are clearly visible in the UDD images. In particular this effect enhances highlights the cuts in the liver and gives a *3-dimensional* appearance resembling the photograph in (c) much more closely than the CPMG image.

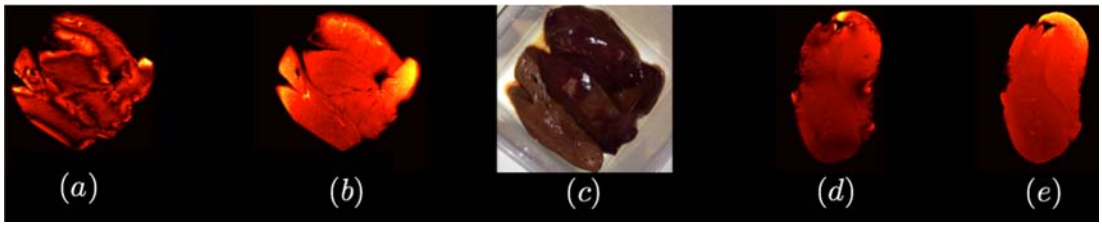

Figure 2: (a) Coronal UDD4 acquisition of a lamb liver cut into three slices. (b) CPMG4 of the same liver. (c) Photograph of the cut liver. (d) A different whole liver image acquired with UDD4 and (e) the same liver imaged with CPMG4.

Discussion. The results suggest that UDD does show promise in elucidating tissue structure but interpretation of the images can be complicated. In particular, significant coherence lifetime extension of the transverse magnetization leads to steady state effects resulting in complex banding artefacts. In some cases the banding artifacts are obvious while other cases they can be subtle and could be mistaken for tissue inhomogeneities. Increasing T_R can reduce banding artifacts but at the cost of long imaging times. While often undesirable, these features also reveal information about subtle field inhomogeneities and susceptibility variations that could be used to construct B-field or susceptibility maps. Furthermore, UDD appears to enhance fat-water contrast at long T_R.

Conclusion. The UDD sequence shows much promise for imaging applications though caution must be used when interpreting the images. More work is required to fully understand the merits, pitfalls and applicability of the UDD pulse sequence.

References. [1] G.S. Uhrig, *Phys. Rev. Lett.* **98**, 100504 (2007) [2] E.J.Jenista, A.M. Stokes, R., Tamara Branca and W.S. Warren, *J. Chem. Phys.* **131**, 204510 (2009) [3] A.M. Stokes, Y. Feng, T. Mitropoulos, *Magnet. Reson. Med.* **69**, 1044 (2013)