Finding the ideal IDEAL acquisition scheme for multi-echo UTE imaging

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<u>*Target Audience*</u>: Physicists and clinicians interested in UTE and Dixon/IDEAL

<u>*Purpose*</u>: An inherent challenge to clinical utility for 'ultrashort-echo-time' (UTE) imaging is low conspicuity in anatomy of interest; proton density and T_1 alone often provide insufficient contrast (fig. 1). To overcome this obstacle, Dixon method decomposition of images from multi-echo UTE acquisition can be used and has been shown capable of separating water, fat and short-T_2 components[1,2]. The feasibility of estimating components depends strongly on the measurements, i.e. the echo times determine the estimation problem condition. But the relatively inefficient nature of 3D radial sampling required for UTE can make acquiring multiple echoes during one TR necessary to avoid prohibitive scan times (fig. 2), which constrains the echo spacing. Furthermore, given typical gradient system performance relative to the chemical shift frequency of lipids, finding a set of measurements for which the estimation problem is even tractable becomes challenging at field-strengths of 3T and higher. By investigating how acquisition parameters affect the estimation, an optimal set of measurements given the constraints can be identified, enabling separation for any particular strategy and field strength.

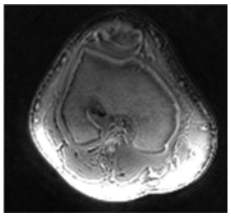

Fig. 1: Axial knee image w/ typical UTE contrast

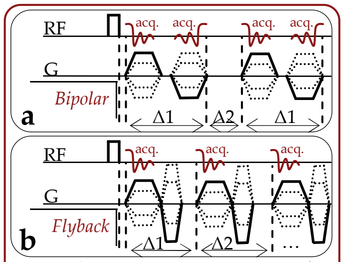

Fig. 2: Strategies to acquire multi-echo UTE images in 1 TR; echo spacings (Δ1, etc.) affect estimates of water, fat & short-T_2 anatomy

<u>*Methods*</u>: The i^{th} image signal of a multi-echo (multi-TE) UTE acquisition resembles conventional fat-water imaging with the addition of a short-T_2 component:

$$s_i = m_w + m_f \Sigma_k a_k e^{i\omega_k TE_i} + m_s e^{-TE_i/T_2} = m_w f_1(TE_i) + m_f f_2(TE_i) + m_s f_3(TE_i),$$

assuming inhomogeneity off-resonance is corrected[1,2]. A six-peak fat model is used with spectral peaks as previously reported[3], and if the second echo time is longer than the short T_2's, $f_3(TE_i)$ is essentially a Kronecker delta. The signal model induces 'measurement matrix' A with $A_{i,j} = f_j(TE_i)$. To find echo times suited to separating multi-TE UTE at 3T and 7T, the equivalent 'number of signal averages' (NSA)[4,5] for estimation of water, fat and short-T_2 anatomy were computed over a grid of echo-spacings. From the Fisher information matrix F, which delimits the Cramer-Rao Lower Bound (CRLB) for estimation and which reduces to A^*A in this scenario, the NSA of the j^{th} component estimate is computed as $[F^{-1}]_{j,j}$.

Computations were implemented and performed using MATLAB. Images were acquired by a bipolar multi-TE UTE sequence (fig. 2b) implemented on commercially-available 3T and 7T scanners using echo times with high NSA for each component and satisfying the constraints. For typical gradient hardware, the feasible region of the bipolar sequence may be more suitable, particularly at 7T.

<u>*Results*</u>: Maps of the NSA over varying TE spacings reveal regions of feasible estimation, as well as configurations that cause failure (fig. 3). Imaging with four echoes, water, fat and short-T_2 components are successfully separated (fig. 4).

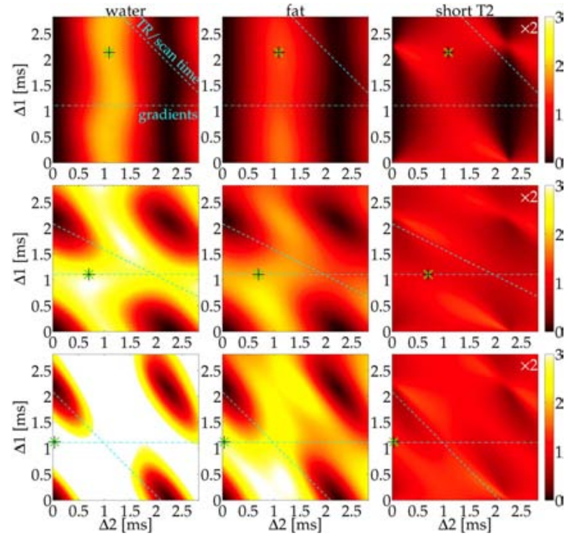

Fig. 3: NSA for estimating water, fat and short-T_2 (at 3T) from (*top to bottom*) 3-, 4- and 5-echo bipolar acquisitions with an optimum marked; high NSA aids estimation; dot-dash line is an example hardware speed constraint (depends upon FOV and resolution); dash line is an example scan time constraint; maps computed with independent Δ3,4 show similar results

<u>*Discussion*</u>: Using three measurements to estimate three components is, while sufficient, quite fragile (fig. 3). There are several large regions of infeasibility (dark area) for the estimation, and separations will be very susceptible to measurement errors (e.g., field inhomogeneity).

The short-T_2 component suffers from low NSA—this is a fundamental challenge, as the short-T_2 basis vector cannot be manipulated and made orthogonal to the water and fat bases. It is very sensitive to the echo spacing and can quickly drop to zero with small TE changes.

Typical hardware performance may make optimal measurements challenging for flyback sequences, but artefacts (e.g., from gradient delays) are more consistent in flyback acquisitions, so depending also upon hardware performance, bipolar acquisitions may be impractical.

<u>*Conclusion*</u>: In multi-echo UTE Dixon imaging, as in traditional Dixon imaging, the choice of echo times has significant ramifications for the estimation problem. By computing the NSA and searching over the space of hardware- and scan-time-compatible TEs, the optimal measurements can be identified, and successful separation of water, fat and short-T_2 components can be achieved.

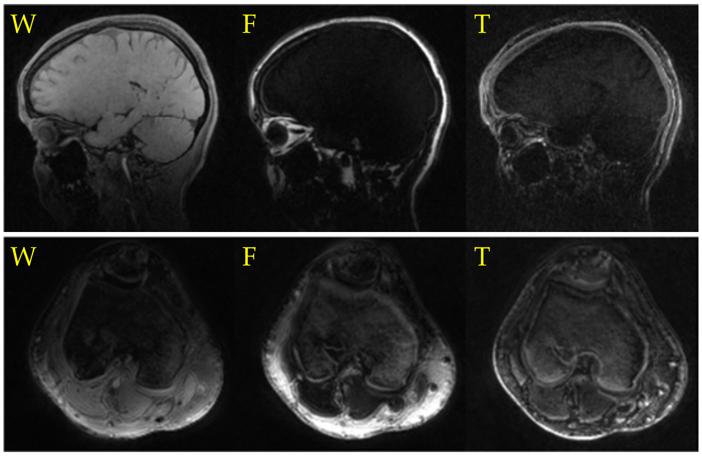

Figure 4: Water—fat—short-T_2 estimates computed from bipolar acquisition images of (*top*) head at 3T with TE=[0.03,1.14,1.83,2.94]ms and (*bottom*) knee at 7T with TE=[0.04,1.40,1.80,3.16]ms.

<u>*References*</u>: [1] Johnson EM, Pauly JM. ISMRM Data & Reconstruction. 2013. [2] Al Saleh H, et al. ISMRM. 2013;1507. [3] Hernando D, et al. MRM. 2010;64:811. [4] Glover G. JMRI. 1991;1:521. [5] Reeder SB, et al. MRM. 2004;54:35.