Water Specific Magnetization Transfer in Skeletal Muscle using MT-IDEAL

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Introduction. A reduced magnetization transfer (MT) effect has been observed in the muscles of patients affected by neuromuscular disease[1,2]. This abnormal MT may be due to a combination of lipid infiltration, edema, and/or macromolecular differences relative to healthy muscle. As lipids are known to have no MT effect[3], their presence in a voxel masks MT changes due to edema and macromolecular abnormalities. This work aims to remove the MT dependence on lipid concentration through the integration of a chemical-species separation imaging technique, Iterative Decomposition of water and fat with Echo Asymmetry and Least-squares estimation (IDEAL)[4], within an MT-weighted imaging acquisition. The new method, MT-IDEAL, calculates water-separated images with and without MT effects enabling the construction of an MT ratio (MTR) map showing only MT changes due to non-lipid sources.

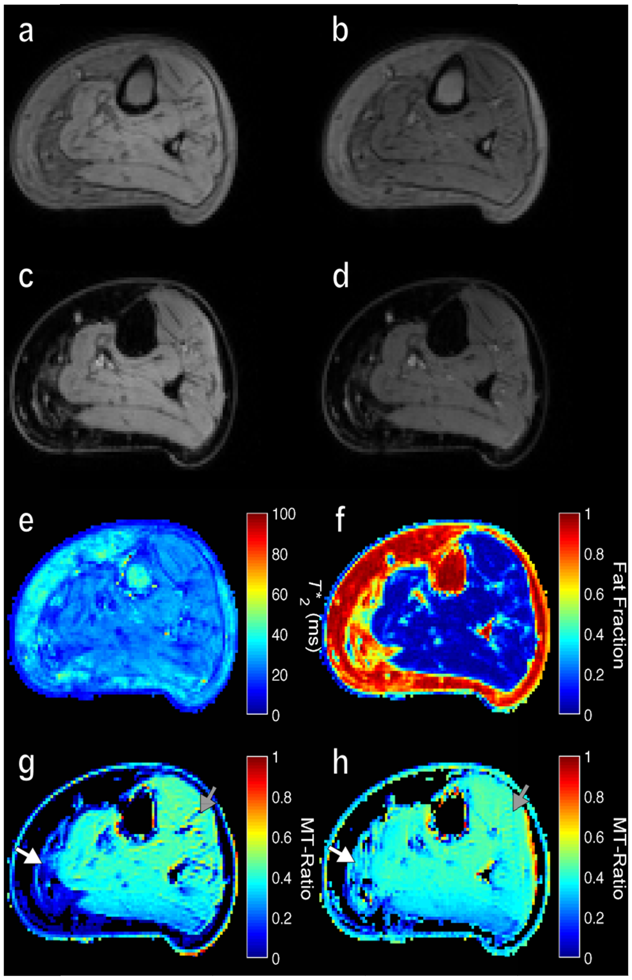

Figure 1. MT-IDEAL in the calf of a patient with IBM. The upper panels show source images without (**a**) and with (**b**) MT contrast. Panels (**c**) and (**d**) show the calculated water image $\rho_{\mathrm{w,MT_{on}}}$ and $\rho_{\mathrm{w,MToff}}$, respectively. In panel (**e**) the resulting T_2^* generated during the MT-IDEAL reconstruction is shown alongside the fat fraction map (**f**). In the lower panels the MTR is shown using a conventional MT experiment (**g**) and using MT-IDEAL (**h**). In the MT-IDEAL MTR map, a more homogenous MTR is calculated within the TA (gray arrow) along with recovery of the MTR signal within the gastrocnemius (white arrow) where severe fat replacement has occurred. The MTR is only shown in (g,h) for pixels with greater than 15% water content as determined by the fat fraction map.

Methods. The measured signal in a given voxel can be modeled as $s_n = \left(\rho_{\mathrm{w,MT_{on}}} + \rho_{\mathrm{f}}\sum\alpha_i e^{j2\pi\Delta f_i t_n}\right)e^{j2\pi\hat{\psi}t_n}$ if an MT pulse is used, or $s_n = \left(\rho_{\mathrm{w,MT_{off}}} + \rho_{\mathrm{f}}\sum\alpha_i e^{j2\pi\Delta f_i t_n}\right)e^{j2\pi\hat{\psi}t_n}$ if no MT pulse is used. $\rho_{\mathrm{w,MT_{on}}}$ and $\rho_{\mathrm{w,MToff}}$ are the complex water signal with and without an off-resonance MT pulse, respectively; ρ_{f} is the complex fat signal; t_n is the echo-time; α_i and Δf_i are the relative fat peaks and frequency offsets; and $\hat{\psi} = \psi + j\frac{1}{2\pi}R_2^*$ accounts for the local field off-resonance, ψ, and the apparent transverse relaxation rate[4]. The fat signal, ρ_{f}, and off-resonance term, $\hat{\psi}$, are unaffected by the off-resonance MT pulse. This MT independence enables the construction of a set of N coupled equations,

$$\begin{bmatrix} s_1 \\ s_2 \\ \vdots \\ s_{N-1} \\ s_N \end{bmatrix} = \begin{bmatrix} e^{j2\pi\hat{\psi}t_1} & 0 & e^{j2\pi\hat{\psi}t_1}\sum\alpha_i e^{j2\pi\Delta f_i t_1} \\ 0 & e^{j2\pi\hat{\psi}t_2} & e^{j2\pi\hat{\psi}t_2}\sum\alpha_i e^{j2\pi\Delta f_i t_2} \\ \vdots & \vdots & \vdots \\ e^{j2\pi\hat{\psi}t_{N-1}} & 0 & e^{j2\pi\hat{\psi}t_{N-1}}\sum\alpha_i e^{j2\pi\Delta f_i t_{N-1}} \\ 0 & e^{j2\pi\hat{\psi}t_N} & e^{j2\pi\hat{\psi}t_N}\sum\alpha_i e^{j2\pi\Delta f_i t_N} \end{bmatrix} \mathrm{x} \begin{bmatrix} \rho_{\mathrm{w,MT_{on}}} \\ \rho_{\mathrm{w,MT_{off}}} \\ \rho_{\mathrm{f}} \end{bmatrix},$$

where N is the number of collected images. The set of coupled equations can then be solved using IDEAL reconstruction[5] and the water isolated MTR calculated as $\mathrm{MTR} = \left(|\rho_{\mathrm{w,MT_{off}}}| - |\rho_{\mathrm{w,MT_{on}}}|\right)/|\rho_{\mathrm{w,MT_{off}}}|$.

All data were collected at 3T (Magnetom TIM Trio, Siemens Healthcare, Germany) using a 3D gradient echo sequence. N=24 unique echos ranging from 1.85 ms to 35.3 ms were collected over two acquisitions, one with and one without an MT pulse. A conventional MT dataset was also collected with a 1.85 ms echo-time. Both the conventional MT and MT-IDEAL acquisitions used a partial Fourier acquisition, 68 ms TR, 1.56 x 1.56 x 5 mm^3 voxel size, GRAPPA factor = 2, and 20 partitions for a total scan time of 2m 54s.

Results. Representative MT-IDEAL results are shown in Figure 1 from a patient with the neuromuscular disease inclusion body myositis (IBM). Fat infiltration in the gastrocnemius results in a low MTR (white arrow, Fig. 1g) using a conventional MT acquisition, while this effect is markedly reduced in the MT-IDEAL approach (Fig. 1h). In healthy-appearing muscle, e.g. the tibialis anterior (TA), similar MTR values were found by both sequences (grey arrow, Fig. 1g and 1h).

Discussion. The specific absorption rate limits the minimum achievable TR in MT imaging. The time afforded by the longer TR has previously been used to increase SNR through averaging of multiple gradient echos[6]. Instead, MT-IDEAL uses multiple echoes to increase SNR as well as calculate the fat fraction, T_2^*, and an MTR map that is unbiased by the presence of fat with no scan time penalty. In combination with a T_2 mapping technique, MT-IDEAL might be used to differentiate fatty infiltration, fibrosis, and edema in neuromuscular disorders.

References.[1]McDaniel JD et al., JCAT 1999; 23(4): 609-14, [2]Sinclair CDJ et al., J Neurol Neurosurg Psychiatry 2011, [3]Wolff SD et al., MRM 1989; 10(1):135-44, [4]Reeder et al., MRM 2005;54 :636-44, [5]Yu et al., MRM 2007;26:115-61, [6]Gringel T. et al., JMRI 2009; 29(6): 1285-92