Two-scan Multiple Echo Diffusion Tensor Acquisition Technique on a 3T clinical scanner with application to skeletal muscle

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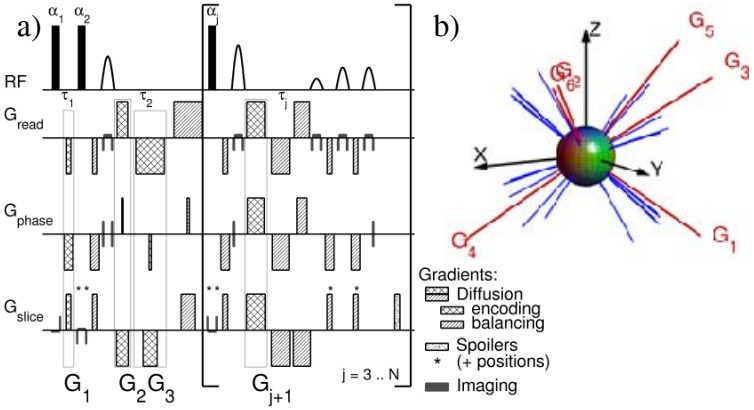

Fig. 1 (a) Multiple-Modulation-Multiple-Echo Diffusion Tensor Imaging Sequence. Five RF pulses (N = 5) generate 13 echoes, each of which encodes a diffusion weighting and direction in three dimensions as determined by the diffusion gradient vectors G_1-G_6. (b) Diffusion gradient vectors G_1-G_6 and effective diffusion sensitizing directions of the 13 echoes (blue lines).

<u>*Target audience*</u> Scientists and clinicians interested in the technical development of novel diffusion MRI pulse sequences.

<u>*Purpose*</u> To describe the concepts and implementation of an MRI method capable of accelerated acquisition of apparent diffusion tensor maps in two scans. The method is demonstrated in *in vivo* skeletal muscle.

Diffusion Tensor Imaging (DTI) uses multidirectional diffusion sampling to provide biomarkers of tissue anisotropy and microstructure. This multidirectional diffusion encoding is accelerated in the <u>M</u>ultiple <u>E</u>cho <u>D</u>iffusion <u>T</u>ensor <u>A</u>cquisition <u>Te</u>chnique (MEDITATE) sequence by encoding multiple echoes with each a different diffusion weighting and direction, together sufficient to estimate the 3D diffusion tensor (Fig. 1). Earlier versions of MEDITATE required more than two scans to accurately estimate DTI-parameters of fibrous phantoms [1-4]. The present work extends the original MEDITATE-approach, which is limited by the low SNR in materials with short T_2 [1-4], to a two-scan *in vivo* method, by exploiting longitudinal magnetization storage. This modification is coupled with spoiler adjustment for signal fidelity, and flip angle optimization guided by the target tissue of skeletal muscle.

<u>*Methods*</u> The MEDITATE pulse sequence, which uses 5 RF-pulses and a pattern of diffusion gradients on three axes, was implemented on a 3T full body Siemens Skyra scanner (Fig. 1). The diffusion gradients were optimized to minimize the error on the diffusion tensor estimates, giving a condition number [5] of 4.42. Besides diffusion weighting, the echo amplitudes are also weighted by the RF flip angles and spin relaxation [1,2]. To isolate diffusion contrast, DTI-analysis is performed on the ratio of equal timing acquisitions with different diffusion weighting strengths and analyzed by the difference in B-matrices, computed in the standard way [2,3,6]. Fully segmented Cartesian encoding is used for image encoding in this phase of optimization.

MEDITATE datasets of the right calf muscle were collected in five healthy volunteers (3 male and 2 female, age 33.0±3.4 y/o) with cardiac-gating (ECG, trigger delay of 600ms from the R-wave; 15-channel knee coil, TR = 4000 ms, 3x3x10 mm resolution, scan time 4:16 per diffusion gradient set). Flip angles $\alpha_1/\alpha_2/\alpha_3/\alpha_4/\alpha_5$ of 61°/73°/100°/45°/60° were chosen in order to maximally equalize the magnitudes of the relaxation weighted echoes [1] (human muscle T1 = 1420±40ms and T2 = 32±2ms at 3T [7]). For the latter 11 echoes, echo times were 90 – 245 ms (timing parameter τ = 9 ms) and isotropic B-values were 167 to 790 s/mm^2 (median 388 s/mm^2). The datasets were processed offline (Matlab, Mathworks) to generate maps of diffusion tensor parameters. Comparisons of accuracy and directional diffusion sensitivity were performed with standard twice-refocused spin echo (TRSE) DTI (TR/TE = 7400/59 ms, 3×3×10 mm resolution, 6 directions, b = 0, 500 s/mm^2, 3 averages, scan time 2:59).

<u>*Results and Discussion*</u> Figure 2 illustrates the agreement (2a, quantitative, 5 healthy volunteers; 2b, qualitative, one healthy volunteer) between the diffusion tensor parameters of *in vivo* skeletal muscle estimated with a standard TRSE-DTI and MEDITATE. The eigenvalues and FA of *in vivo* calf muscle estimated with both methods are in good quantitative agreement, despite the different diffusion time, relaxation and diffusion weighting of each of the echoes in MEDITATE. In this comparison, the diffusion eigenvalues and FA are estimated slightly higher with MEDITATE, possibly due to a residual ghosting artifact in the segmented Cartesian sampling, or higher variance due to the different conditioning of the MEDITATE diffusion encoding.

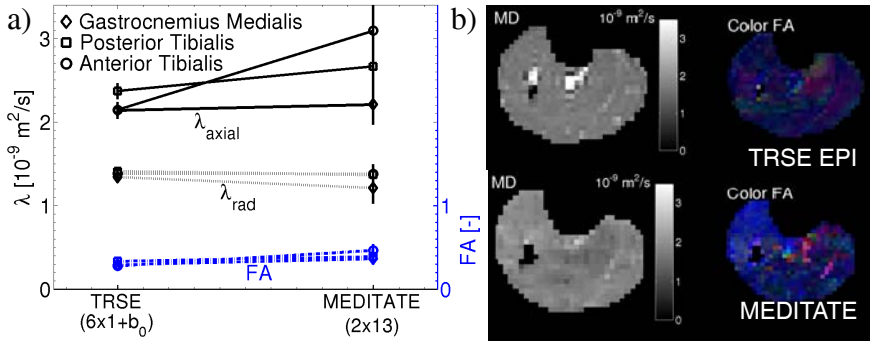

Fig. 2 (a) Average λ_{axial}, λ_{radial} and FA-values of in vivo calf muscle of 5 volunteers sampled over a ROI's in DTI parameter maps and (b) sample MD and Color FA-maps of the right calf muscle of a single volunteer obtained with a TRSE EPI and the MEDITATE sequence.

<u>*Conclusion*</u> The two-scan MEDITATE method of accelerated diffusion encoding is feasible on the clinical scanner platform. When combined with an appropriate k-space trajectory employing self-navigation and view-sharing, which improves on the slow fully segmented image encoding, this technique may be used in clinical applications requiring time-sensitive acquisition of DTI parameters such as dynamical DTI in muscle.

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