# Feasibility of In Vivo Dynamic Diffusion Tensor Imaging on a 3T clinical scanner with a Multi Echo Sequence and compressed sensing reconstruction

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*Target audience* People interested in dynamic Diffusion Tensor Imaging.

*Purpose* Diffusion Tensor Imaging (DTI) provides biomarkers of tissue anisotropy and microstructure [1]. Following exercise, muscle tissue properties change dynamically (e.g. [2-4]). However, traditional DTI methods lack sufficient temporal [2,3] or spatial resolution [5] to resolve the dynamics in detail.

In this work, we present a dynamic DTI method, namely Multiple Echo Diffusion Tensor Imaging (MEDITI), in which both diffusion and spatial encoding are accelerated. That is, the necessary multidirectional diffusion encoding is accelerated by modulating multiple echoes, generated by a train of RF-pulses, with different weightings and directions [6,7](Fig 1). Two scans, alternatingly acquired with different diffusion gradient strengths (b an $b_0$), suffice in order to calculate the diffusion tensor [1,6]. In addition, k-space is encoded with a highly efficient k-space trajectory (STAR, Single TrAjectory Radial [8], Fig 1) and the diffusion weighted images are reconstructed using a multidimensional compressed sensing (CS) approach that exploits sparsity along both echo and time dimensions. In this work, we demonstrate the feasibility of dynamic DTI both in a phantom and in *in vivo* muscle of the lower leg following exercise.

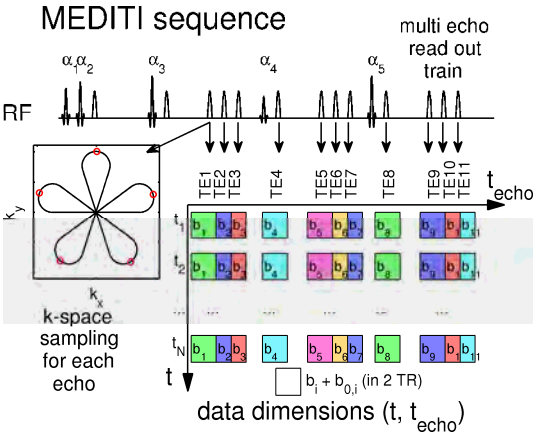


**Fig. 1** The MEDITI-sequence acquires a STAR-trajectory for each of 11 diffusion weighted echoes in each TR, alternating between b and $b_0$-sets in subsequent TRs. The reconstruction algorithm exploits similarities between diffusion weighted images along $t_{echo}$- and t-dimensions.

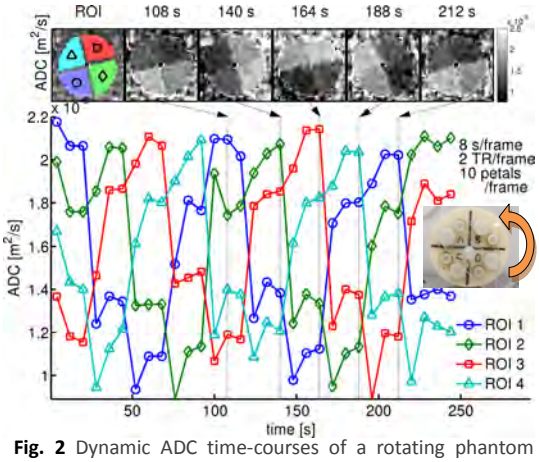


**Fig. 2** Dynamic ADC time-courses of a rotating phantom (inset) filled with gels with different ADCs. The phantom was manually rotated 90° counter clockwise every 12TR.

*Methods* The MEDITI pulse sequence, based on the MEDITATE sequence [7], captures each of 11 echoes by a 5-petal STAR-trajectory [8]. The angle between consecutively acquired STAR trajectories is chosen according to the GRASP-scheme (Golden Radio Angle Radial Sparse Parallel)[9], optimizing k-space coverage in both echo ($t_{echo}$)- and time (t)-dimensions. Phase maps are calculated from low resolution reconstructions of each individual echo k-space [10].

For image reconstruction, readouts from consecutive TRs (2 for phantom, 4 *in vivo*) with the same diffusion weighting are added and a time series is formed. In the reconstruction, sparsifying transforms exploit the similarity between diffusion weighted images along the echo ($t_{echo}$)- and the time (t)-dimensions to avoid undersampling artifacts:

$$\hat{\boldsymbol{X}} = \arg min_{\boldsymbol{X}}\{\|\boldsymbol{EX}-\boldsymbol{Y}\|_2^2 + \lambda_{PCA}\|PCA^{t_{echo}}\boldsymbol{X}\|_1 + \lambda_{PCAt}\|PCA^{t}\boldsymbol{X}\|_1 + \lambda_{TV}TV^{xy}\boldsymbol{X}\}$$

with $\boldsymbol{X}$ the time-series of images to be reconstructed, $\boldsymbol{Y}$ its k-space, $\boldsymbol{E}$ the multicoil encoding matrix, including coil sensitivities [11] and the NuFFT-transform, $PCA$ the Principal Component Analysis, $TV^{xy}$ the in plane total variation and $\lambda_{PCA}$, $\lambda_{PCAt}$ and $\lambda_{TV}$ regularization parameters chosen heuristically as 2.5e-5, 2.5e-5 and 5e-5 multiplied by the norm of $\boldsymbol{X}$. The solutions were found using a non-linear conjugate gradient method. Dynamic MEDITI measurements (11 echoes, TE: 90-245ms, isotropic B-values: 167-790 s/mm$^2$, flip angles 61°/73°/85°/45°/85°, TR=2000ms, 5x5x20 mm$^3$ resolution) were obtained from a phantom filled with gels with different ADCs [12] which was rotated during the scan and *in vivo* from the muscles of a healthy volunteer (male, age 42 y/o) using a 15 channel knee coil. In vivo MEDITI datasets were acquired from the right lower leg of the subject before and after a 4 min in-scanner plantar-flexion exercise using an in-house built ergometer.

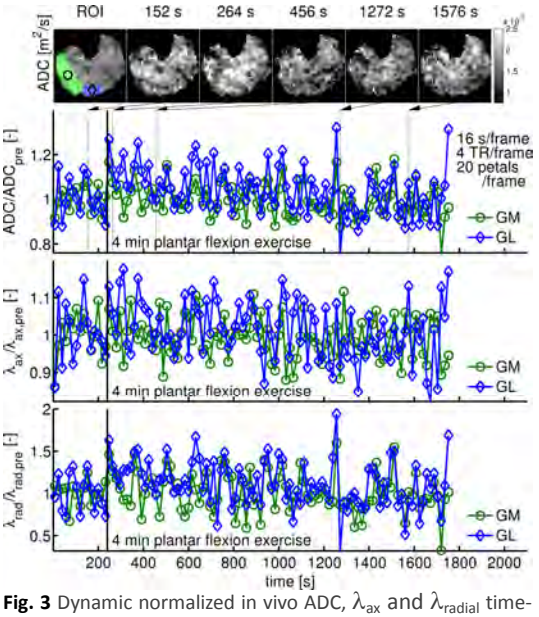


**Fig. 3** Dynamic normalized in vivo ADC, $\lambda_{ax}$ and $\lambda_{radial}$ time-courses of the Gastrocnemius Medialis (GM) and Lateralis (GL) of a healthy volunteer before and after a 4 min in-scanner plantar-flexion exercise.

*Results and Discussion* In the rotating phantom experiment (Fig 2), full maps of the DTI parameters are calculated every 8 s, demonstrating the potential of the MEDITI sequence (an undersampling of 10 at this resolution). The accuracy of the obtained DTI-parameters is indicated in the displayed time-courses. In the *in vivo* experiment (Fig 3), transient changes of DTI-parameters after exercise can be observed. In order to overcome limitations related to low SNR (due to short muscle $T_2$), we combined more TRs per frame. Therefore, we reconstructed one frame every 16 s. In this example, we observed small but measurable changes in the diffusion parameters, consistent with healthy muscle capacity. The sensitivity of our method to detect these small changes may enable us to detect early symptoms of compromised muscle capacity. Indeed, affected muscles in e.g. Chronic Exertional Compartment Syndrome and Dermatomyositis have been shown to exhibit larger exercise response factors [13,14].

*Conclusion* The MEDITI sequence can be used to image transient changes in tissue anisotropy in phenomena such as muscle fatigue and exertion at higher temporal resolution than previously possible. In a next step, incorporation of the DTI-model in the reconstruction [15] might improve SNR.

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