Dynamic diffusion tensor parameters in muscle tissue using Single Voxel Multiple Echo Diffusion Tensor Acquisition Technique on a 3T clinical scanner

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Target audience Scientists and clinicians interested in the study of dynamic changes of Diffusion Tensor parameters.

Purpose To demonstrate the implementation of an MRI method for dynamic diffusion tensor acquisitions in a single voxel in clinical scanners, both in a phantom and *in vivo*.

Measurements of diffusion tensor parameters, requiring multidirectional diffusion sampling, provide biomarkers of tissue anisotropy and microstructure [1]. When these biomarkers display transient changes, as in muscle tissue following exercise (e.g. [2-4]), traditional Diffusion Tensor Imaging (DTI) methods lack sufficient temporal resolution to resolve the dynamics of the DTI parameters. The single voxel Multiple Echo Diffusion Tensor Acquisition Technique (SV-MEDITATE) method, presented in this work, aims to capture transient changes in tissue anisotropy and miscrostructure with high temporal resolution albeit with lower spatial resolution. The multidirectional diffusion encoding is accelerated by encoding each of multiple echoes with different diffusion weightings and directions [5-7]. As a result, two scans acquired with different diffusion weighting strengths suffice to accurately estimate DTI-parameters. Finally, a single voxel is selected by applying slice selection gradients along two directions and selecting the central part of the resulting linescan (Fig. 1).

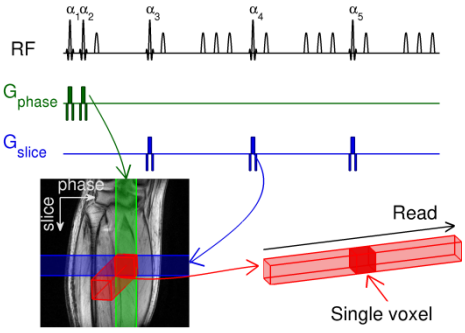

Fig. 1 SV-MEDITATE sequence. Five RF pulses generate 13 echoes, each of which encodes a diffusion weighting and direction in three dimensions as determined by diffusion gradients (not shown). A linescan volume is selected by applying slice selection in two orthogonal directions, eventually allowing selection of a single voxel.

Methods The SV-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 [7](Fig. 1). Scans with two different diffusion weighting strengths were acquired alternatingly in order to isolate the diffusion weighting; the data was analyzed by the difference in B-matrices (condition number of 4.42 [8]), calculated in the standard way [1,5,6]. For the latter 11 echoes, echo times were 90–245 ms and isotropic B-values were 167 to 790 s/mm^2 (median 388 s/mm^2) (flip angles $\alpha_1/\alpha_2/\alpha_3/\alpha_4/\alpha_5$ of 61°/73°/85°/45°/85°, TR = 2000 ms (phantom)/1000 ms (in vivo) (hence, one DTI measurement per 4s/2s), single voxel of 25x25x25 mm). Comparisons of accuracy were performed with single time point data acquired 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, 2:59 min).

Dynamic SV-MEDITATE measurements were performed on a rotating anisotropic phantom (asparagus, Fig 2a) and in *in vivo* muscle tissue, in a 15-channel knee coil. For both cases, the excitation line was oriented anterior-posterior and placed using a gradient echo localizer image (Fig. 1). SV-MEDITATE datasets of the right calf muscle were collected in a healthy volunteer (male, 38 y/o) with cardiac-gating (ECG-triggered, trigger delay of 600ms from the R-wave) before and after a 2 min period of repeated plantar-flexion against an exercise rubber band. The datasets were processed offline (Matlab, Mathworks) to extract diffusion tensor parameters in a time-resolved manner. In addition, datapoints with low SNR (SNR < (mean SNR)/2) were removed and the time-curves were smoothed temporally (Gaussian filter, width 10 time-points = 20 s).

Results and Discussion Figure 2b illustrates the correct identification of the directionality of the first diffusion eigenvector (expressed in terms of the azimuthal angle) of a rotating anisotropic phantom (Fig. 2a) in a dynamic single voxel DTI measurement. In the *in vivo* data, the high temporal resolution time-courses of the DTI-parameters in the Soleus muscle before and immediately after a 2 min plantar-flexion exercise (Fig. 2c) agree in absolute value with the low temporal resolution results in the literature (e.g. [2-4]) and our own static DTI (Fig. 3c). The higher temporal resolution allows to better resolve the delayed exercise response [4] (initial decrease of the axial eigenvalue and mean diffusivity and delayed increase of the radial eigenvalue).

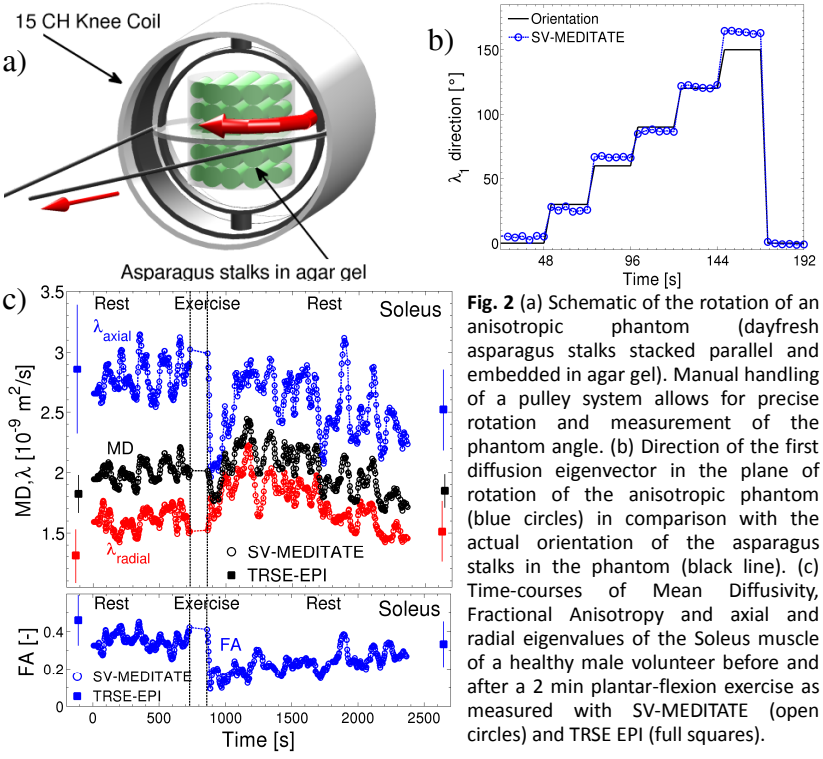

Fig. 2 (a) Schematic of the rotation of an anisotropic phantom (dayfresh asparagus stalks stacked parallel and embedded in agar gel). Manual handling of a pulley system allows for precise rotation and measurement of the phantom angle. (b) Direction of the first diffusion eigenvector in the plane of rotation of the anisotropic phantom (blue circles) in comparison with the actual orientation of the asparagus stalks in the phantom (black line). (c) Time-courses of Mean Diffusivity, Fractional Anisotropy and axial and radial eigenvalues of the Soleus muscle of a healthy male volunteer before and after a 2 min plantar-flexion exercise as measured with SV-MEDITATE (open circles) and TRSE EPI (full squares).

Conclusion Dynamic single voxel DTI, employing the accelerated diffusion encoding of the MEDITATE-approach, is demonstrated in an anisotropic phantom and in *in vivo* muscle tissue on a clinical scanner platform. This dynamic DTI method may be useful in transient phenomena such as muscle fatigue, exertion, or reperfusion. In a next step, the accelerated diffusion encoding of MEDITATE might allow for dynamic DTI imaging when combined with an appropriate k-space trajectory employing self-navigation and view-sharing.

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