Potential of Fiber Tracking and Connectivity Mapping with Multi Diffusion Tensor

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INTRODUCTION

Most fiber tracking algorithms are based on diffusion tensor imaging (DTI) which provides information about fiber directions in brain white matter. However, the model using only one diffusion tensor (signleDT) is invalid for fiber crossings [1]. This approach fails with tracks passing areas of crossing fibers in the brain, for example the area where tractus corticospinalis is crossed by the fasciculus longitudinalis superior. A Multi-Diffusion-Tensor (MDT) model, as it has already been introduced, can resolve the direction of crossing fibers [2, 3]. A probabilistic algorithm [4] and the FACT algorithm [5] were extended to support the MDT-Model. The tractus corticospinalis was tracked with singleDT as well as with MDT by the implemented algorithm. The different tracking results reflect the power and the correctness of MDT in vivo.

MATERIALS AND METHODS

MDT-Approach: As described in [2], two anisotropic, rotational invariant tensors and one isotropic tensor was fitted to the diffusion weighted data. To avoid local minima the fitting was repeated five times for each voxel. An F-test was applied to decide if MDT fits significantly better to the experimental data than singleDT. If a significant improvement was found, the voxel was marked as MDT. To estimate the fraction of the compartments of the MDT-model the FA-index of the anisotropic diffusion tensor components were set to 0.85.

In vivo DTI measurements were done with a multi-slice single-shot DW SE EPI sequence. The whole brain was covered with contiguous 4mm slices and in-plane resolution was 2x2 mm^2. TE/TR were 102ms/6s. The effective b-value (=Trace(**B**)) was 1500 s/mm^2 and the diffusion-encoding was done in 60 different directions, which were homogeneously distributed over a sphere. The off-diagonal elements of the b-matrix were negligible.

ROI-Selection: The tractus corticospinalis, which is crossing with the fasciculus longitudinalis superior, was marked near the third ventricle (see fig. 1, left, ROI A). Three ROIs were created in the primary motor cortex in the area of the gyrus precentralis (see fig. 1, right). The first ROI (ROI B in magenta) was placed in the medial region, which represents leg/foot, the second ROI (ROI C in red) in the more lateral region, which represent the trunk, and the last ROI (ROI D in yellow) was placed in the so called 'hand knob', which represent the hand and the fingers.

Probabilistic connectivity: Koch et al introduced in a 2D algorithm based on singleDT, which produce probability maps of connectivity [4]. This approach was extended to 3D and MDT: The jump probability $p_{\text{singleDT}}(m \to n)$ for singleDT und $p_{\text{MDT}}(m \to n)$ for MDT voxels to jump from the current voxel m to the adjoining voxel n was defined as:

$$p_{\text{singleDT}}(m \to n) = \frac{[d(\mathbf{r}_{m,n}, m) + d(\mathbf{r}_{m,n}, n)]^A}{\sum_{n'} [d(\mathbf{r}_{m,n'}, m) + d(\mathbf{r}_{m,n'}, n')]^A} \qquad p_{\text{MDT}}(m \to n) = c_a \frac{[d_a(\mathbf{r}_{m,n}, m) + d(\mathbf{r}_{m,n}, n)]^A}{\sum_{n'} [d_a(\mathbf{r}_{m,n'}, m) + d(\mathbf{r}_{m,n'}, n')]^A} + c_b \frac{[d_b(\mathbf{r}_{m,n}, m) + d(\mathbf{r}_{m,n}, n)]^A}{\sum_{n'} [d_b(\mathbf{r}_{m,n'}, m) + d(\mathbf{r}_{m,n'}, n')]^A}$$

Thereby $\mathbf{r}_{m,n}$ is the direction from voxel m to n, $d(\mathbf{r}_{m,n}, m)$ the diffusion of voxel m in direction $\mathbf{r}_{m,n}$, $d_a(\mathbf{r}_{m,n}, m)$ and $d_b(\mathbf{r}_{m,n}, m)$ the diffusion of the two anisotropic tensor components of voxel m, and c_a and c_b the particular fractions. To reduce noise propagation, the mean diffusion of all neighbor voxels was averaged during probability calculation. The exponent A was set to 7 and all voxels with FA-index>0.1 and Tr(**D**)<3*10^{-9}m^2/s were allowed for the random walk. The ROI A was chosen as seed point. All probabilities lower than 0.001 were excluded from the maps.

MDT-FACT Fiber tracking: The FACT tracking-algorithm [5] was extended in the following way: If an as MDT marked voxel was reached by the algorithm, a junction was created. The FACT tracking continues recursively in the directions of both anisotropic diffusion tensors. To avoid memory overload, the number of junctions was limited to a maximum of 20 for each track. The tracking was aborted, if the FA-index was lower than 0.15 or if the curvature was higher than 50 degrees. After FACT tracking fibers were selected which cross the ROI A and at least one of the cortical ROIs C, D, or E.

RESULTS

Probabilistic connectivity: From the selected ROI (ROI A) in the posterior limb of the internal capsule, cortispinal fibers deriving from the hand and leg area were correctly detected by the singleDT and MDT method (see also fig. 2). Additionally, thalamocortical fibers, projecting into the sensomotor area were also found by the MDT method with an up to ten times higher probability compared to the singleDT based method.

FACT Fiber tracking: Using singleDT the medially localized leg region (ROI B) and the more lateral localized hand region (ROI E) were not found (see fig. 3). Instead, the cortical region, which represent the trunk (ROI C), was reached. Using MDT, the ROI of the trunk was found as well as the hand knob.

DISCUSSION

Tracking with MDT improves fiber tracking in regions with fiber crossings. Therefore more relevant fibers can be detected with both kinds of tracking algorithms, as for example in the gyrus pre- and postcentralis. However, the more lateral lying cortical regions, which are responsible for the tongue and face were neither found with singleDT nor with MDT. This can be traced back to the limited curvature of the track. Additionally, the MDT model cannot decide between fibers 'kiss' and 'cross', this can only be done by likelihood decision. So, further investigation have to be done to extend the algorithm by some a priori constraints.

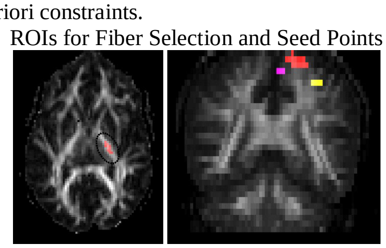

Fig. 1: Left: ROI A of the tractus corticospinalis. Left: ROIs B, C, and D in the gyrus precentralis. The magenta ROI B represent the leg/foot region, the red ROI C the trunk und the yellow ROI D the region of the hand.

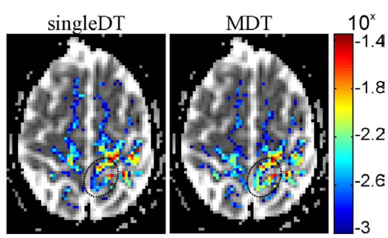

Fig.2: Logarithmic probability-maps of the connectivity to ROI A. The left one shows the singleDT based result and the right map shows the result of the MDT.

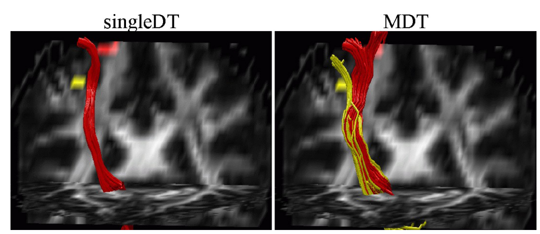

Fig. 3: Frontal view of the resulting fibers of the FACT-tracking. The red fibers correspond to the connecting fibers between ROI A and ROI C (trunk) and the yellow fibers to the ROI D (hand). The left image shows the singleDT and the right one the MDT based tracking result.

REFERENCES

[1] Frank LR, Magnetic Resonance in Medicine 47:1083 (2002)
[2] Kreher BW et al, Proc. Intl. Soc. Mag. Reson. Med., 11, 241 (2003)
[3] Blyth R et al, Proc. Intl. Soc. Mag. Reson. Med., 11, 240 (2003)
[4] Koch MA et al, NeuroImage(16), 241:250 (2002)
[5] Mori S. et al. Ann Neurol(45), 265:269 (1999)