Comparison of DT tractography algorithms with MEMRI and BOOT-TRAC

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Introduction:

Diffusion Tensor Imaging (DTI) is the first noninvasive technique to retrieve orientation information of white matter (WM) tracts by mapping intravoxel diffusivity of water molecules [1]. Based on the orientation information from DTI, the tractography shows the connections between brain regions by reconstructing three-dimensional continuous WM tracts. In recent years, the confirmation of tractography has been discussed either in simulation [2] or on histology [3] but only one algorithm is considered. In this study, three tractography algorithms, FACT [4], RungeKutta (RK) [5], and TEND [6], are compared using bootstrap tractography (BOOT-TRAC) [7], which evaluates the uncertainty of tractography according to the resampling of DTI data. The noise tolerance of tractography algorithm is also evaluated by changing the number of averages. The manganese-enhanced MRI (MEMRI), which visualizes the neuronal pathways anterograde in vivo [8], is used to enhance the target fiber tracts as a gold standard. The trajectories reconstructed by all three algorithms can map fiber pathways accurately with adequate SNR. In addition, RK attains a better success rate (SR) comparing with TEND and FACT methods.

Materials and Methods:

Manganese administration: Male Sprague-Dawley rats (300-500g) were initially anesthetized with pentobarbital (50 mg/kg) via intraperitoneal injection. Two neuronal tracts, anterior commissure (AC) and optic nerve (ON), were enhanced by MEMRI. The front one was stereotaxic injected to anterior olfactory nucleus (AON) (AP= +0.52 mm, ML= +/-0.24 mm) of 100 mM $MnCl_2$ at a total volume 100 nl. The latter one received 1 M of Mn^{2+} intravitreally to bilateral eyeballs with a volume 1 μl respectively. Injection rate (200 nl/min) was slow enough to not destroy the balance of intraocular pressure. About 24 hrs later, SD rats were sacrificed through overdosing.

Image acquisition: MR images were acquired at a 3 Tesla MRI Biospec system (Bruker, Germany) with a phased array rat brain coil. T1WI and DTMRI used the same geometric parameters, including FOV=38.4x38.4 mm^2, matrix size=96x96, and slice thickness = 0.4 mm, yielding the voxel size of 0.4x0.4x0.4 mm^3. MEMRI was obtained using rapid acquisition with relaxation enhancement (RARE) sequence with TR/TE=436.968/9.694 ms for ON and using inversion recovery-RARE sequence with TR/TE= 3500/10 ms for AC. In addition, DTMRI were acquired with 12 gradient encoding directions and 1 reference image using spin-echo pulsed gradient sequence with TR/TE=2000/37.3 ms, Δ/δ=18.29/7.9 ms, b=1178 s/mm^2.

Data analysis: The three different algorithms embraced FACT, RK, and TEND were quantified by repeating 1000 times of BOOT-TRAC. To investigate the influence on SNR, the BOOT-TRAC was performed with average 1 to 7. The condition of termination for tractography were set as FA=0.2 and angle=60^{O} for all methods mentioned above, yet RK was modified by another parameter, step size, ranging from 0.1 to 1 with an increment of 0.1. The seed points were drawn manually based on the enhanced fiber tracts by the MEMRI. Two regions of interest (ROIs) were selected at the middle and the end of the tracts. Then, the success rate (SR), defined as the number of the fiber trajectories passing through the target ROI, was used to evaluate the performance of the tractography.

Results:

AC and ON were successfully enhanced on T1WI after 24 hrs of manganese administration (Fig 1a & 1b). The seed region was located on the yellow round pattern, and the green and violet rounds represented the middle and the end ROI respectively. All trajectories followed the Mn-enhanced pathways via FACT, TEND and RK using BOOT-TRAC (Fig 1c~h). In the case of AC, the trajectories from TEND showed an obvious departure from the neuronal tract, which was not observed on FACT and RK (Fig 1c,e,g). Fig 2 indicated the SR of FACT, TEND and RK with ten step sizes. The percentage of trajectories constrained by the middle ROI was larger than that constrained by the end ROI, and approximately increased with the number of averages. Additionally, the tendency of SR for RK with various step sizes was similar and higher than the other two methods for the most part.

Discussions:

The study shows DTI tractography is capable of estimating fiber tracts as visualized by MEMRI. The results also show a larger SR is obtained from RK as well as TEND. However, the AC trajectories reconstructed from TEND show a little deviation from the Mn-enhanced tracts and result in a poor SR with the end ROI. The deviation may be due to the crossing between the internal capsule (yellow arrows in Fig 1c,e,g) and AC. It can also be noticed that the SR with the end ROI is smaller than that with the middle ROI, which may be caused by the curvature of fiber tracts. Furthermore, the selection of the seed points and the termination criteria may also affect the tractography results. In conclusion, the performance of tractography is evaluated using BOOT-TRAC and MEMRI. At the same time, the DT tractography shows more accurate estimation of fiber tracts with higher SNR.

Acknowledgement:

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References:

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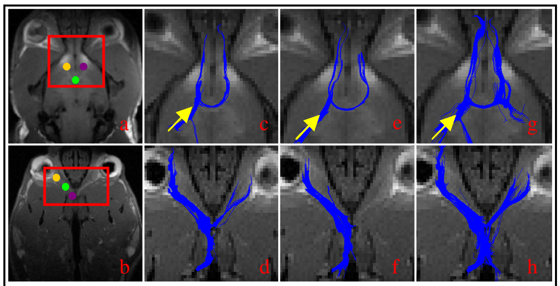

Fig 1. The results of fiber trajectories reconstructed by FACT (c&d), TEND (e&f) and RK_0.9 (g&h) using BOOT-TRAC with average 7. The colorful round pattern shown on MEMRI of AC (a) and ON (b) represented where the seed regions located (yellow: initial seed; green: middle ROI; violet: end ROI).

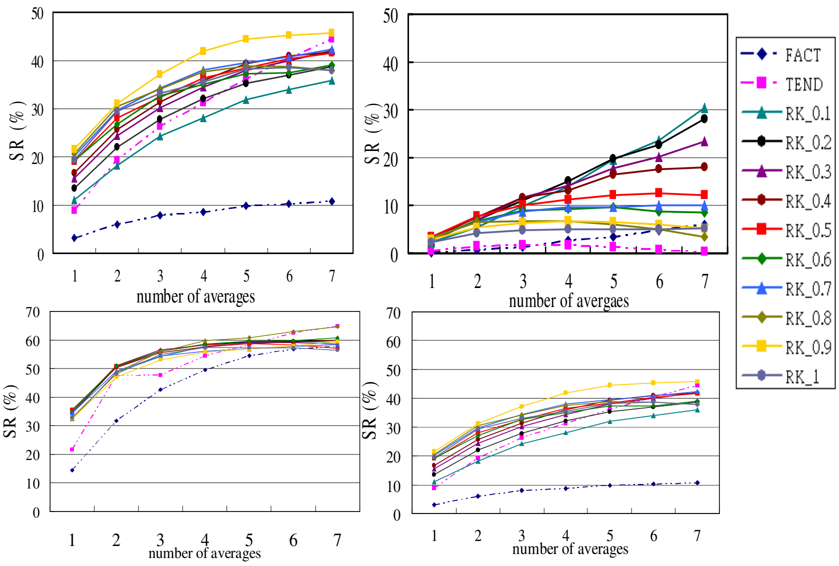

Fig 2. The SR of FACT, TEND and RK tracking through AC (top row) and ON (bottom row). The SR was calculated from middle ROI (left column) and end ROI (right column) respectively.