# Automatic Detection of Primary Motor Cortex and Corticospinal Tract Using Diffusion MRI Tractography:

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**Targeted audience:** clinicians and researchers in pediatric neurology. **Purpose**: Epilepsy is one of the most common neurologic disorders and impacts the quality of life of affected individuals. Surgical removal of the epileptogenic brain tissue is an option for children (and adults) whose seizures cannot be controlled with medications. Thereby, the primary motor areas have to be identified and preserved. The current gold standard for identifying the primary motor areas in young children who cannot follow functional tasks in functional MRI (fMRI) is electrical stimulation mapping (ESM) which, however, is invasive and often inadequately sensitive in young children[1]. Diffusion weighted imaging (DWI) is a powerful technique that does not require patient cooperation and may be used to investigate the white matter tracts such as cortico-spinal tract (CST), of which damage would result in deficits of contralateral motor function. We determined whether DWI tractography can provide automatic localization of cortical areas and white matter pathways associated with movement of mouth/lip, fingers, and ankle/legs, by testing a new method: a maximum *a posteriori* probability (MAP) classification[2] using neural connectivity of the cortico-spinal tract (CST) between the precentral gyrus (PCG) and posterior limb of internal capsule (PLIC). **Methods:** Subjects included 17 normally developing children (age: 10.0±3.3 years, 4.3-17.8 years, 9 boys) and 10 children with focal epilepsy (age: 12.3±4.9 years, 2.4-17.1 years, 6 boys). MRI scans were performed on a 3T GE-Signa scanner (GE Healthcare, Milwaukee, WI) equipped with an 8-channel head coil and ASSET. DW-MRI was acquired with a multi-slice single shot diffusion weighted echo-planar-imaging (EPI) sequence at TR = 12,500ms, TE = 88.7ms, FOV = 24cm, 128x128 acquisition matrix (nominal resolution = 1.89mm), contiguous 3 mm thickness in order to cover axial slices of the whole brain using 55 isotropic gradient directions with b= 1000s/mm$^2$, one b=0 acquisition, and number of excitations (NEX)=1. Whole brain fMRI data, to map the areas of mouth/lips, fingers, and ankle/legs, were also acquired from normally developing children using T2*-weighted EPI sequence at TR=2000ms, TE=30ms, matrix=64×64, FOV=24cm, thickness=4mm. An independent component analysis tractography combined with ball-stick model (ICA+BSM) tractography[3] was performed to identify unique CST pathways originating from mouth/lip, finger, and ankle/leg areas determined by fMRI. Group averaging of these pathways was performed across subjects in MNI space to construct homunculus representations of primary motor areas in PCG and PLIC, $P_{PCG}(x,y,z|C_i)$ and $P_{PLIC}(x,y,z|C_i)$, which represents the estimate of probababilty that a given fiber penetrates to a voxel (x,y,z) in PCG and PLIC of $C_{i=1}$ = "mouth/lip", $C_{i=2}$ = "finger", $C_{i=3}$ = "ankle/leg", repectively. We designed a maximum *a posteriori* (MAP) classifier that can make a classification of a given tract of CST pathways into four classes of interest, "mouth/lip", "finger", "ankle/leg", and "others", by transfering the maps of $P_{PCG}(x,y,z|C_{i=1,2,3})$ and $P_{PLIC}(x,y,z|C_{i=1,2,3})$ into individual subject's space via spatial deformation obtained between the subject's b0 image and MNI b0 template. The resulting maps were then used to approximate the conditional probability maps of a given voxel (x,y,z), $P(x,y,z|C_i)$ for i=1,2,3 for "mouth/lip", "finger", and "ankle/leg", respectively. Also, to decrease ambiguous classification, we defined an "other" class, $C_{i=4}$ for unnecessary false fibers. Since the conditional probability map, $P(x,y,z|C_i)$ defined the probability of voxel (x,y,z) belongs to the i-th class, the MAP classifier makes a decision of a given tract of CBT-CST pathways, $fiber_j$ into four classes of interest, $C_1$ = "mouth/lip", $C_2$ = "finger", $C_3$ = "ankle/leg", and $C_4$ = "other". $P(fiber_j|C_i) = \frac{P_{PCG}(x,y,z|C_i)+P_{PLIC}(x,y,z|C_i)}{2}$, i=1,2,3,4. if $P(fiber_j|C_{i=1,2,3}) \geq P_{th}$, $MAP(fiber_j)=argmax_i\ P(fiber_j|C_i)$ else, $MAP(fiber_j)=4$, where $P_{PCG}(x,y,z|C_i)$ and $P_{PLIC}(x,y,z|C_i)$ represent $P(x,y,z|C_i)$ of the $fiber_j$ penetrating at the voxel of (x,y,z) in PCG and PLIC, respectively. Since we assume an equal prior of $C_i$ for i=1,2,3, the argument of i having the most probable posteriori probability $P(fiber_j|C_i)$ greater than an arbitrary threshold, $P_{th}$ determines the membership of the $fiber_j$. Note that the $P_{PCG}(x,y,z|C_i)$ of the $fiber_j$ is highly correlated with the p-value of BOLD activation at (x,y,z) of the i-th fMRI cluster since every $fiber_j$ anatomically connects to PCG and PLIC. **Results:** The DWI-MAP classifier predicted the primary motor areas as localized with fMRI in normally developing children with high accuracy, 85% for mouth/lip, 96% for fingers, and 97% for ankle/leg at a p-value of 0.05 (**Fig 1**). Likewise, the DWI-MAP classifier revealed high accuracy for the CST fibers terminating in proximity to the primary motor areas, 93% for mouth/lip, 77% for fingers, and 70% for ankle/leg (**Fig 2**).

**Discussion and Conclusion:** This study provides preliminary evidence that an integrative tool can delineate not only the primary motor cortices but also visualize the underlying CST fibers for presurgical planning.

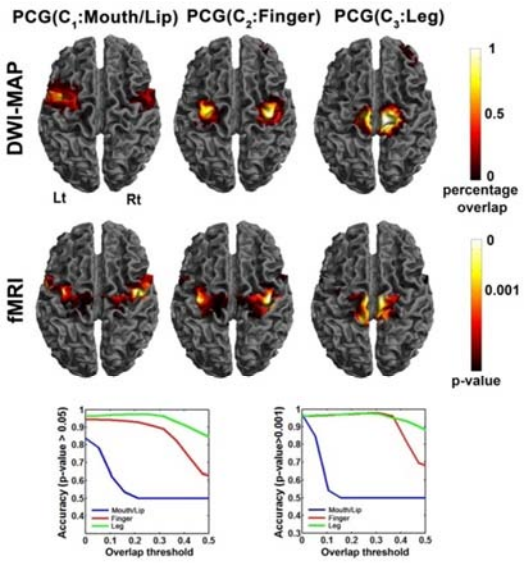


**Figure 1.** Comparison of DWI-MAP classification (top) and fMRI group analysis (middle) obtained from normal control group. In order to assess the accuracy of localization provided by DWI-MAP classifier, Receiver operating characteristic (ROC) curve was plotted at two different thresholds of p-value (bottom, left: 0.05 and right: 0.001).

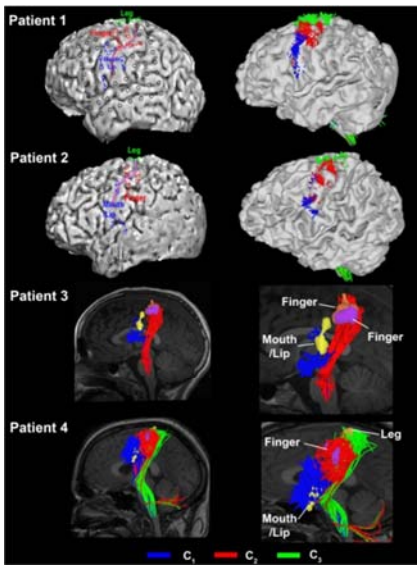


**Figure 2**. Automatic detection of primary motor pathways using DWI-MAP classifier obtained from four patients with focal epilepsy. Black circles on the three dimensional brain surface represent the locations of electrodes used for ESM. $C_1$: 'mouth/lip pathway', $C_2$: 'finger pathway', $C_3$: 'leg pathway' were obtained at $P_{th}$ = 0.30.

**References:** [1] Lesser RP, Crone NE, Webber WR. Subdural electrodes. Clin Neurophysiol 2010;121(9):1376-92. 2. DeGroot M. Optimal Statistical Decisions: McGraw-Hill, 1970. 3. Jeong JW, Asono E, Yeh FC, et al. Independent component analysis tractography combined with a ball-stick model to isolate intra-voxel crossing fibers of the corticospinal tracts in clinical diffusion MRI. Magn Reson Med. 2012;doi.10.1002/mrm.24487.