Sematotopic Organization of Motor Fibers in the Corticospinal Tract - A Combined fMRI and DTI Study

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Synopsis
The sematotopic organization of motor fibers in the corticospinal tract is poorly understood. However, it is known that superior-inferior white matter fiber tracts connect the motor cortex to the spinal cord. Although animal models have demonstrated sematotopic organization in primates, human data has been limited to patients with Wallerian degeneration. In this work, diffusion tensor imaging is used in vivo to track the corticospinal tract from the spinal cord through posterior limb of the internal capsule to different sections of the motor cortex that are identified using functional MRI.

Methods
MR-DTI data was acquired using a GE 3T scanner with 40 mT/m gradients using a 2D spin echo EPI acquisition with TE/TR = 100ms/10s. Data was acquired axially with a matrix of 128x128x60 and 1.7x1.7x2.5 mm³ voxel size, with 64 gradient directions [1] (b=815 s/mm²) and 9 acquisitions with no diffusion weighting (acquisition time 12 min 10s). The diffusion tensor was fitted using singular value decomposition with account taken of the differing SNR in the b=0 and b=815 s/mm² images.

A continuous tracking algorithm was used in which the path follows the principal eigenvector of the diffusion tensor on a sub-voxel level until the voxel edge is met, at which point the direction abruptly changes to that of the new voxel [2]. The tracking terminated when the voxel relative anisotropy dropped below a threshold value of 0.2. Seed voxels were placed in the posterior limb of the internal capsule.

Functional data was acquired using a gradient echo EPI acquisition with TE/TR = 40ms/2s. A matrix of 64x64x30 was used to cover the same volume as the DTI acquisition, but with half the spatial resolution in each dimension. Three paradigms were used to localize different areas of the motor strip: bilateral finger tapping, foot movement and tongue rolling. In each case, 20s of rest followed by 20s of activation were repeated 5 times followed by an additional 20s rest period. Data was analyzed by cross correlation with the expected activation pattern using STIMULATE [3].

Results
Figure 1 shows that the corticospinal tract can be followed over a length of 15 cm from the spinal cord to the motor cortex. Sematotopic organization of the fiber bundles making up the corticospinal tract is displayed in Figure 1. These different motor bundles do not intermix and stay separate through the entire length of the corticospinal tract followed in our experiment. In the posterior limb of the internal capsule, the motor fibers associated with movement of the feet (red bundle) are more posterior than the fibers that control the fingers (blue bundle). The sagittal view shows that the red bundle reaches the region of the cortex activated during the foot movement (light blue activation).

Discussion
The motor tract passing through different parts of the internal capsule fan out separately from each other. The functionally distinct motor fiber bundles may be successfully tracked from the cortex to the spinal cord. While the motor fibers can be seen to connect directly to the functionally activated area that controls the feet (Figure 1, sagittal view), it is difficult to follow the connection from the cortical area involved with motor control of fingers to the corticospinal tract. Closer inspection indicates that these motor fibers cross the longitudinal fasciculus. Since the tracking algorithm tracks only the principal axis of the fitted diffusion ellipsoid within each voxel, crossing fibers are more difficult for the tracking algorithm to follow.

Our in vivo data expands the understanding of the sematotopic organization of the corticospinal tract which has previously been reported in animal models [4] and stroke patients [5].

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References