Spatial Functional Distribution in the Corticospinal Tract at the Corona Radiata: A Three-dimensional Anisotropy Contrast Study

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Abstract

The spatial functional distribution of the nerve fibers was investigated in the corticospinal tract at the level of the corona radiata. Thirteen patients with corona radiata infarction underwent axial single-shot echo planar diffusion-weighted magnetic resonance imaging using a 1.5 Tesla scanner. Image analysis used the three-dimensional anisotropy contrast (3DAC) method to demarcate the nerve fibers in the corticospinal tract. Axial 3DAC images demonstrated the corticospinal tract as a distinct area indicating nerve fiber integrity in all normal hemispheres and infarction as a dark or black area in affected hemispheres. Seven patients with upper extremity-dominant motor dysfunction had infarction located in the middle one third of the corticospinal tract. A patient with lower extremity-dominant motor dysfunction had infarction in the posterior one third. Five patients with equal motor dysfunction in the upper and lower extremities had infarction in both the middle and posterior one thirds of the corticospinal tract. The recovery of motor dysfunction at one month follow up correlated with the location of the corticospinal tract injury on the initial 3DAC images. The findings of the 3DAC images provide an indicator of the pattern and the recovery from acute and chronic motor dysfunction in patients with corona radiata infarction.

Key words: three-dimensional anisotropy contrast, corona radiata, corticospinal tract

Introduction

Cerebral cortical function can be evaluated by various methods including direct electrical cortical stimulation,3) functional magnetic resonance (MR) imaging,1,6,23) and magnetoencephalography.14,25,34) Evaluation of subcortical function is also important, especially in patients with brain diseases involving the subcortical structures. Surgical strategy for patients with brain tumor or intracerebral hematoma may depend on the spatial relationship between the lesion and the subcortical structures.24) For example, the risk of surgery for removal of the lesion will depend on the proximity of the lesion to important subcortical structures such as the corticospinal tract. Functional recovery after surgery may be limited by previous subcortical injury, so preoperative evaluation of the subcortical integrity is desirable.1,6,23) Information about the potential for functional recovery from motor dysfunction early in the clinical course of patients with cerebral infarction may be useful for the timing of intervention and/or the method of rehabilitation.30,44) Despite the clinical importance of the subcortical structures, especially the corticospinal tract, few investigations of the functional topology have been reported.11,22,43)

Diffusion-weighted imaging (DWI) can be used to evaluate the subcortical white matter nerve fiber pathways.7,17,21,26,33,45) DWI is sensitive to the molecular motion of water molecules.29,42) Tissue molecular motion is restricted by nerve fiber membranes in the brain.5,15,16) The three-dimensional anisotropy contrast (3DAC) method32) is a reliable technique to visualize the anisotropy caused by the nerve fibers, and allows investigation of the corticospinal tract at the level of the internal capsule or corona radiata.18,19,33)
The present study investigated the relationship between the clinical symptoms and the location of infarction within the corticospinal tract at the level of the corona radiata by the 3DAC method.

Subjects and Methods

Thirteen patients, five females and eight males aged 49 to 76 years (mean 65 years), underwent the current imaging protocol as approved by the ethical committee of Kohnan Hospital after obtaining informed consent. MR imaging and MR angiography showed that five patients had right and eight had left corona radiata infarction, due to ipsilateral middle cerebral artery occlusion in two patients and lacular infarction in 11 patients. All patients underwent evaluation of the degree of motor dysfunction in the upper and lower extremities. Although some patients had additional sensory deficit, dysarthria, and/or facial nerve paresis, the present study concentrated on investigation of the motor dysfunction in the limbs. Motor dysfunction was classified according to the National Institute of Health stroke scale. The patients were evaluated twice, in the acute to subacute stage (1–14 days after the onset, mean 7.7 days) and in the chronic stage around one month after the onset.

All imaging was performed with a commercial 1.5 Tesla whole body scanner (General Electric Medical Systems, Milwaukee, Wis., U.S.A.) and the standard head coil, using a single-shot echo planar DWI sequence (repetition time = 4000 msec, effective echo time = 100 msec, matrix 128 × 128, field of view 24 cm, b value = 1000 sec/mm², slice thickness 8 mm, gapless). Sixteen axial slices were selected to cover the whole brain.

After acquisition, the DWIs were transferred to a Macintosh computer (Apple Japan Inc., Tokyo) and processed by the 3DAC technique with Photoshop software (Adobe Systems Japan, Tokyo). Later in the series, a 3DAC analysis program was introduced by one of the authors (H.K.) and used on a workstation (Advantage Workstation™; General Electric Medical Systems, Milwaukee, Wis., U.S.A.) as a subprogram of the Functool™ software (General Electric Medical Systems, Buc, France). The images obtained using the superior-inferior, left-right, and anterior-posterior diffusion gradients were first transformed into grayscale levels, and then color-coded using red, green, or blue, respectively. These colored images were then composited into a single color image. Identical intensities of the three colors, which indicate isotropic diffusion, appear as the color showing the greatest strength and direction of the diffusion gradient. Thus, nerve fibers running in the superior-inferior, left-right, or anterior-posterior directions appear as red, green, or blue, respectively, in the final image. Mixed colors indicate oblique orientation of the nerve fibers.

Results

Clinical and imaging characteristics of all patients are shown in Table 1. Seven patients had upper extremity-dominant motor dysfunction, five patients had equal degrees of motor dysfunction in the upper and lower extremities, and one patient had lower extremity-dominant motor dysfunction.

Representative 3DAC images of patients are shown in Fig. 1. The tracts that run in the vertical direction, like the corticospinal or corticopontine tracts, were depicted as red elliptical areas at the level of the corona radiata in normal hemispheres, and the infarcted lesion appeared as an abnormally dark or black area, suggesting decreased anisotropy in water diffusion, in all patients.

The infarct locations associated with the three types of motor dysfunction are illustrated in relation to the corticospinal tract in Fig. 2. Patients with upper extremity-dominant motor dysfunction had infarctions including the middle one third of the corticospinal tract. The patient with lower extremity-dominant motor dysfunction had an infarction confined to the posterior one third of the corticospinal tract. Patients with equal degrees of motor dysfunction in the upper and lower extremities had infarctions occupying both the middle and posterior one thirds of the corticospinal tract.

Follow-up examinations found that the patterns of motor dysfunction remained the same in individual patients, although the degree of motor dysfunction tended to improve. Patients with upper extremity-dominant motor dysfunction, associated with infarctions in the middle one third of the corticospinal tract, showed more clinical recovery in the lower extremity than in the upper extremity. In contrast, five patients with equal degrees of upper and lower extremity motor dysfunction, associated with infarctions in the middle and posterior one thirds of the tract, showed similar recovery, or no recovery, in both extremities. The patient with lower extremity-dominant motor dysfunction, associated with tract injury in the posterior one third of the corticospinal tract, showed recovery only in the upper extremity.
### Table 1 Motor dysfunction and infarction location

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Sex</th>
<th>Age</th>
<th>Side</th>
<th>Motor dysfunction* (at imaging, mean 7.7 days)</th>
<th>Location of infarction in the corticospinal tract</th>
<th>Motor dysfunction* (at follow up, mean 31 days)</th>
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<td>72</td>
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<td>8</td>
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*0: no drift, 1: drift, 2: some effort against gravity, 3: no effort against gravity. both: both middle and posterior one thirds.

### Discussion

The present study showed that the 3DAC method can clearly image damage to the corticospinal tract at the level of the corona radiata. The results suggest that the fibers for the upper extremities are located in the middle one third, and the fibers for the lower extremities are located in the posterior one third of the corticospinal tract at the level of the corona radiata.

Most previous evaluations of the corticospinal tract have been based on postmortem whole brain dissection or neuroimaging findings such as computed tomography (CT) or conventional MR imaging. Some information is available about the functional distribution in the corticospinal tract at the level of the internal capsule. Stereotactic stimulation study of patients with Parkinson’s disease and isolated internal capsule infarcts indicates that the corticospinal tract is located in the third quarter or one-third of the posterior limb of the internal capsule in the axial plane. The somatotopy for the upper and lower extremities within the corticospinal tract in the internal capsule has an anterior-to-posterior arrangement. However, the somatotopy in the corticospinal tract has not been well investigated at the level of the corona radiata. Previous evaluation of the relationship between infarction location in the corona radiata and contralateral limb paresis showed that the somatotopy of the corticospinal tract at the level of the corona radiata has an anterior-posterior arrangement for spatial distribution of face and upper and lower extremity functions.

Although CT and conventional MR imaging are useful to image the corona radiata, 3DAC imaging may be superior to demonstrate the relationship between the corticospinal tract within the corona radiata and the lesion itself. 3DAC imaging may be more useful to investigate the corticospinal tract at the level of the corona radiata than that at the level of the internal capsule because the tract is more widespread in the former.

Only one patient had lower extremity-dominant motor dysfunction in our series. The low incidence of lower extremity-dominant motor dysfunction may reflect the supply of the posterior part of the corona radiata by the perforating arteries from the posterior communicating artery, whereas the anterior part is supplied by the lenticulostrate arteries.

Our patients with corticospinal tract injury in the middle one third showed little recovery in the upper extremity but marked recovery in the lower extremity at follow up, indicating that the middle one third of the corticospinal tract at the level of the corona radiata is strongly correlated with upper extremity motor function. Similarly, our findings also suggest that the posterior one third of the corticospinal tract is involved in lower extremity motor function.

Although neurological deficits other than limb weakness were not separately analyzed, the present study indicates the potential of 3DAC imaging for evaluation of detailed functional distribution within...
Lesion locations and the three types of motor dysfunction. Infarct areas were traced in an axial slice at the level of corona radiata with the corticospinal tract indicated as the elliptical red area. Lesion definition could be achieved blind to the clinical information. *left:* A patient (Case 5) with upper extremity-dominant motor dysfunction. *center:* A patient (Case 8) with lower extremity-dominant motor dysfunction. *right:* A patient (Case 13) with equal motor dysfunction in the upper and lower extremities.

*Fig. 1* Three-dimensional anisotropy contrast images of representative patients with corona radiata infarction. The corticospinal tract appears as a red elliptical area beside the lateral ventricle in normal hemispheres. *left:* A patient (Case 5) with upper extremity-dominant motor dysfunction. *center:* A patient (Case 8) with lower extremity-dominant motor dysfunction. *right:* A patient (Case 13) with equal motor dysfunction in the upper and lower extremities.

*Fig. 2* Lesion locations and the three types of motor dysfunction. Infarct areas were traced in an axial slice at the level of corona radiata with the corticospinal tract indicated as the elliptical red area. Lesion definition could be achieved blind to the clinical information. *left:* Infarct areas in seven patients with upper extremity-dominant motor dysfunction. The lesions are located in the middle one third of the corticospinal tract. *center:* Infarct area in a patient with lower extremity-dominant motor dysfunction. The lesion is located in the posterior one third of the corticospinal tract. *right:* Infarct areas in five patients with equal motor dysfunction in the upper and lower extremities. The lesions are located in both the middle and posterior thirds of the corticospinal tract.
tomats.

3DAC imaging of damage to the corticospinal tract in the acute or subacute stage indicates little potential for recovery in the corresponding motor functions, whereas absence of injury to a part of the corticospinal tract indicates recovery of the corresponding upper or lower extremity motor function with time.

References


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Commentary

The authors are to be congratulated for having elaborated an imaging tool that allows demarcation of nerve fibers within the corticospinal tract. Data obtained by single-shot echo planar diffusion-weighted imaging were processed by the three-dimensional anisotropy contrast method using the Photoshop software. The color-coded images obtained with this method provided useful information about the spatial orientation and the somatotopic arrangement of nerve fibers within the corona radiata. The clinical significance of this noninvasive imaging method is obvious. It may greatly contribute to planning surgery in the vicinity of the corona radiata and has a prognostic value particularly in patients with intracerebral hemorrhage or infarction. Hopefully, the authors will continue their investigations in order to refine the method and to address other important clinical questions as well.

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The corticospinal tract fibers descend from the cortex to the internal capsule via the corona radiata. Somatotopic localization of corticospinal tract in the internal capsule is well studied, whereas few studies have been done in the corona radiata. The present authors studied the location of lesions within the corona radiata in thirteen patients with cerebral infarction using a new method, three-dimensional anisotropy contrast (3 DAC) method. They concluded that the fibers for the upper extremities are located in the middle one third, and the fibers for the lower extremities are located in the posterior one third of the corticospinal tract. The results seem to correspond well to the distribution in the corticospinal tract at the level of internal capsule. The value of this study is further increased by the introduction of the 3 DAC method which will serve as a useful method of future neuroanatomical study.

Inoue and co-workers investigated the spatial functional distribution of the nerve fibers in the corticospinal tract at the level of the corona radiata using axial single-shot echo planar diffusion-weighted imaging. In the present study, a three-dimensional anisotropy contrast method was used to demarcate the nerve fibers and to localize the area of infarctions in the corona radiata. The three-dimensional anisotropy contrast method was originally developed to visualize neuronal fibers and their directionality in the pyramidal tract using 3.0 Tesla high field MR imaging. In the present study, the authors applied this technique to visualize the involvement of the pyramidal tract of the corona radiata using 1.5 Tesla MR imaging and a standard head coil, and single-shot echo planar diffusion-weighted imaging sequences. The authors clearly demonstrated differences between the involved side and the normal side in patients with corona radiata infarctions located at the middle and posterior one thirds of the cortico-spinal tract. Their results were well correlated with the neurological recovery of the patients one month after the examination. For the next step, the authors should also examine the follow-up images of this three-dimensional anisotropy contrast method to determine whether it is useful to indicate the recovery from paresis of the patients.

Diffusion-weighted MR imaging is used in many neurological centers, but the three-dimensional anisotropy contrast method requires much computer processing to obtain the three-dimensional color images. Further improvement in the image resolution of the three-dimensional anisotropy contrast method and in the techniques as well as the software for the image processing will be required for this technique to become widely accepted.