

Fiber-Tracking Method Reveals Sensorimotor Pathway Involvement in Stroke Patients

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Background and Purpose—We tested the feasibility of a new MRI technique that provides visualization of the sensorimotor tracts in vivo in a group of stroke victims.

Summary of Report—Fourteen patients with small infarctions involving the white matter of the supratentorial brain were evaluated. Sensorimotor tracts on the lesional and contralesional sides were successfully depicted in all cases. The position of the sensorimotor tracts relative to the infarct was in good agreement with clinical symptoms. The overall sensitivity and specificity for sensorimotor tract involvement were 100% and 77%, respectively.

Conclusions—Our proposed fiber-tracking method was shown to be a clinically feasible technique that correlates well with clinical symptoms. (*Stroke*. 2003;34:e159-e162.)

Key Words: infarction ■ magnetic resonance imaging ■ magnetic resonance imaging, diffusion-weighted

Methods that allow early and accurate prediction of the degree of functional recovery after brain infarcts have been sought for many decades.¹⁻³ Clinical risk factors associated with poor functional outcomes have included advanced age, urinary incontinence, prestroke disability, dysarthria, and National Institutes of Health Stroke Scale score. Some authors have proposed that more effective predictions might be obtained through the use of a combination of clinical observations and imaging parameters such as the volume of ischemic tissue on MRI.^{2,3} This is a plausible conclusion because larger infarcts tend to be associated with a higher degree of functional loss. Functional recovery and the return to independent daily living depend largely on residual motor function in the extremities. Therefore, it is conceivable that information regarding the degree of motor tract involvement in ischemic lesions may contribute to the prediction of functional recovery.

Fiber-tracking images, generated from diffusion-weighted imaging (DWI) scans, are a recent advance in neuroimaging^{4,5} that may offer an objective assessment of the corticospinal tracts. This method uses a standard DWI scanning technique, along with a minimum of 6 diffusion-sensitizing gradient directions and higher image quality characterized by high signal-to-noise ratio, high spatial resolution, and reduced distortion. The major drawback of previous fiber-tracking techniques has been the lengthy examination time (often >30

minutes). Our method reduces this time to <5 minutes,⁶ making it applicable for stroke victims. This faster DWI scanning technique has been incorporated into our routine protocol for stroke imaging. In this feasibility study, we sought to validate this imaging technique for evaluating sensorimotor pathways in patients with acute/subacute infarctions. To simplify the interpretation of results, we limited our study to patients with small infarcts involving the white matter of the supratentorial brain.

Materials and Methods

Patient Population

This study was approved by an institutional review board, and written informed consent was obtained from each patient. We performed MRI on 215 consecutive patients who presented to our institute from August 2001 to July 2002 to be evaluated for acute/subacute brain infarction. Within this group, 14 patients had isolated small infarcts involving the white matter of the supratentorial brain. Demographic data for this group are summarized in the Table.

Imaging Methods

DWI scans for fiber-tracking were obtained in 4 minutes 24 seconds. DWI scanning was performed at the end of the routine stroke protocol used in our institute. Images were obtained with a 1.5-T whole-body scanner (Gyrosan Intera, Philips Medical Systems) with a gradient strength of 30 mT/m. A single-shot echo-planar imaging technique was used for DWI (repetition time/echo time,

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TABLE 1. Demographic Data and Lesion Location Correlated With Symptoms

Case	Age	Sex	Risk Factors				Time From Onset	Lesion Characteristics		Lesion Location Based on Fiber-Tracking Results	Symptoms	
			DM	HT	HL	Arrythmia		Location	Size (x × y × z), mm		Motor	Sensory
1	58, y	F	+	–	–	–	0, d	Int, capsule	6 × 6 × 6	Motor	+	–
2	91, y	F	–	+	+	–	0, d	Cent, semi	10 × 10 × 9	Moto/sensory	+	–
3	83, y	M	+	+	–	–	0, d	Cent, semi	3 × 3 × 3	Motor	+	–
4	75, y	F	+	+	+	+	0, d	Int, capsule	8 × 12 × 15	Motor	+	–
5	76, y	M	+	+	+	–	12, d	Int, capsule	10 × 12 × 12	Motor	+	–
6	83, y	F	+	–	+	–	0, d	Cent, semi	15 × 12 × 18	Motor	+	–
7	47, y	F	+	–	+	–	6, d	Int, capsule	6 × 9 × 12	Motor/sensory	–	+
8	83, y	M	–	+	+	–	0, d	Cent, semi	7 × 7 × 6	Motor	+	–
9	62, y	F	–	+	+	–	1, d	Thalamus	14 × 9 × 12	Motor/sensory	+	–
10	71, y	M	–	+	–	–	3, d	Cent, semi	10 × 8 × 9	Motor	+	–
11	57, y	M	–	+	–	–	13, d	Thalamus	11 × 12 × 12	Sensory	–	+
12	69, y	M	–	+	–	–	0, d	Cent, semi	12 × 12 × 15	Motor/sensory	+	+
13	48, y	M	+	–	–	–	1, d	Cent, semi	10 × 10 × 15	Motor	+	–
14	52, y	F	+	–	+	–	0, d	Int capsule	11 × 13 × 15	Motor	+	–

DM indicates diabetes mellitus; HT, hypertension; HL, hyperlipidemia; Int, internal capsule; and Cent semi, centrum semiovale.

6000/88 ms) with a motion-probing gradient in 6 orientations, a field of view of 230 mm, *b* values of 0 and 800 s/mm², and image averaging of 6 times. The recorded data points were 128×37 with the parallel-imaging technique.^{7,8} The parallel-imaging technique allows image reconstruction with half the encoding steps, the advantage of which lies in its reduction of the geometric image distortion that is unique to echo-planar imaging. The true resolution of the acquired images was equivalent to 128×74. A total of 36 slices were obtained with a thickness of 3 mm without interslice gaps.

Data Processing

We transferred the DWI data to an offline workstation for analysis. Diffusion tensor elements and anisotropy at each voxel were calculated, and color maps were created. Translation of the vectors into neuronal trajectories was achieved by a previously described method.⁴ The procedure for mapping neural connections is started by designating 2 arbitrary regions of interest (ROIs) in the 3-dimensional space. Tracking was terminated (stop criterion) when it reached a pixel with low fractional anisotropy (FA) and/or a predetermined trajectory curvature between 2 contiguous vectors. Fiber tracts that pass through both ROIs were designated the final tract of interest. All ROIs were determined by 2 authors (K.Y., O.K.) on a consensus basis. The traced fiber tracts included the corticospinal tract and sensory pathways. Total data processing time for the preliminary depiction of sensory and motor tracts on both sides was <20 minutes.

Results

Sensorimotor tracts of both normal and affected hemispheres were successfully depicted in all patients. Locations of involved tracts relative to the infarcts were categorized into 3 types—motor, sensory, or both—as illustrated in Figure 1. The relationships between affected tracts and the presence of motor or sensory symptoms are summarized in the Table. Twelve patients had lesions involving motor tracts; all 12 had motor symptoms. There were 3 instances of lesions involving sensory tracts, and all of these patients had sensory symptoms. Thus, the true positive rate (sensitivity) was 100% for

sensory and motor tracts combined. True negative results were observed in 10 tracts, and false-negative results were observed in 3 tracts. Thus, the true negative rate (specificity) was 10 of 13 or 77% for sensory and motor tracts combined. Two representative cases are depicted in Figures 2 and 3. The first patient (Figure 2) reported sudden onset of dysarthria. She did not have limb weakness or sensory symptoms. Fiber-tracking images revealed a slight lateral deviation of both sensorimotor tracts but no direct involvement, which was in good agreement with the patient’s symptoms. The second patient (Figure 3) had a rapidly progressive hemiparesis in the absence of sensory symptoms. The fiber-tracking result showed direct involvement of the motor tract but complete sparing of the sensory tract.

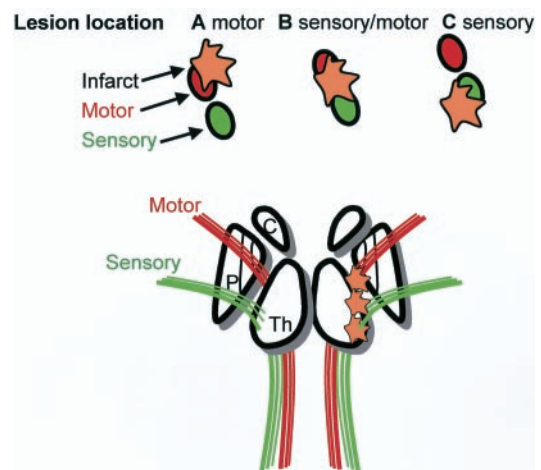


Figure 1. A, Location of the involved tract was categorized as motor (red), sensory (green), or both. B, Representative lesion at the level of the basal ganglia is shown as an example.

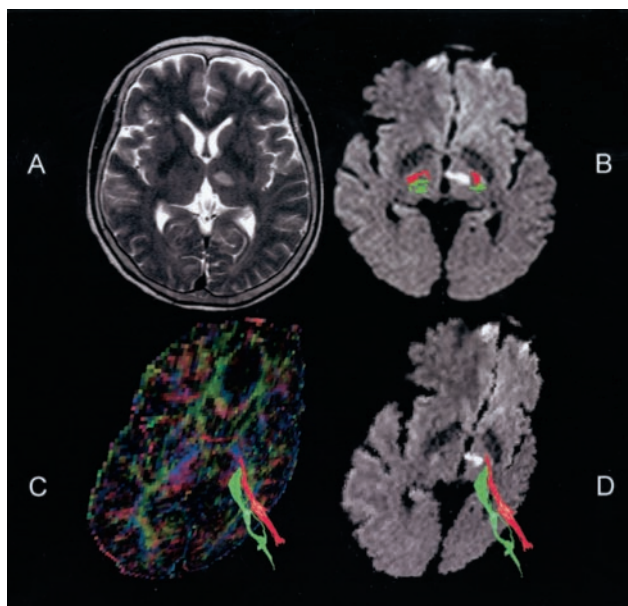


Figure 2. A 62-year-old patient with dysarthria. A, T2-weighted image shows a small hyperintense lesion involving the left thalamus. B, Fiber-tracking results overlaid on the DWI scan show slight lateral deflection of the left sensory (green) and motor (red) fibers. C, D, Fiber tracts reconstructed in 3-dimensional space are superimposed on the vector map (C) and DWI scan (D). Color-coded vector map (C) shows the direction of the local fibers, represented by red (left to right), green (anterior to posterior), and blue (superior to inferior).

Discussion

The present feasibility study provides support for the fiber-tracking method as a readily applicable technique for routine clinical stroke imaging. The method takes only an additional 4.5 minutes. The time for postprocessing of the DWI data to acquire preliminary fiber-tracking images is ≈ 10 to 20 minutes after completion of the examination. These times for data acquisition and postprocessing are thought to be acceptable for clinical use.

The relationship between the position of the infarct and clinical symptoms was highly correlated. For sensory and motor tracts combined, sensitivity and specificity were 100% and 77%, respectively. Degree of involvement, however, cannot be quantified from the current data. A method that allows quantification or accurate grading of tract involvement would be an important step and warrants further investigation. A simple method for estimating tract involvement with this technique is to compare lesional and contralesional tract anatomy. For instance, as shown in Figure 3, there is a slight laterality in the size of the motor tract so that the motor tract on the lesional side is smaller than on the contralesional side. An example of laterality in tract location is shown in Figure 2, in which there is a slight lateral deviation of the sensorimotor tracts on the lesional side.

It may be worthwhile to note that the fiber-tracking method was successful even when the infarction completely engulfed the tract. In some cases, the FA of the infarcted tissue may be maintained or even slightly increased at the acute/subacute stage,^{9,10} which makes it possible to perform fiber tracking at even the earliest stages of infarction. Because the FA de-

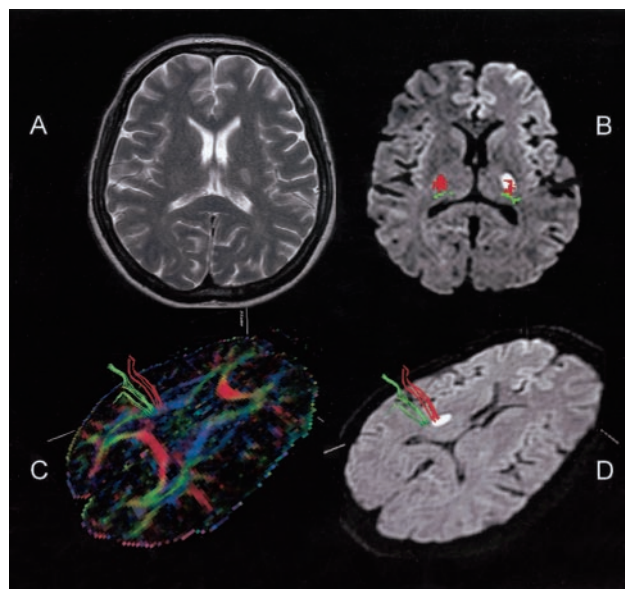


Figure 3. A 52-year-old patient with right hemiparesis. A, T2-weighted image shows a small hyperintense lesion at the left thalamus/internal capsule. From this T2-weighted image alone, it is difficult to discern whether the internal capsule or thalamus is involved. B, DWI with superimposed sensory (green) and motor (red) tracts reveals the lesion directly involving the left motor fibers, a finding well correlated with the patient's motor symptoms. C, D, Fiber tracts reconstructed in 3-dimensional space are superimposed on the vector map (C) and DWI (D). Notice that the tracts are observed from the cranial aspect and thus the infarct is shown on the opposite side compared with A and B.

creases with time, the fiber-tracking method might be more difficult to perform during the later, chronic stages.

Our ultimate goal in the clinical setting is to contribute to outcome predictions for stroke patients, and the ability to directly depict the sensorimotor pathways offers novel approaches. For example, measurements of FA along the tract may yield useful semiquantitative information to assess the degree of tract involvement.

Several limitations in the present study should be noted. First, the number of patients is small; thus, we did not attempt to correlate fiber-tracking results and severity of clinical symptoms. Second, we have limited our study to patients with small infarcts because the tract-infarct relationship would be most straightforward in these cases. A study that attempts fiber tracking for major territorial infarcts is currently in progress.

In conclusion, we have shown that the fiber-tracking method using DWI data is clinically feasible and that results can be correlated with clinical symptoms. Although the method is currently limited in depicting tract location, further research may facilitate outcome predictions for stroke victims.

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