Diffusion Tensor Imaging for Intracerebral Hemorrhage Outcome Prediction: Comparison Using Data from the Corona Radiata/Internal Capsule and the Cerebral Peduncle

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Background: Magnetic resonance–diffusion tensor imaging (DTI) was used to predict motor outcome for patients with intracerebral hemorrhage. We compared the predictive accuracy of data sampled from the cerebral peduncle with data from the corona radiata/internal capsule. This study included 32 subjects with thalamic or putaminal hemorrhage or both. *Methods:* DTI data were obtained on days 14 to 18. Mean values of fractional anisotropy (FA) within the cerebral peduncle and the corona radiata/internal capsule were analyzed using a computer-automated method. Applying ordinal logistic regression analyses, the ratios between FA values in the affected and unaffected hemisphere (rFA) were modeled in relation to motor outcome scores at 1 month after onset, assessed using the Medical Research Council (MRC) scale (0 = null to 5 = full). *Results:* For both cerebral peduncle and corona radiata/internal capsule, the relationships between rFA and MRC matched logistic probabilities. While cerebral peduncle rFA values had statistically significant relationships with MRC scores (upper extremity $R^2 = 0.271$; lower extremity $R^2 = 0.191$), rFA values for the corona radiata/internal capsule showed less significant relationships (upper extremity $R^2 = 0.085$; lower extremity $R^2 = 0.080$). When estimated cerebral peduncle rFA values were <0.7, estimated probability of MRC 0 to 2 was close to 85% for the upper and 60% for the lower extremities. Meanwhile, when estimated rFA values were >0.9, estimated probability for MRC 4 to 5 nearly equaled 50% for the upper and 60% for the lower extremities. *Conclusions:* FA values from within the cerebral peduncle more accurately predicted motor outcome and is a promising technique for clinical application. **Key Words:** Hematoma—paresis—prognosis—recovery—stroke.

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Intracerebral hemorrhage (ICH) often causes severe hemiparesis, resulting in poor functional independence in activities of daily living.[1,2] To facilitate the most effective rehabilitative treatment, outcome prediction is critically important.[3] Imaging data, such as computed tomography (CT) and magnetic resonance imaging (MRI) are often used for prediction. Diffusion tensor imaging (DTI), a newly developed MRI technique, has been found useful for evaluating neural degeneration affected by ICH and further applied for motor outcome prediction.[4-9]

DTI sensitively detects the direction of diffusion of water molecules, evidence that reveals the orientation of neural fibers.[6] This enables clinically useful characterization of

Wallerian degeneration of neural fibers. From the parametric data obtained from DTI, taking advantage of the much larger fractional anisotropy (FA) values of highly directional neural fibers, FA images are used to index Wallerian degeneration.[10]

The most prominent motor-related neural fibers are the corticospinal tracts. These are located within relatively small areas, including the corona radiata/internal capsule and the cerebral peduncle. The corona radiata/internal capsule area is located adjacent to the thalamus and putamen, which are common sites of origin of ICH.[1] By contrast, the cerebral peduncle is separate from the thalamus and putamen, and is less often directly affected by hematoma.

Recent studies using DTI have indicated that low FA values within the corticospinal tract are tightly associated with poorer motor outcome.[4,5] Other studies have investigated the quantitative relationship of FA and motor outcome.[6,7,9] Most of these studies have focused on neural degeneration, indicated by lower FA values, recorded in cerebral peduncle areas that are remote from hematoma. More commonly, however, motor-related neural fibers are directly affected by hematoma in adjacent corona radiata/internal capsule areas. Even so, no previous studies have systemically compared the clinical accuracy of FA values recorded in these two different areas of corticospinal tracts.

To more fully explore the clinical utility of DTI for outcome prediction, in this study, we compared the predictive accuracy of FA values from the cerebral peduncle with those from the corona radiata/internal capsule. Our results indicated that FA values recorded from the cerebral peduncle more accurately predicted motor outcome than those from the corona radiata/internal capsule.

Methods

Patients

The study population was comprised of stroke patients with ICH who were admitted to our hospital between January 2010 and March 2011. These patients were transferred to our hospital soon after onset. Typically, these patients underwent conservative treatment such as medication to reduce hypertension and, for some, necessary surgical removal of hematoma. During hospitalization, they also underwent physical therapy, occupational therapy, and speech therapy for a combined daily total of up to 180 minutes.

Criteria for inclusion in the database were no previous history of stroke, prestroke ability to walk unaided and functional independence in daily activities in the local community, and the need to receive inpatient medical treatment for >3 weeks. In this study, we also limited our sample to patients with thalamic or putaminal hemorrhage or both. Patients who subsequently required acute medical services (for recurrence of stroke, angina pectoris, or other coincidental condition) were excluded. For MRI safety, patients with any implanted metal items (e.g., artificial pacemaker) were also excluded. Patients (or, if more appropriate, relatives) provided written consent for inclusion in the study.

CT Acquisition

On arrival at our hospital, manifesting hemiparesis or other symptoms, the patients in the study population were suspected of stroke (either hemorrhage or ischemia) and underwent head CT scanning using an Aquilion 64SP scanner (Toshiba Medical Systems Corp., Tochigi, Japan). Imaging parameters were 120 kVp and 250 mAs, in-plane resolution was 0.86 mm $\times$ 0.86 mm, and slice thickness was 8 mm. The volume of ICH was estimated conventionally.[11,12]

DTI Acquisition

DTI was performed on days 14 to 18 after admission using a 3.0 Tesla MR scanner (Trio; Siemens AG, Erlangen, Germany) with a 32-channel head coil. Employing a single-shot echo-planar imaging sequence, the DTI scheme included acquisition of 12 images with noncollinear diffusion gradients ($b = 1000$ s/mm^2) and 1 non–diffusion-weighted image ($b = 0$ s/mm^2). We obtained 64 axial slices from each patient. The field of view was 230.4 mm $\times$ 230.4 mm, the acquisition matrix was 128 $\times$128, and the slice thickness was 3 mm without a gap, which resulted in voxel dimensions of 1.8 mm $\times$ 1.8 mm $\times$ 3.0 mm. Echo time was 83 ms and repetition time was 7000 ms. Besides DTI scans, we also obtained T1- and T2-weighted MRI scans for other diagnostic use. Including those scans, the total time for MRI acquisition was approximately 20 minutes per patient. Patients who were unable to stay still long enough to enable complete MRI acquisition were also excluded from our database.

Image Processing

The brain image analysis package FSL, comprising various tools including BET, FDT, FNIRT, FSLUTILS, and FSLVIEW, was used for image processing.[13] Using the FDT tool, to align all images in volumetric relation to the first image ($b = 0$ s/mm^2), DTI data were corrected for motion and eddy current distortion.[14] Then, extracerebral matter was excluded from the images using the BET tool.[15] Next, to evaluate tensor diffusion and calculate each patient's brain FA values, we analyzed DTI using the FDT tool (FA brain map). Using FNIRT,[16] we mapped these FA values to standard stereotaxic space (ICBM DTI-81 Atlas).[17] In this study, as recommended in the manual, to keep the transformation procedure simple, we employed the "standard tasks" settings for FNIRT.[16] Spatial transformations of the FA brain maps were confirmed by visual comparisons with images generated by FSLVIEW.[18] These image processing procedures were the same as in our previously published report.[9]