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Original Article

Patterns of Structural Reorganization of the Corticospinal Tract in Children With Sturge-Weber Syndrome

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ABSTRACT

BACKGROUND: Reorganization of the corticospinal tract after early damage can limit motor deficit. In this study, we explored patterns of structural corticospinal tract reorganization in children with Sturge-Weber syndrome. **METHODS:** Five children (age 1.5-7 years) with motor deficit resulting from unilateral Sturge-Weber syndrome were studied prospectively and longitudinally (1-2 years follow-up). Corticospinal tract segments belonging to hand and leg movements were separated and their volume was measured by diffusion tensor imaging tractography using a recently validated method. Corticospinal tract segmental volumes were normalized and compared between the Sturge-Weber syndrome children and age-matched healthy controls. Volume changes during follow-up were also compared with clinical motor symptoms. **RESULTS:** In the Sturge-Weber syndrome children, hand-related (but not leg-related) corticospinal tract volumes were consistently decreased in the affected cerebral hemisphere at baseline. At follow-up, two distinct patterns of hand corticospinal tract volume changes emerged. (1) Two children with extensive frontal lobe damage showed a corticospinal tract volume decrease in the lesional hemisphere and a concomitant increase in the nonlesional (contralateral) hemisphere. These children developed good hand grasp but no fine motor skills. (2) The three other children, with relative sparing of the frontal lobe, showed an interval increase of the normalized hand corticospinal tract volume in the affected hemisphere; these children showed no gross motor deficit at follow-up. **CONCLUSIONS:** Diffusion tensor imaging tractography can detect differential abnormalities in the hand corticospinal tract segment both ipsi- and contralateral to the lesion. Interval increase in the corticospinal tract hand segment suggests structural reorganization, whose pattern may determine clinical motor outcome and could guide strategies for early motor intervention.

Keywords: Sturge-Weber syndrome, corticospinal tract, motor deficit, reorganization, diffusion tensor imaging, tractography, longitudinal study

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Introduction

The corticospinal tract (CST) is one of the most important pathways of the brain, connecting the motor cortex to the spinal cord, enabling voluntary motor control of the limbs. About 80% to 90% of CST fibers cross to the contralateral side in the medulla and exert motor control of the contralateral limbs, whereas some fibers, especially those related to the trunk and proximal upper extremity motor functions, remain uncrossed.[1,2] Although the normal anatomy of the CST is well studied, we have less knowledge about its structural development and reorganization after brain injury. According to data obtained using transcranial magnetic stimulation (TMS) in patients with unilateral CST injury, the brain can use several different compensatory

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strategies to restore motor functions.[3] One of these mechanisms involves the ipsilateral CST projections that can take over control of the paretic limbs to a certain extent.[4,5] If a unilateral CST injury occurs during early life, the ipsilateral projections may remain permanent instead of being eliminated.[4,5] If CST injury is inflicted at an older age (e.g., in adult stroke patients), the compensatory recruitment of remaining (although limited) ipsilateral CST projections can occur.[5] Occasional recovery of the affected CST has also been well documented.[3]

Our knowledge about the CST has been expanded by radiographic information provided by diffusion tensor imaging (DTI). DTI enables the in vivo study of neural tracts based on water diffusion along the axons.[6-8] Although DTI has been widely used to study the anatomy and reorganization of the CST after injury, the current techniques mainly investigate the CST as a whole, disregarding possible differences in the segments related to the upper vs lower limb motor control. Our group has recently developed and validated a novel DTI approach to separate and quantify function-specific segments, associated with hand vs leg vs face movements, of the CST.[9-12] In the present longitudinal study, we used this approach in a small pediatric population with early unilateral brain injury and motor deficit resulting from Sturge-Weber syndrome (SWS). SWS is characterized by facial port-wine birthmarks and leptomeningeal vascular malformation.[13] Clinical symptoms, including motor deficit, cognitive decline, and seizures, commonly manifest in the first year of life.[14] Because the leptomeningeal involvement and underlying brain damage is limited to one hemisphere in 85% of the cases, SWS is an excellent clinical model for studying reorganization of the brain, including the CST, after an early (often ongoing) postnatal unilateral brain injury.[15,16] In this study, we hypothesized differential changes in the CST segments associated with hand vs leg motor control and also looked for patterns of structural reorganization and their relation to clinical symptoms.

Materials and Methods

Study subjects

Five children (three boys, two girls) with unilateral SWS and some degree of motor dysfunction and 24 control children were selected for the study. All SWS children participated in a prospective, longitudinal clinical and neuroimaging study of children with SWS approved by the Wayne State University Human Investigations Committee. Parents signed the informed consent form. For each patient, magnetic resonance (MR) scans were acquired at two time points, at least 1 year apart (see clinical data in the Table). Evaluation of motor functions was performed on the day of the MR scans. Clinical assessment of gross motor functions was performed by a pediatric neurologist (H.T.C.), and presence and severity of hand weakness (with or without grasp) was noted. Gross motor functions were also assessed via standardized semistructured interview (Vineland Adaptive Behavior Scales, 2nd ed.), and, in children with no gross motor abnormalities, fine motor dexterity was also assessed by Purdue Pegboard task (30 months to 5 years of age) or the Grooved Pegboard task (older than 5 years of age) by a certified pediatric neuropsychologist (M.E.B.).[17-19] MR DTI data in the SWS patients were compared with age-matched control groups of 4 normal subjects for each individual SWS patient, with a total of 24 control children (three normal groups at baseline and three at follow-up; because of similar age, patients 1-3 shared the same control groups for both the first and the second time point, see Table). These children were selected from a clinical DTI database of children who underwent MR imaging at our hospital because of a history of seizures. None of the control children had structural lesions on MR imaging and none had motor impairment or significant developmental delay based on their clinical reports. We had permission form the Wayne State University Human Investigations Committee to use the clinically acquired MR imaging scans from these children after deidentification.

MR imaging acquisitions

For children with SWS, a Siemens MAGNETOM Trio 3T scanner (Siemens Medical Solutions, Erlangen) with a standard head array coil

TABLE.
Clinical data of the study subjects

Patient	Sex	Age at First Neurological Symptoms	Age		SWS Angioma Location	Additional MRI Findings	Hand Motor Functions		Control Groups	
			Baseline	Follow-up			Baseline	Follow-up	Mean Age ± SD	
1	M	0.3 yr	1.5 yr	2.5 yr	L-FrTPO	L-FrTPO atrophy	R paresis	Same, but grasp improved		
2	F	0.4 yr	1.8 yr	3.1 yr	R-TPO	R-Fr atrophy	L paresis	Same, but grasp improved	1.5 ± 0.6 yr	2.8 ± 0.3 yr
3	F	0.1 yr	1.7 yr	2.7 yr	R-TPOFr	Limited R-Fr atrophy	L paresis	Improved; fine motor		
4	M	0.9 yr	4.4 yr	5.4 yr	R-P	R-P atrophy	Mild L fine motor	Normal	4.3 ± 0.3 yr	5.5 ± 0.6 yr
5	M	7.0 yr	10.0 yr	12.0 yr	R-TPO	R-TPO atrophy, small subcortical infarct	L fine motor	L fine motor	9.4 ± 0.5 yr	12.7 ± 1.6 yr

Abbreviations:
F = Female
Fr = Frontal
L = Left
M = Male
O = Occipital
P = Parietal
R = Right
SD = Standard deviation
SWS = Sturge-Weber syndrome
T = Temporal