Diffusion Tensor Imaging and Fiber Tracking in Delineating the Degeneration of Motor and Sensory Pathways in Periventricular Leukomalacia

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Introduction

Periventricular Leukomalacia (PVL) is a major neuropathologic form of brain injury encountered in survivors of premature birth. The primary long-term neurological findings include spastic diplegia affecting legs more than arms, and less commonly, hemi or quadriplegia. Conventional structural MR imaging cannot differentiate the exact white matter pathways involved in the degenerative process associated with this condition. Diffusion Tensor Imaging (DTI) and Fiber Tracking open a new and robust way to evaluate not only the corticospinal tracts (CST) but also the sensory thalamocortical connections in this clinical situation.

Methods

We recruited 5 cerebral palsy patients of 9 to 15 yrs (3F, 2M, mean age 12 yrs), with known PVL and structural changes detected on conventional MRI and 5 age and sex matched control subjects for the study. The patient group included four children with hemiparesis and one with quadriparesis and all underwent a thorough neurological evaluation by a Pediatric Neurologist. All of them had normal intelligence.

MR data acquisition and post processing

All the patients and the controls underwent MR examination including T1 weighted 3D TFE, T2 FLAIR and DTI (Diffusion weighted single shot echoplanar imaging, performed along 15 directions with data matrix = 96 x 96; field of view = 200 x136 mm, TR = 1758 ms and TE = 64 ms. Slice thickness was 2 mm without gaps and the b values were 900 s/mm^2 and 0 s/mm^2) on a 1.5T magnet (Intera, Philips, Best, the Nederlands). Eigenvalues and eigenvectors of diffusion tensors were calculated using multivariate fitting. Anisotropy maps were obtained using fractional anisotropy (FA). In DTI based color maps, vector elements of an eigenvector associated with the largest eigenvalue were assigned to red (x element, left-right), green (y, anterior-posterior) and blue (z, superior-inferior). Intensities of maps were scaled in proportion to FA. Tract reconstruction was done with Fiber Assignment by Continuous Tracking (FACT) with a termination criteria of FA smaller than 0.25 or the angle between two connected pixels smaller than 0.75. Fibers for both CST and the posterior thalamic radiations were developed bilaterally. In addition the cross sectional area of the CST on both sides compared with the total cross sectional area of the brainstem was measured on color maps at upper pons level and a ratio was calculated.

Results

There was significant reduction in the number of descending fibers in the CST on the affected side on all 4 hemiparetic patients compared to the opposite side and fibers in normal volunteers on either side. There was also a marked reduction in the ratio of area of CST to the area of brain stem at upper pons level on the affected side (0.032 +/- 0.007) compared to the opposite side on the same patient (0.089 +/- 0.006) and normal volunteers on either side (0.084 +/- 0.008) (fig 1). This correlated very well with the side and extend of the Periventricular lesion detected on structural MRI scans (T1 and FLAIR). However there was no direct correlation between the clinical severity and the MRI findings in at least two patients. In addition there was reduction in the number of fibers in the posterior thalamic radiation (sensory) in at least 3 of the hemiparetic patients (fig2). In the fifth patient with quadriparesis and bilateral Periventricular lesion there was bilateral reduction in size of the CST and the sensory fibers.

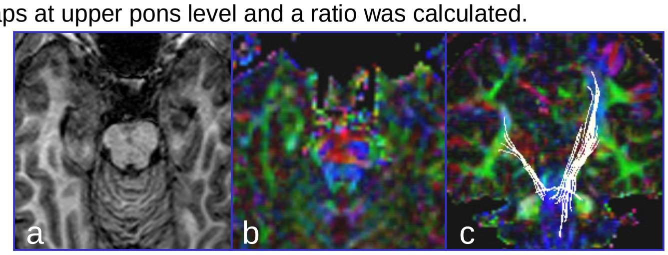

Fig 1: Wallarian degeneration of the corticospinal tract due to right sided Periventricular lesion. Note the marked reduction in number of fibers and the area of CST on the right side at upper pons level.

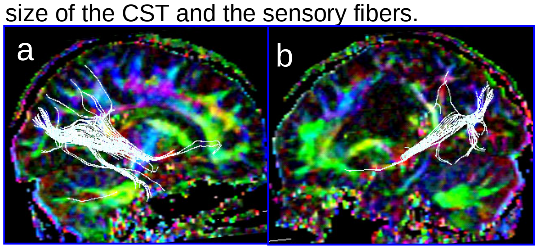

Fig 2: Posterior Thalamic Radiation- note the Marked reduction in fibers on the left side (b)

Discussion

PVL has emerged as a major form of brain injury in premature infants. Routine MR sequences cannot delineate precisely the white matter fiber tracts involved in these patients. Diffusion Tensor Imaging and Fiber tracking offer a new and robust method to solve this problem. Today DTI appears to be the only clinically feasible technique to tract the white matter pathways in vivo. In the four patients with spastic hemiparesis, marked rarefaction of the descending corticospinal tracts due to Wallarian degeneration was noted on the affected side, which was proportional to the size of the periventricular white matter lesion. Also sensory tracts like the posterior thalamic radiation was involved in at least 3 of them, suggesting its role in the pathogenesis of PVL, notably spasticity. Two patients with exactly similar clinical grading of spasticity and motor weakness had differing degrees of brain damage detected on MRI. This could be explained by the difference in brain plasticity. The fifth patient with bilateral lesion and quadriparesis, both the CST and the sensory tracts appeared to be involved on visual impression compared to normal volunteers, however objective analysis could not be performed due to obvious reasons.

Reference

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