Application of the Combined DTI and fMRI for Spinal Cord Assessment

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Synopsis

Two different Magnetic Resonance Imaging methods were combined to develop a novel method for assessing the injured spinal cord. In the present work this method was developed and tested in non-injured rats. Diffusion Weighted Imaging (DWI) was used for the investigation of anisotropic water diffusion in neuronal fibers while functional Magnetic Resonance Imaging (fMRI) was used for the evaluation of neuronal activity of the spinal cord. The acquisition of combined DTI and fMRI in one scan provides complete information about the morphological and functional condition of the cord essential in the study of spinal cord injury.

Introduction

A spinal cord injury results in partial or complete loss of motor and sensory function as a result of destruction of ascending white matter tracts, direct damage to spinal gray matter, and loss of inputs from descending brain pathways. After the injury occurs the overall condition of the cord can improve as a result of reduced pressure on the cord, plasticity and/or healing, or it can worsen with further deterioration of damaged neurons, formation of scar tissue, etc. The full characterization of the extent of injury and the determination of the changes that occur over time or with treatment are therefore very challenging. The long-term goal of the work we are carrying out is to develop an effective method for the complete assessment of the injured spinal cord. It is known that DTI provides a definition of the extent of axonal and gray matter changes enabling localization of the injury site [1], whereas fMRI can provide a map of altered neuronal activity as it changes with injury and recovery [2]. Although these two techniques are complimentary, they have not yet been combined or correlated in the same subject. As a first step forward the application of both fMRI and DTI in the assessment of the spinal cord injury we studied the correlation between DWI and fMRI data in the normal spine. To perform such analysis rats were used and functional and diffusion-weighted images were taken of spinal cord close to the most common injury site, namely the upper and lower thoracic lumbar spine.

Materials and Methods

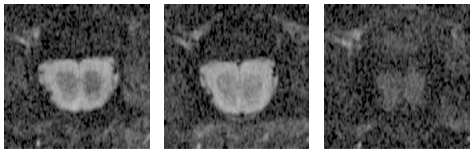
Animal preparations: Sprague Dawley rats (250-300g) were used. The animals were anesthetized with 2-2.5% isoflurane and intubated. The femoral artery and vein were cannulated for blood gas measurements, blood pressure monitoring, and drug delivery. The rectal temperature was monitored and maintained at 37+- 0.5˚ C using a temperature controlled water-heated pad. Anesthesia was gradually switched from isoflurane to alpha chloralose (initial dose of 80 mg/kg, maintenance dose of 40mg/kg) to reduce suppression of neuronal activity.

Experimental Setup: A 9.4T/21cm horizontal bore magnet (Magnex, UK) with Avance console (Bruker, Germany) was used, with a 400 MHz quadrature 5 × 7cm surface coil for signal transmission and reception. Data were analyzed using custom made software [3,4,5].

Experiment design: DWI and fMRI were obtained at the levels of 10th thoracic vertebrae to the 2nd lumbar, to span the lumbar segments of the spinal cord. All imaging sequences were gated with the respiration. For diffusion measurements, standard SE images were acquired with diffusion gradients applied in 3 directions (parallel and perpendicular to the spinal cord) with gradient b-values of 1000s/mm^2 (TE=40ms, TR=900ms, matrix size128 x 128, FOV 2 cm, slice thickness of 1.6 mm, NA=8). A RARE sequence (TE=4ms, TR~4sec, 128x64 matrix, slice 1.6mm, FOV 2x2cm) was used for fMRI studies. ***Stimulation paradigm***: electrical hindpaw stimulation was applied (2.5 Hz, 6mA, 0.3msec) in accordance with the stimulation paradigm which was a block design consisting of 5 cycles of an on-off paradigm. The total acquisition time was about 5 minutes.

Results

High quality fMRI and DTI images were obtained in all animals studied, after technical development of the methods. The longitudinal diffusion D_L=Dzz, transverse diffusion D_T=(Dxx+Dyy)/2 and isotropy index ID = D_T/D_L were calculated. DT images show anisotropic water diffusion at the different levels of the spinal cord [Fig1]. fMRI data show different levels of activity within the spinal cord [Fig.2 and 3]. This preliminary study demonstrates that both DTI and fMRI can be carried out in a practical interleaved manner to enable eventual correlation with the degree and the extent of injury. This preliminary study shows the potential of combined fMRI and DTI in the same animal for the assessment of the spinal cord, and provides a baseline for comparison in studies of spinal cord injury to follow.



A B C

Fig. 1. .An example of the spinal DTI (diffusion gradients in: A - read, B- phase, C- slice direction)

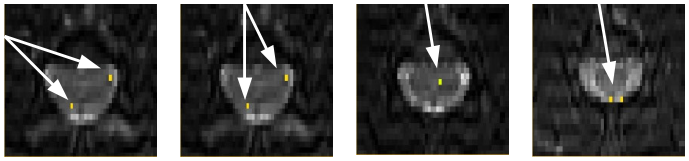


Fig 2. An example of spinal fMRI in the same animal as in Fig 1 from different levels of spinal cord from thoracic to lumbar spinal cord segments (p-value=0.001). Arrows indicate areas of activation.

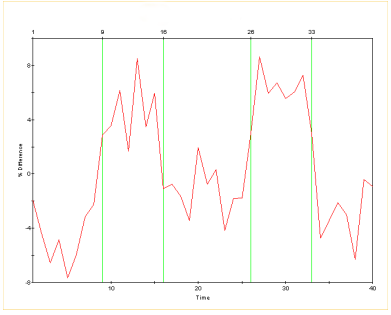


Fig. 3 Time course of the fMRI experiment shown in Fig 2.

References

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