DTI Detection of Symptomatic and Asymptomatic Injury
Due to Repetitive Head Blows

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Introduction

Diffusion tensors computed from diffusion-weighted imaging (DWI) have been used to detect white matter (WM) abnormalities in mild traumatic brain injury (mTBI) patients, including those who have histories of concussion from sport (e.g., [2]). Recent work using fMRI and neurocognitive testing [1,4,5] has confirmed the postulation [3] that blows that do not result in clinical diagnosis of concussion (typically requiring overt deficits) can still produce changes in brain function. Further, incidence rates of cognitive impairment do not appear to be related to history of concussions [2], suggesting that accumulated sub-concusive blows may be a critical factor in eventual development of cognitive deficits. Detection of pre-symptomatic changes could be critical to prevention or treatment of neurodegenerative diseases, such as chronic traumatic encephalopathy (CTE), associated with repeated blows to the head.

Methods

Participants

68 male football players (range: 14-18 years) and 21 age-matched controls (non-contact sport athletes) participated in the study. Subjects were recruited from two local high school football teams, over three seasons. Subjects who participated in more than one season were treated independently, resulting in 264 total scans. Also 3 symptomatic subjects with diagnosed concussions were included in the study as a reference for symptomatic injuries.

Magnetic Resonance Imaging

All imaging was performed using a GE 3T Signa HDx and a Nova Medical Inc. 16-channel brain array. Subjects participated in pre-season, in-season, and post-season sessions (see [5]). DWI data (b=1000 s/mm²) were acquired over the period of the study using two sets of diffusion angles: (1) 25 angles for Season 2 and Controls; (2) 30 angles for Seasons 3, 4 and Symptomatic Subjects. Note that in1 and in2 refer to in-season scans performed in first and second halves of season, respectively.

Image Processing

FA values were extracted from DWI images after eddy-current correction. A non-linear transformation was applied to the 25 angle data to match the FA distribution of the 30 angle data, as derived from a population of 17 college-aged volunteers undergoing DWI with both angle sets. FA images were co-registered using non-linear registration with a FMRIBB86 FA template, aligned into the 1x1x1mm MN152 standard space by affine transformation, and a white-matter mask was applied.

Statistical Analysis

Due to limited control size (N=21; 30 total measurements), the mean and standard deviation of the general population cannot be well-characterized. Therefore, a bootstrapped z-score (zBS) [6] was used to characterize deviant and non-deviant measurements: zBS=(μ(M)−μ(u))/STD(u), where μ is the subject's FA measurement at the voxel; μRB where μ is the mean of a set of uniformly sampled data with replacement for b = 1, ..., B; and B is the number of bootstrapped samples (here B=1000). We have assumed that the resulting errors in FA values due to misregistration are smaller than FA changes due to injury or aggregate head blow history.

Results

Conclusions

• The zBS distribution analysis detects changes in FA in individuals with a history of concussive and/or sub-concussive head trauma. The analysis suggests that different WM injuries are associated with the presence or absence of concussion symptoms (Figure 5).

• Team-based differences (Figure 2) coupled with an apparent FA recovery (Figure 4) suggests that technique instruction and the associated contact-sport experience prior to high school can affect the integrity of white matter in the brain of high school athletes. Recovery suggests healing occurs in the months following the end of exposure, but accumulation over multiple years is likely to be the cause of the differential distribution of FA in football players, relative to non-contacts sport controls (Figure 2).

• These findings suggest the proposed DTI analysis can be an effective means of detecting pre-symptomatic white matter damage associated with repetitive blows to the head.

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