SUPPLEMENTAL MATERIAL

Supplemental Method:

Head Impact Surveillance

The accelerometers were oriented in the left inside crown of the helmet, approximately 45-75 degrees from the horizontal plane of the helmet and roughly in line with the vertical axis of the helmet. Prior to the initial exposure (i.e., first practice), each accelerometer was calibrated according to device specifications and relative to the placement of the sensor in each helmet. During each practice and game, the athletic trainer activated the accelerometers and monitored the real-time telemetry transmission of impact data displayed on a laptop. The start and end times of each exposure were recorded, and only accelerations recorded within that time window were aggregated from each participant's accelerometer data. At the conclusion of each practice session or game the accelerometers were removed from the helmets and the data from that session was uploaded to the study database. The accelerometers were then charged and returned to each helmet prior to the start of the next session.

Participants based on ITT Design

As described in the Method section and from the flow chart in the Figure 2 in the Main document, 62 high school varsity football athletes were recruited into the study. These 62 athletes were initially assigned into two groups: (1) Non-collar group (n=30); (2) Collar group (n=32). Eleven athletes from the non-collar group were excluded for missing post-season MRI (n=3), season ending injury (n=1) and head motion during the scan (n=7). Seven athletes from the collar group were excluded due to excessive head motion (n=5), contraindication in MRI (n=1), and season ending injury (n=1). Therefore, based on the ITT design, 44 athletes (19 in the Non-collar group; 25 in the collar group) were included in the analysis and demonstrated 90.6%

daily compliance (days of wear during impact practice or competition/days possible) to collar usage as prescribed by the study protocol.

Statistical Analysis

The data analyses based on the ITT design were identical to that used in the per protocol design except for the difference in the subject assignment. We first tested the pre- to post-season change in DTI in the two study groups separately. We also tested the group difference of pre- to post-season DTI change using independent 2-sample t-test. White matter areas that showed significant results were localized and analyzed for their association between DTI change and impact experienced. During the initial analysis, a series of potential confound factors, including the time between last session and the post-season scan, the total number of impact, the cumulative G-force experienced, the average G-force in each impact, as well the different cut-off levels of G-force for the three impact related variables (>20g, >50g, >100g), were tested for their effect on the group difference of pre- to post-season DTI change. Since none of these factors showed any significant effect (same as observed in the per protocol analysis), the final data analyses were reported without any of these factors included as covariate. Details for the data processing and analyses can be found in the Method section in the main document of the study.

Supplemental Results

Head Impact Surveillance

Figure S1 shows the distribution of number of impacts at different *g*-force indices in the two study groups based on the ITT design. Because of the difference in the number of athletes (19 vs. 25), the collar group had a slightly larger number impacts than the non-collar group at many g-force range ($p<0.05$). However, the group difference became in-significant after the group size

was taken in to account (when compared based on number of impact per subject at different G-force interval) **Table S1A, S1B and S1C.**

Cross-sectional Group Comparison of Pre-season DTI Metrics

Using the ITT design, no significant difference was found in any of the four DTI measures in any WM region between the two groups.

Longitudinal Change and Group Difference in Pre- to Post-season DTI Metrics

Significant pre- to post-season decrease in MD, AD, and RD (corrected $p<.05$) was found in extensive WM areas in the CTRL group (**Figure S2A**). No statistically significant longitudinal change was found in any DTI measure in any WM region in the collar group (**Figure S2B**).

In the non-collar group, all 19 athletes decreased in AD (percentage of reduction = 2.47%±1.02%, **Figure S3A**). Within the same areas, 10/25 athletes in the collar group decreased in AD (1.16%±0.79%), 14/25 athletes increased in AD (1.01%±0.63%), and 1/25 did not change, with an overall average reduction of AD at the level of 0.10%±1.26% or absolute change of AD to be 1.03%±0.71%, (**Figure S3B**). No significant DTI change was found in any WM area in the collar group.

Based on two-sample *t*-test, the group difference of pre- to post-season DTI change was found in extensive WM areas including the genu, body and the splenium of the corpus callosum, the anterior, superior, and posterior corona radiate, and the superior longitudinal fasciculus (**Figure S4, Table S2**).

Correlation between Pre- to. Post-season DTI Change in the no-collar group and Head Impacts

Among the WM regions with significant group difference of AD **(Table S2)**, the superior longitudinal fasciculus in the was found to have significant correlations between the pre- and

postseason AD reduction and total number of impact (r=0.48, n=19, p=0.014). No other WM region was found to have significant correlation between change in DTI measures and impact measures.

Table S1.

A. Average (±SD) # of Hits at Impact Level

	20G	50G	100G	150G	200G
No Collar	794.42 ± 530.10	130.79 ± 98.32	12.79 ± 8.69	1.89 ± 2.31	0.16 ± 0.50
Collar	901.42 ± 573.68	162.21 ± 116.15	20.21 ± 21.40	2.58 ± 3.11	0.50 ± 1.18

B. Average (±SD) of Total G forces experienced above Impact Level

	20G	50G	100G
No Collar	29086.54 ± 19590.10	9389.69 ± 6899.36	1596.98 ± 1115.43
Collar	33974.58 ± 21437.06	11973.57 ± 9156.67	2637.75 ± 2588.46

C. Average G Force of Hits above Impact Level

	20G	50G	100G
No Collar	36.59 ± 2.97	72.19 ± 3.76	124.18 ± 9.68
Collar	38.06 ± 4.13	71.87 ± 5.44	125.66 ± 8.16

Table S2. The WM regions corresponding to the brain regions with significant pre- vs. post-season DTI changes.

	Volume (mm^3)	WM region located
Region 01	73	Genu of corpus callosum
Region 02	475	Body of corpus callosum
Region 03	245	Splenium of corpus callosum
Region 04	2	Anterior corona radiata R
Region 05	76	Anterior corona radiata L
Region 06	202	Superior corona radiata R
Region 07	64	Superior corona radiata L
Region 08	70	Posterior corona radiata R
Region 09	159	Posterior corona radiata L

Region 10	12	Superior longitudinal fasciculus R
Region 11	22	Superior longitudinal fasciculus L

Figure S1. Results based on ITT design. Histogram showing the distribution of total number of impacts at different G-force. A: non-collar (CTRL) group, 19 athletes; B: collar group, 25 athletes.

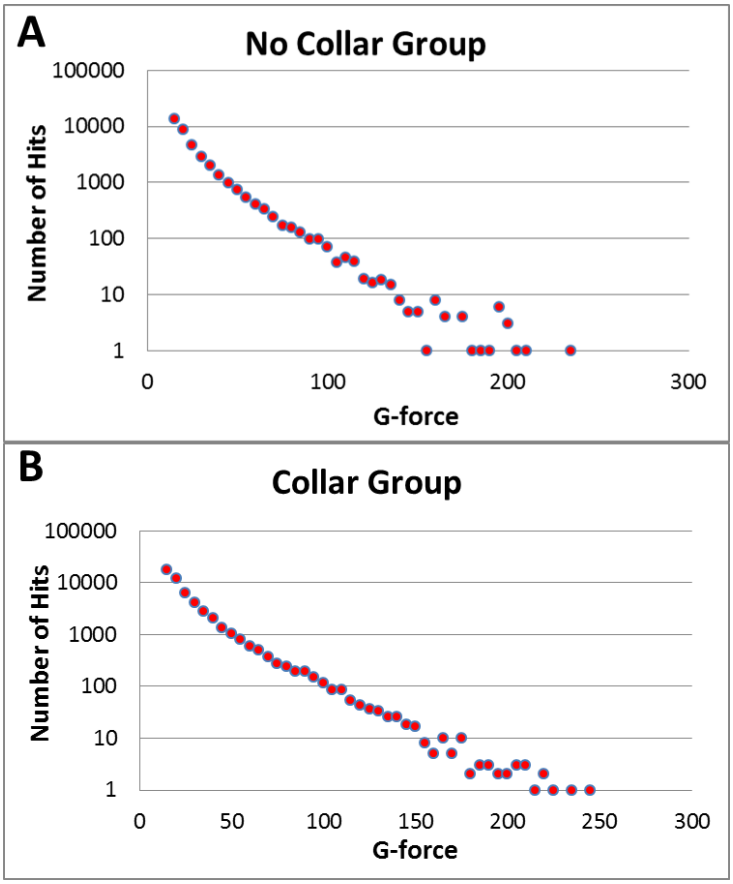

Figure S2, Results based on ITT design A: non-collar group. White matter regions with significant AD reduction at post-season in the CTRL group. The significant regions (blue- light blue regions, p<.05, FWE corrected for multiple comparisons) were overlaid on to the white matter skeleton (green) and standard T1-weighted image in MNI 152 space (gray scale). B: Collar group. AD axial diffusivity; FWE: familywise error rate; MNI: Montreal Neurological Institute.

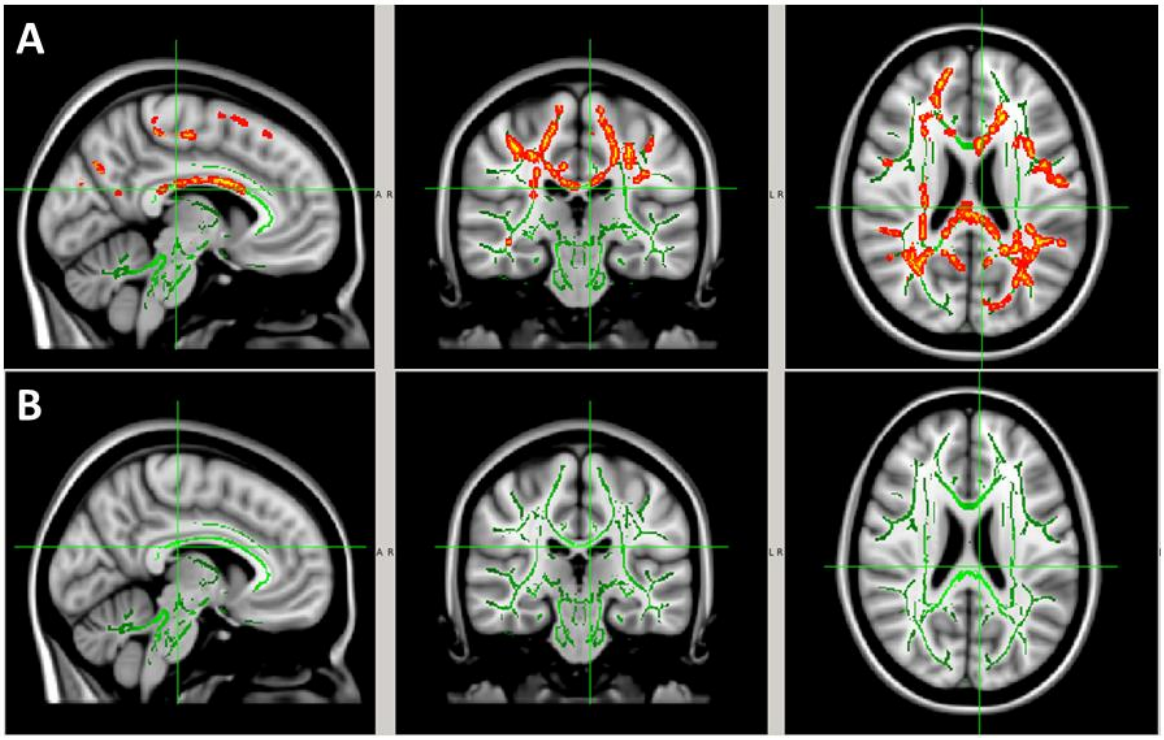

Figure S3. Results based on ITT design. Bar plots of pre- and post-season AD values from individual athletes. A: CTRL group; B: collar group.

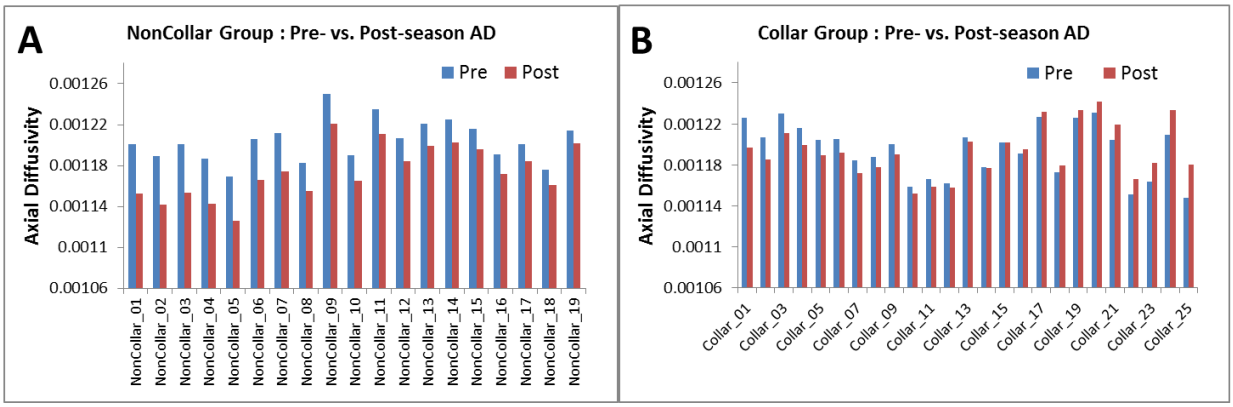

Figure S4. Results based on ITT design. WM areas with significant group differences (CTRL vs. collar) of pre- vs. post-season DTI change. A: MD; B: AD; and C: RD. The significant regions (blue-light blue regions, p<.05, FWE corrected for multiple comparisons) were overlaid on to the white matter skeleton (green) and standard T1-weighted image in MNI 152 space (gray scale). MD: mean diffusivity; AD: axial diffusivity; RD: radial diffusivity.