Cumulative strain-based metrics for predicting subconcussive head impact exposure–related imaging changes in a cohort of American youth football players

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- **ABSTRACT**

OBJECTIVE

Youth football athletes are exposed to repetitive subconcussive head impacts during normal participation in the sport, and there is increasing concern about the long-term effects of these impacts. The objective of the current study was to determine if strain-based cumulative exposure measures are superior to kinematic-based exposure measures for predicting imaging changes in the brain.

METHODS

This prospective, longitudinal cohort study was conducted from 2012 to 2017 and assessed youth, male football athletes. Kinematic data were collected at all practices and games from enrolled athletes participating in local youth football organizations in Winston-Salem, North Carolina, and were used to calculate multiple risk-weighted cumulative exposure (RWE) kinematic metrics and 36 strain-based exposure metrics. Pre- and postseason imaging was performed at Wake Forest School of Medicine, and diffusion tensor imaging (DTI) measures, including fractional anisotropy (FA), and its components (C_L, C_P, and C_S), and mean diffusivity (MD), were investigated. Included participants were youth football players ranging in age from 9 to 13 years. Exclusion criteria included any history of previous neurological illness, psychiatric illness, brain tumor, concussion within the past 6 months, and/or contraindication to MRI.

RESULTS

A total of 95 male athletes (mean age 11.9 years [SD 1.0 years]) participated between 2012 and 2017, with some participating for multiple seasons, resulting in 116 unique athlete-seasons. Regression analysis revealed statistically significant linear relationships between the FA, linear coefficient (C_L), and spherical coefficient (C_S) and all strain exposure measures, and well as the planar coefficient (C_P) and 8 strain measures. For the kinematic exposure measures, there were statistically significant relationships between FA and RWE linear (RWE_L) and RWE combined probability (RWE_{CP}) as well as C_S and RWE_L. According to area under the receiver operating characteristic (ROC) curve (AUC) analysis, the best-performing metrics were all strain measures, and included metrics based on tensile, compressive, and shear strain.

CONCLUSIONS

Using ROC curves and AUC analysis, all exposure metrics were ranked in order of performance, and the results demonstrated that all the strain-based metrics performed better than any of the kinematic metrics, indicating that strain-based metrics are better discriminators of imaging changes than kinematic-based measures. Studies relating the biomechanics of head impacts with brain imaging and cognitive function may allow equipment designers, care providers, and organizations to prevent, identify, and treat injuries in order to make football a safer activity.

ABBREVIATIONS

ABM = atlas-based brain model; AUC = area under the ROC curve; CL = linear coefficient; CP = planar coefficient; CS = spherical coefficient; DTI = diffusion tensor imaging; FA = fractional anisotropy; FE = finite element; HITS = Head Impact Telemetry System; MD = mean diffusivity; mTBI = mild traumatic brain injury; ROC = receiver operating characteristic; ROI = region of interest; RWE = risk-weighted cumulative exposure; RWECP = RWE combined probability; RWEL = RWE linear; RWER = RWE rotational acceleration; VSM = volumetric strain measure; VSRM = volumetric strain rate measure; VSSM = volumetric shear strain measure; VSSRM = volumetric shear strain rate measure; WM = white matter; 6DOF = 6 degrees of freedom.