Assessment of Brain Injury Criteria using Head Kinematics Data from Crash Tests and Accident Reconstructions

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I. INTRODUCTION

Several kinematics-based injury criteria relating six Degrees of Freedom (DOF) head kinematic data to brain injury risk have been proposed and are presently being considered for use, for example BrIC by NHTSA for the THOR Anthropomorphic Test Device (ATD) [1]. Many recently proposed brain injury criteria [2–5] have used simulations with a Finite Element (FE) head and brain model to generate functions that can relate six DOF head kinematics data in a crash test to peak strain in a FE brain model. All these studies have used the same model, the GHBMC brain model [6]. For this study, we used another validated FE head and brain model, the KTH model [7], to compare six head and brain injury criteria to peak brain strain in simulations with six DOF head kinematics data.

II. METHODS

Six DOF head kinematic data were extracted from 64 Frontal impact tests with the THOR-50M ATD as driver (42) and passenger (22), mainly oblique (18) and movable progressive deformable barrier (37) tests. Six DOF head data from the WorldSID-50M ATD in 90 Near-Side and 65 Far-Side impacts were included in the analysis as well. Of these, 83 were from barrier impacts and 72 from pole impacts. A CFC1000 filter was used for translational accelerations and CFC60 for head rotational velocities. The data were then used in simulations with the KTH FE head model [7] over a time interval of 0.0–0.17 s, to exclude secondary head impacts. In addition, six DOF head data from 19 detailed Frontal impact Accident Reconstructions with a HBM [8] were included, using a CFC180 filter for the accelerations.

Brain Maximum Principal Strains (MPS) were extracted from the head model FE simulations, and six head and brain injury criteria were calculated for each set of data: HIC_{15} [1], HIP [9], BrIC [2], $UBrIC_{MPS}$ [3], DAMAGE [4], and CIBIC [5]. Linear regression models of each criterion with respect to peak brain MPS were created using Matlab's (Mathworks, Natick, MA) fitlm function.

III. INITIAL FINDINGS

For the linear models generated, all the evaluated head and brain injury criteria were related to brain MPS at the 0.05 level, except HIP for the Accident Reconstructions with the HBM. For the THOR Frontal impact tests DAMAGE had the best goodness of fit to FE model MPS with an R^2 value of 0.84, while BrIC and HIC_{15} had considerably lower fits with R^2 of 0.46 and 0.35, respectively (Fig. 1).

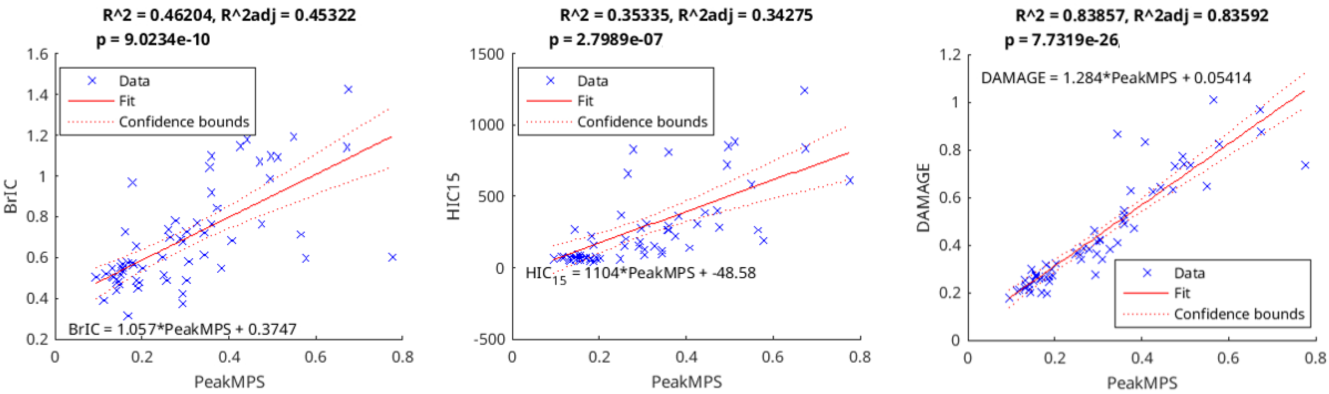

Fig. 1. Linear models of BrIC (left), HIC_{15} (middle), and DAMAGE (right) versus peak brain MPS from the head FE simulations, for the THOR Frontal impact tests.

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The median and the range of the resulting brain MPS were 0.27 (0.09–0.77), 0.3 (0.05–0.91), 0.32 (0.08–0.59), and 0.41 (0.12–1.12), for the THOR Frontal, WorldSID Near-Side and Far-Side impact tests and the HBM Accident Reconstructions, respectively. Ranking the goodness of fit for all subsets of data and injury criteria in relation to the peak brain MPS showed that DAMAGE had the highest correlation for Frontal impacts with THOR. However, for Near-Side impact with the WorldSID ATD, the criteria that account for translational accelerations, such as HIC_{15} and HIP, had the highest correlations (Table 1).

TABLE I
SUMMARY AND RANKING OF THE EVALUATED HEAD AND BRAIN INJURY CRITERIA FOR GOODNESS OF FIT (R^2) TO THE FE HEAD MODEL MPS

	1	2	3	4	5	6
Frontal Impact, THOR	DAMAGE (0.84)	CIBIC (0.74)	UBrIC (0.68)	BrIC (0.46)	HIP (0.45)	HIC15 (0.35)
Near-Side, WorldSID	HIC15 (0.71)	HIP (0.70)	CIBIC (0.64)	DAMAGE (0.53)	UBrIC (0.46)	BrIC (0.30)
Far-Side, WorldSID	CIBIC (0.73)	DAMAGE (0.64)	UBrIC (0.65)	HIP (0.61)	BrIC (0.48)	HIC15 (0.45)
All ATD Combined	CIBIC (0.67)	DAMAGE (0.60)	UBrIC (0.52)	HIC15 (0.40)	HIP (0.39)	BrIC (0.26)
Accident Reconstructions HBM	UBrIC (0.73)	DAMAGE (0.70)	CIBIC (0.62)	BrIC (0.58)	HIC15 (0.53)	HIP (0.16)

IV. DISCUSSION

The kinematics-based head and brain injury criteria HIC_{15}, HIP, BrIC, $UBrIC_{MPS}$, DAMAGE, and CIBIC were compared to brain MPS from the KTH FE head model in simulations of six DOF head data. A similar study was conducted by van Slagmaat et al. [10], who compared global brain injury criteria to KTH head model MPS for 27 paired small and medium overlap impacts. They found UBriC to be the best predictor of brain MPS, while both DAMAGE and BrIC had considerably lower correlation. In the present study, a larger sample of test data was used, including Near-Side and Far-Side impact data from the World-SID and Frontal impact Accident Reconstructions. The best goodness of fit to brain strain was found for the three DOF rotational models DAMAGE and CIBIC which showed the overall best correlation with an R^2 of 0.84 and 0.74, respectively, in Frontal impacts with THOR. For Far-Side and All ATD data Combined, CIBIC was the best predictor. For the Accident Reconstructions with HBM, UBrIC had the highest goodness of fit, followed by DAMAGE and CIBIC. For the Near-Side impacts, another ranking order for the criteria was found. Criteria including linear accelerations, HIC_{15} and HIP, had the highest R^2, indicating a relation between linear acceleration and brain strain for the head FE model when interacting with an inflatable curtain, which was present in all the Near-Side tests included in the sample. This finding is different than for instance for Near-Side impacts with the GHBMC head model for the development of DAMAGE, for which good correlation to brain strain was found [4].

For this study, the MPS of any element in the FE brain, i.e. the 100th percentile strain (MPS100) value in a ranking of all the strains, was used for comparison to the kinematics-based injury criteria. Fahlstedt et al. [11] evaluated the effect of alternative methods, such as using the 99th and 95th percentile peak strain values, and found that the method affects the relation of model strain to the risk of mild traumatic brain injury. Therefore, for continued analysis of the results presented here, analysis of MPS99 and MPS95 will be added as well, and it is possible that the preliminary results here is affected by the use of MPS100.

To conclude, of the rotational kinematics-only predictors, CIBIC, DAMAGE, and UBrIC, all out-performed BrIC in predicting brain MPS in this study. These rotational based head injury criteria seem adequate to capture the brain strain response in Frontal and Far-Side impacts, but they seem to be missing information (i.e. linear acceleration) in Near-Side impacts.

V. REFERENCES

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