D39 Head Injury Criteria (HIC) Scaling for Assessing Closed Head Injury Risk

Robert D. Anderson, MS, Biomechanics Analysis, Tempe, AZ 85281-0023; Billy S. Cox, Jr., Billy Cox Group, Navasota, TX 77868*

Learning Overview: The goal of this presentation is for attendees to learn how to scale HIC.

Impact on the Forensic Science Community: This presentation will impact the forensic science community by demonstrating a method for estimating head injury from available crash test.

Due to the expense associated with automobile crash testing, it is desirable to develop an appropriate scaling technique in order to utilize existing test results to predict the head/brain injury risk at a particular crash severity.

All head impacts involve linear and angular accelerations, as the two head accelerations are inextricably coupled by impact vector and head-neck structures.[1,2] Concussion risk has been correlated with both peak linear and angular head acceleration.[3] Unfortunately, angular parameters are not measured in standardized automotive crash or sled testing.

The Head Injury Criterion (HIC) is based upon the linear resultant head center of gravity acceleration. The HIC is the maximum calculated value over a time frame where $t_2 - t_1 = 15$ or 36msec using the formula shown in Figure 1.

$$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$$

Figure 1. Head Injury Criterion[4]

Excluding combined linear-angular and tissue strain based methods, HIC has been found to be the best predictor of mild traumatic brain injury when compared to other methods, such as the Gadd Severity Index, linear acceleration, and rotational acceleration.[5] HIC is the current worldwide standard for assessing head impact severity and head/brain injury risk and is inherent in Federal Motor Vehicle Safety Standards.

The Abbreviated Injury Scale (AIS) is a standardized system to describe injury severity that ranges from AIS 1 to AIS 6, representing minor through fatal/untreatable injury.[6] Prasad and Mertz set forth a risk curve for severe, AIS ≥4, head or brain injury as a function of HIC.[1] the National Highway Traffic Safety Administration (NHTSA) later expanded the risk curves for all AIS levels.[7] As shown in Figure 2, an event with an HIC of 1,000 is considered to have about a 1 in 6 chance of a severe head or brain injury. Below 50, there is effectively no chance of even the most minor (AIS 1 or 2) head injury.[8] Volunteer studies are routinely conducted in a range that produce HIC's below 50 without consequence.

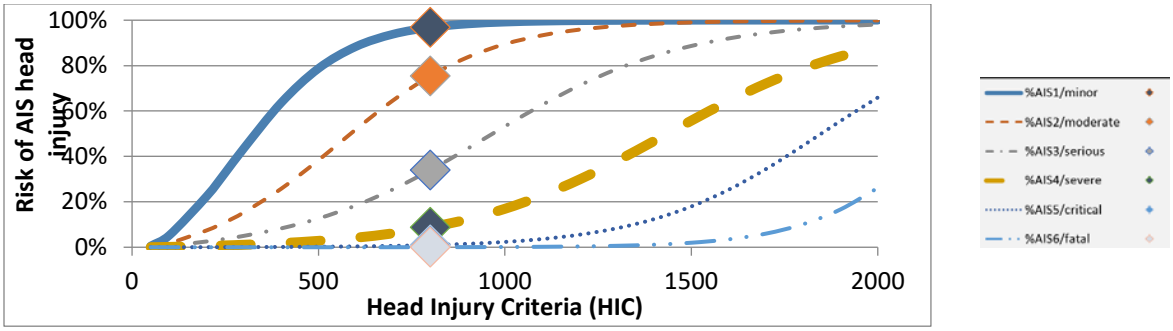

Figure 2. Probability of Head Injury Severity as a function of HIC[8]

Delta V is a common measure of crash severity. Proportional scaling the HIC for Delta V is not appropriate since the HIC is non-linear for head acceleration. However, if head acceleration varies linearly with Delta V, then Delta V can be used to scale head accelerations from a crash test to that of an occupant of an accident vehicle. The head injury risk for that occupant can be estimated using the HIC calculated from the scaled head accelerations, then applied to the Prasad-Mertz curves to estimate head/brain injury risk.

Crash tests at two different Delta Vs, but with comparable vehicles, occupants, restraints, seat positions, etc., are uncommon. An example from a 10mph rear-end sled test scaled down to live human exposure to a rear-end car-to-car impact with same year, make, and model of vehicle, seat belt use, and active head restraint deployment is shown in Figure 3 (left). The live human that was close in stature to that of the 50th-percentile Rear Impact Dummy (RID). Another example is scaling a 25mph barrier impact to a 30mph barrier impact with the same year, make, and model of vehicle, both with an unrestrained 5th-percentile female HBDIII dummy with the passenger seat adjusted to the same position, shown in Figure 3 (right).

*Presenting Author

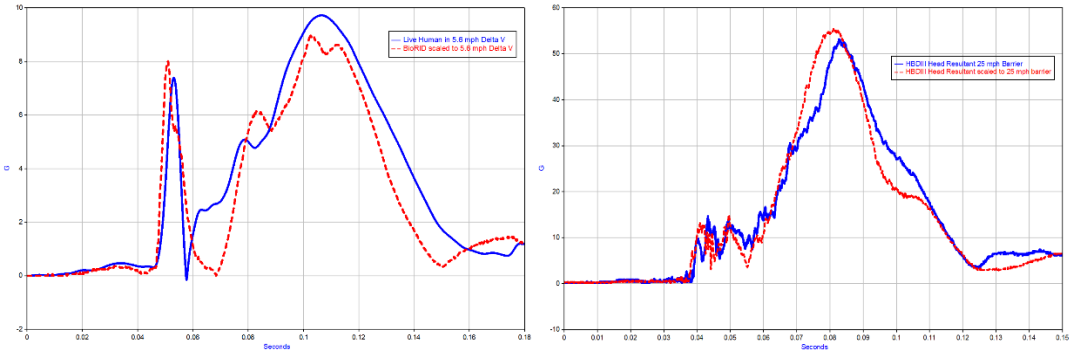

Figure 3. Results of scaling a rear sled test to a bumper-to-bumper impact (left) and frontal barrier crash tests (right)

By scaling the resultant head acceleration, the estimated HIC_{15}'s compared favorably but somewhat over-estimated the actual values from the lower speed crash tests. As would be desirable in practice, in these examples as many parameters as possible were kept constant. Inherent in this technique is the assumption that the collision durations are approximately the same so that the vehicle and head acceleration varies approximately linearly with Delta V.

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HIC, Scaling, Risk