EVALUATION OF THE SIMULATED RESPONSE OF THE HUMAN BRAIN SUBJECTED TO DIFFERENT ACCELERATIONS DURING A FRONTAL IMPACT

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DESPITE THE USE OF AIRBAGS, traumatic brain injuries still occur frequently in car crash. Head injury results from direct or indirect impact applied to the head when the thorax is decelerated. In both cases, the head sustains a combined linear and angular acceleration. While skull fractures are seldom in indirect loading, severe brain injuries can occur due to the rapid momentum changes resulting from the velocity difference between the head and the restrained thorax. In both linear and angular loadings, the brain encounters deformations that can damage the neuronal or vascular structures. Numerical models of the head could be useful tools to improve the understanding of brain injury mechanisms. SIMon is one of the models developed to assess the risk of brain injury in car crash, (Takhounts *et al*., 2003). The injuries were simulated with a FE model of the brain, in which kinematics data of the head are used as input. Estimations of three forms of brain injury are predicted using three criteria. The evaluation of the model's injury criteria is presented in this study and compared against current criteria using different sled tests configurations.

BRAIN INJURY CRITERIA AND HEAD KINEMATICS FROM EXPERIMENTAL DATA

The *HIC* is a function of the linear acceleration and impact duration and is currently used to evaluate both skull and brain injuries. However its capability to detect rotationally induced injuries appears limited. The *Gambit* criterion takes into account the angular acceleration, but not the duration. SIMon proposes three new specific criterion for the three common types of brain injuries: Diffuse Axonal Injury, contusions, and Acute SubDural Hematoma. The Cumulative Strain Damage Measure is a correlation for *DAI* and assumes that *DAI* is associated with the cumulative volume of brain tissue submitted to critical tensile strain level. The Dilatation Damage Measure is used for injury resulting from dilatational stress conditions. The probability of contusion is correlated with the fraction of brain volume where negative pressures can produce damage. The Relative Motion Damage Measure is used for injuries related to brain motion relative to the skull, such as the rupture of the bridging veins. The input data of the FE model came from tests on fresh cadaver: three series at 50kph with a 22Gs peak deceleration pulse (one with airbag and a 4kN load-limited belt, two without steering wheel and with a 4 and 6kN load-limited belt, respectively). A series at 30kph with lower deceleration pulse (15Gs), and only a 4kN belt was also performed. The head kinematics was measured at the centre of gravity using multi-accelerometers. The sled tests and methodology are described in Vezin *et al*. 2003.

RESULTS

The results are given in Table 1. The influence of impact conditions is evaluated comparing tests with identical restraint devices and reducing the velocity and deceleration. The *HIC* decreases strongly for a lower crash severity. The magnitude of the linear acceleration is similar, but the shapes of the curves are different (Vezin et al. 2003). The rotational accelerations are also reduced but not the angular velocity. The change of the severity does not appear clearly on the *Gambit* value, because this criterion depends on both the linear and angular accelerations and, there is a lack of correlation between these two variables (Fig. 1). There is also a great dispersion between the tests for the three brain injury criteria without any clear trend.

The influence of restraint systems is assessed at 50kph using three different restraint systems. It appears that the *HIC* and *Gambit* values are lower with the 6kN belt than for the 4kN belt. The highest values of these criteria are found for the tests with airbag, but the two other series were performed without steering wheel (i.e. without head contact). The kinematics data showed the same trend. However, the angular accelerations and velocities do not show significant differences between the tests with and without airbag using the same belt.

Table 1- Summary of Injury criteria an kinematics data vs. test conditions

Test Conditions	CSDM	DDM	RMDM	HIC	Gambit	Lin. Acc. (G)	Ang. Acc. (rad/s²)	Ang. Vel. (rad/s)
30kph 4kN FL	0.054	0.14%	0.37	53.7	0.08	20.7	1711	34.3
	0.117	0.18%	0.47	135	0.16	37.4	2249	55.5
	0.019	0.34%	0.65	141	0.28	59.0	1426	61.8
50kph 4kN FL	0.081	0.05%	1.22	371	0.26	32.7	4187	73.9
	0.021	1.72%	0.43	446	0.18	44.2	2485	38.3
50kph 6kN FL	0.512	0.62%	0.72	116	0.15	26.9	3051	34.8
	0.498	3.93%	0.82	153	0.12	30.5	1300	31.4
50kph 4kN FL+AB	0.445	0.34%	0.65	576	0.28	59.0	4514	61.8
	0.074	0.01%	0.60	324	0.21	50.6	2746	34.6
	0.206	0.76%	0.25	325	0.22	45.8	3713	45.7

As for the influence of the velocity, no trends can be found for the influence of the restraint systems on the *RMDM* values, which were quite identical, nor on the *DDM* values which were scattered. The greatest *CSDM* values, corresponding to about 40% of the probability of *DAI* are obtained for the test with a 6kN belt. All the other test conditions do not show *CSDM* values above 20% except for one test with airbag where all the kinematics data were found high, and the lowest values (corresponding to less than 10% of probability) were found for the test with only the 4kN shoulder belt.

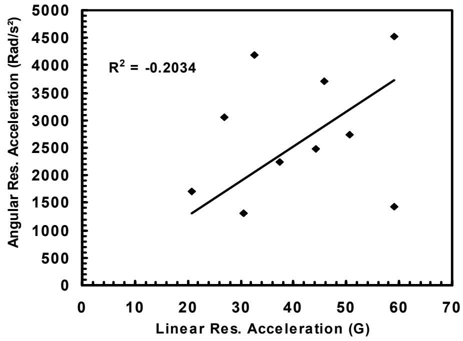

Fig. 1 – Comparison of linear and angular resultant accelerations (R^2=-0.2034)

DISCUSSION / Conclusion

The advantage of the SIMon model is that it assesses brain injury risks based on local rather than global data. Consequently, this tool could provide injury assessments for any impact direction without requiring an adjustment of the injury criteria. From the results, it can be observed that the *DDM* were found very low, less than 1%, except for two tests performed at 50kph without airbag but with two different types of belt. No correlations were found between the *DDM* and the kinematic parameters. This suggests that high stress rates in the brain arise in multiple complex configurations, where both rotational and linear accelerations in all directions are involved. Only one test exceeded a *RMDM* value of 1 corresponding to 50% probability of occurrence of *ASDH*. All the other tests recorded *RMDM* values that lead to less than 20% risk of occurrence of *ASDH*. Nevertheless, correlations were found between the *RMDM* values and the transversal linear acceleration (y-axis) and with the vertical angular velocity and acceleration (z-axis). If this first observation is confirmed by a more detailed analysis, it could show that one mechanism that can lead to the rupture of bridging veins is a rotation of the head around the vertical axis (torsion of the neck) associated with a transversal displacement (lateral flexion). The *CSDM* exhibited a very different behaviour for the same test conditions, except for the series with the highest value of the load limit in the belt (i.e. the thorax was more restrained compared to the other configurations). However, a high value of *CSDM* was found to correlate with high values of the longitudinal and vertical linear accelerations. This observation shows that a rotation of the head around the transverse axis associated with a high deceleration in the sagittal plane can lead to *DAI*. The results presented here are preliminary observations from simulations conducted with SIMon in order to assess the traumatic brain injury risk in frontal car crash. Some attempt of description of injury mechanisms are given, but more detailed analyses are necessary and are planned for future work on more cases including the comparison with direct impact (impactor test in different directions).

REFERENCES

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