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QUANTIFICATION OF HEAD KINEMATICS IN A MODEL OF MILD BRAIN INJURY IN RATS

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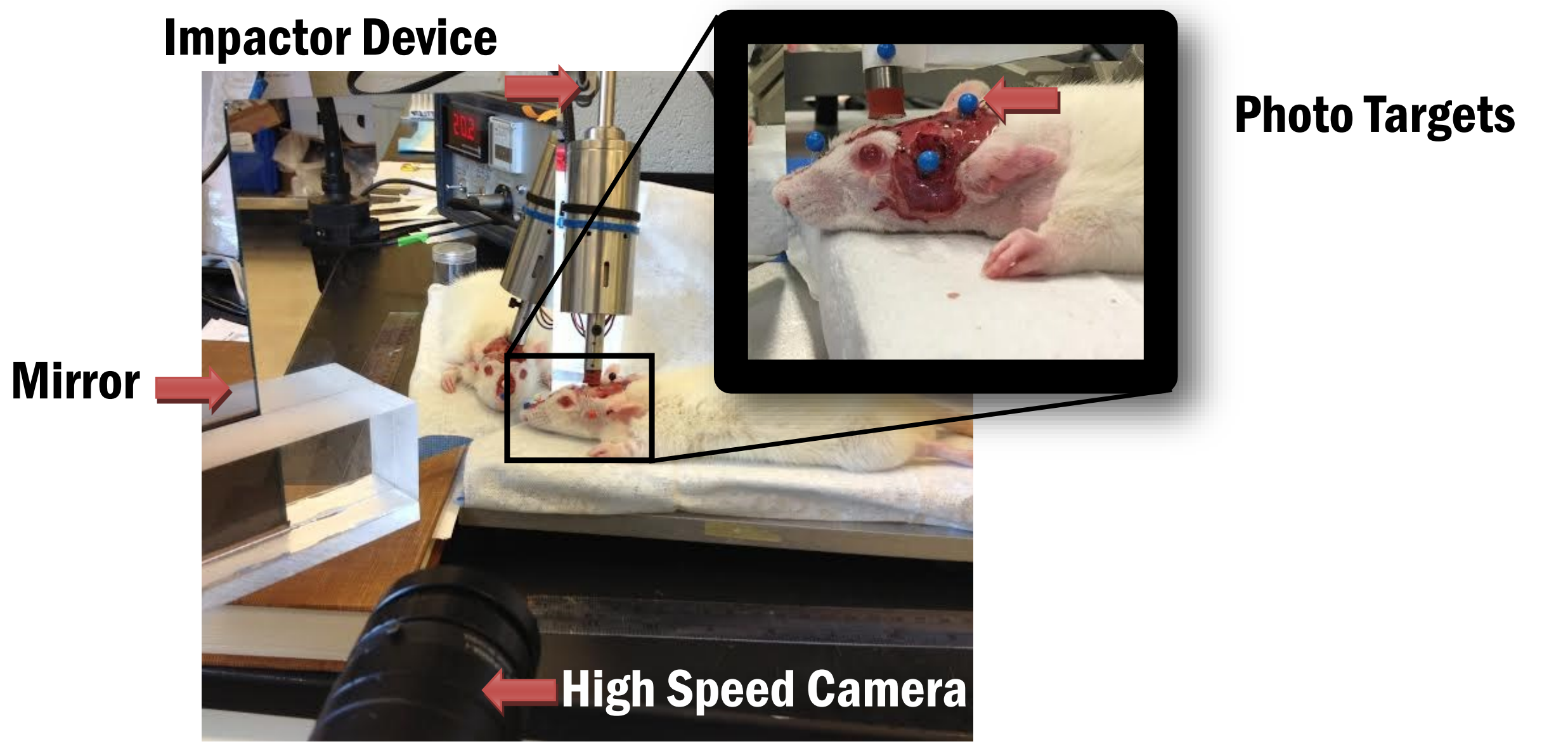
ABSTRACT

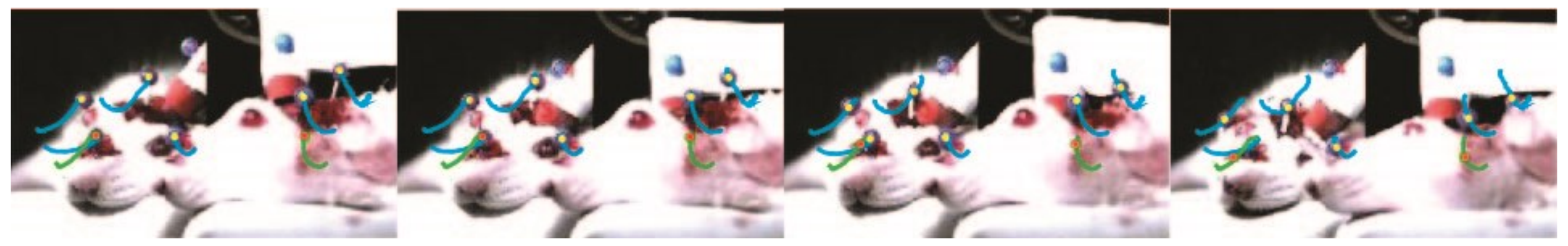
Traumatic Brain Injury (TBI) is a leading cause of death and disability worldwide. In order to investigate the diagnosis and treatment of injury, and improve the protective equipment, different rodent injury models have already been developed and utilized. One of the closed head injury (CHI) models widely used in such studies uses a linear impactor to directly hit the rat head. While the kinematic aspects of head trauma, including the head linear and angular velocities and accelerations have been shown to correlate with the severity of the injury, in the CHI models only test input parameters such as impactor speed, depth of penetration, angle of impact, and impactor tip diameter and material are provided. In order to compare the result of one study with others, or to scale the results from animal head to human head, knowing the kinematics of the head is essential. Understanding how the test parameters affect the kinematics of the head during the impact will allow researchers to more reliably replicate controlled brain injuries. In the current study, the kinematics of the rat head in a CHI model is characterized for different impactor angles and depths.

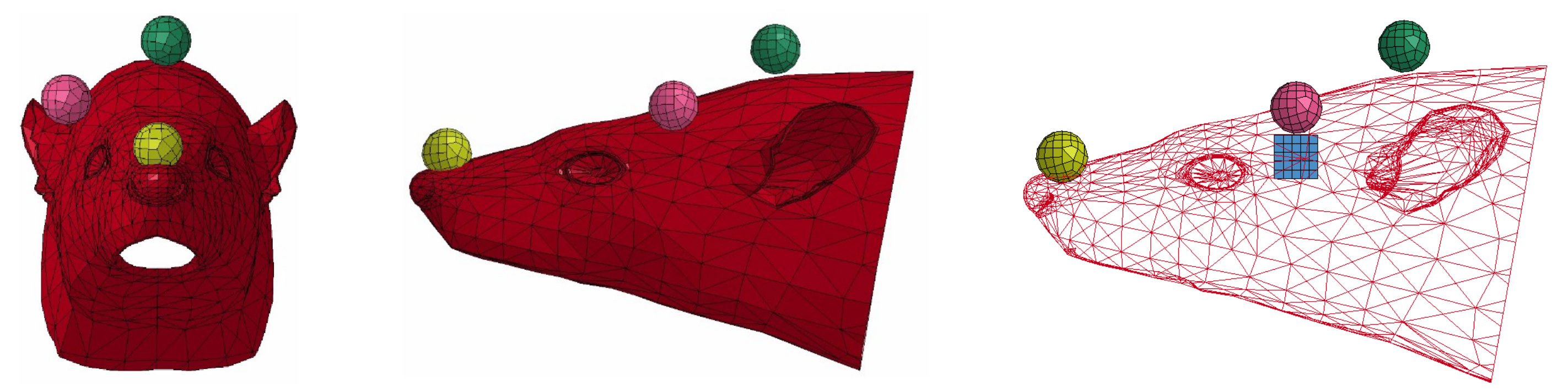
METHODS

- Rat skull was exposed, 3 photo targets were attached to the skull, and the animal was positioned under a solenoid impactor.
- Animal was struck on the skull at the velocity of 5m/s, at lateral angles of 20 and 40 degrees, to depths of 2 , 3, and 5 mm. This was recorded with a high speed camera at 2200 fps..
- The positions of the photo targets and their image in a mirror that was placed in front of the animal were tracked using image processing software. This was used to determine the position and motion of each marker in 3 dimensions.
- The approximate location of head centroid was determined in relation to the photo targets, and its linear and rotational velocities and accelerations were found over time using a finite element model developed in LSDyna.

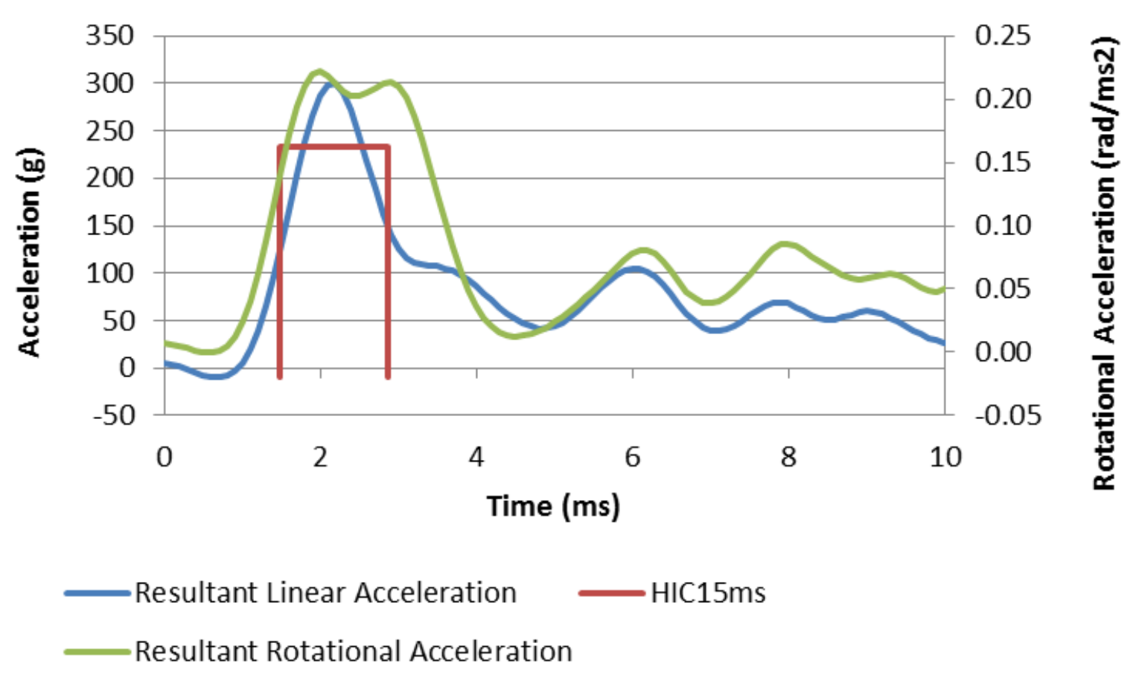


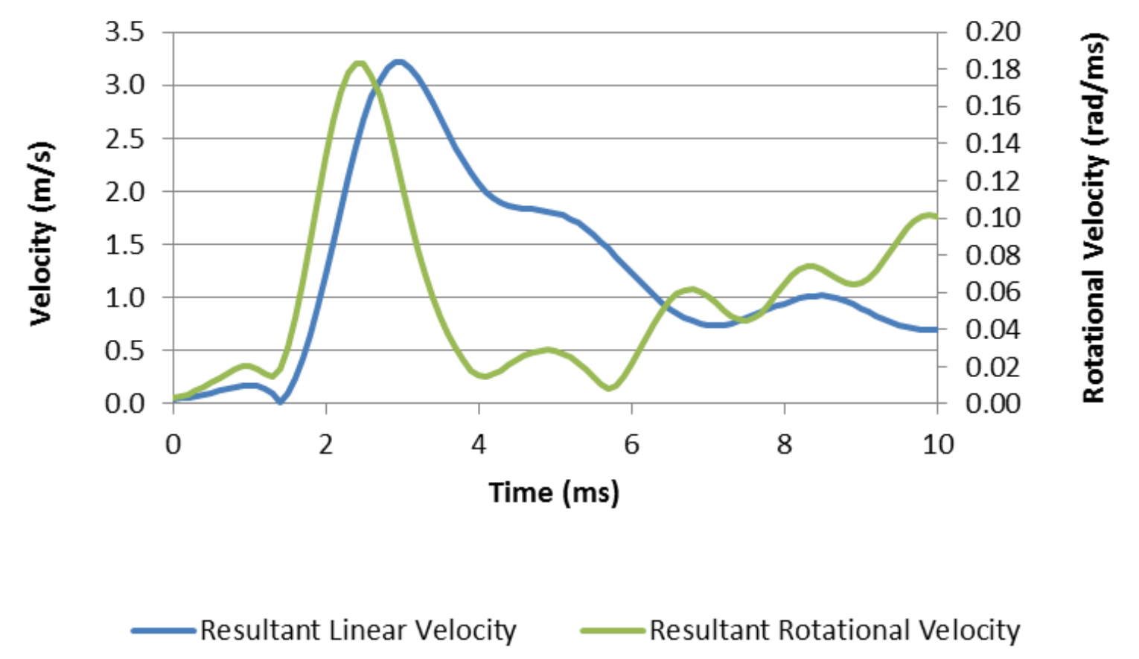
A—0.00 ms B—1.84 ms C—2.88 ms D—5.00 ms

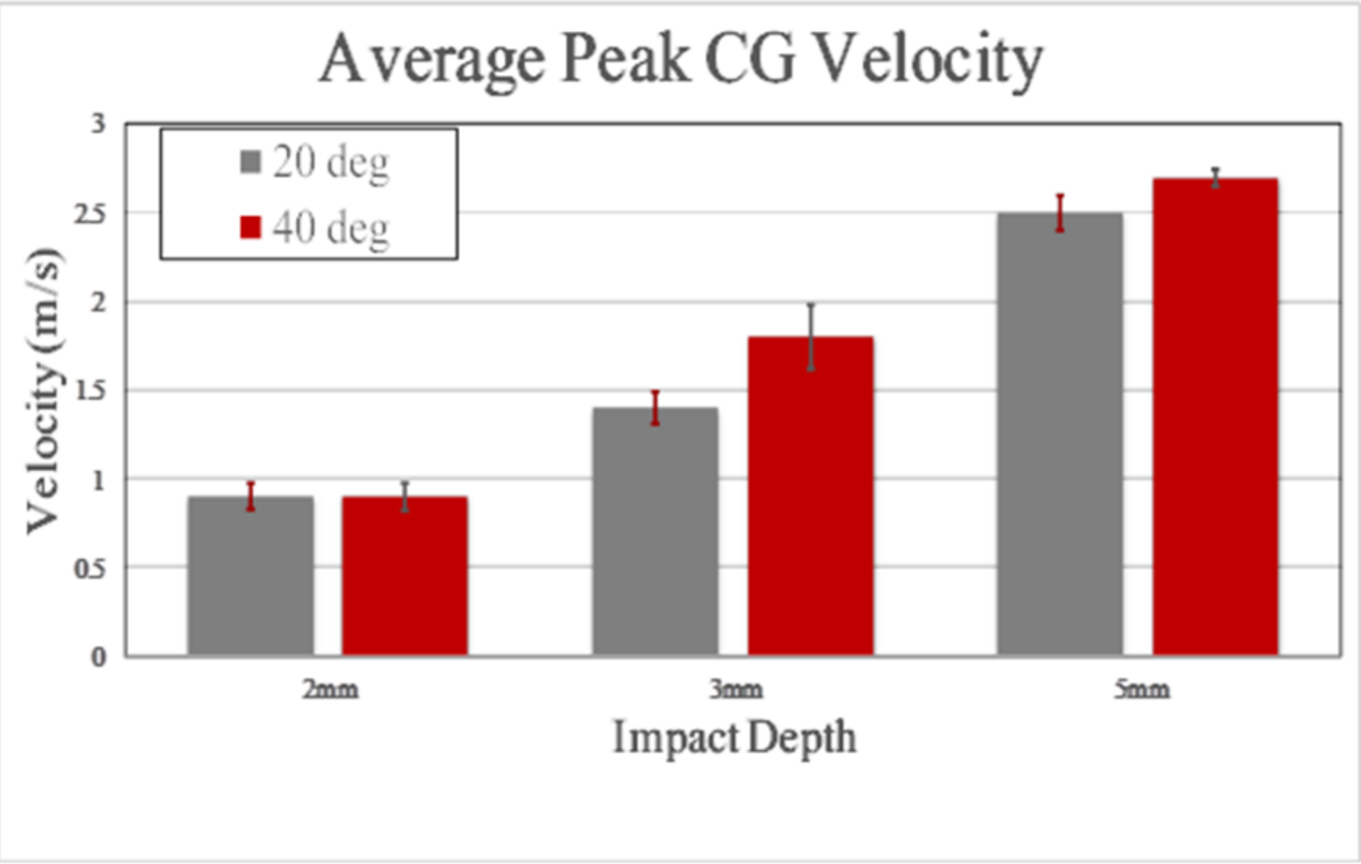




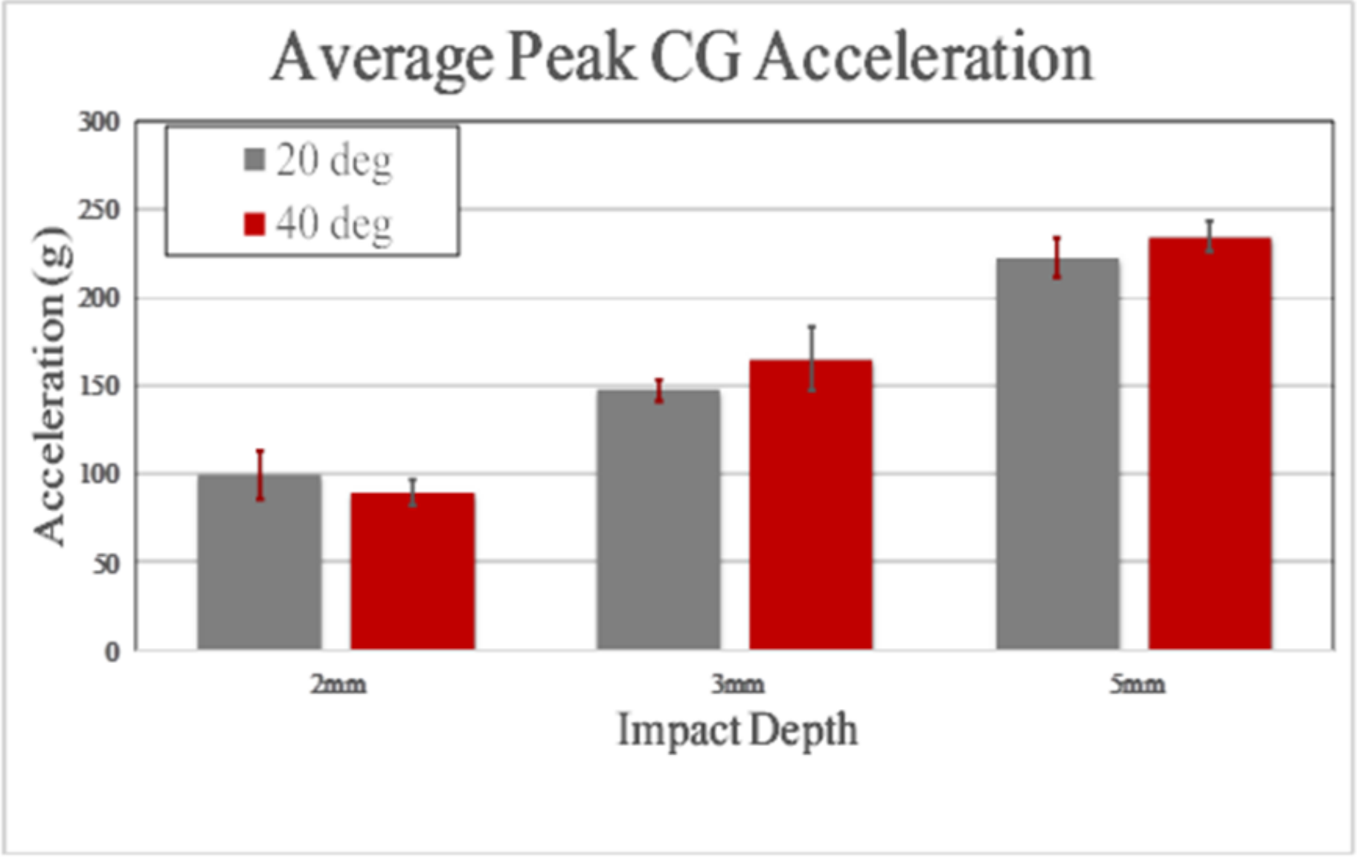
RESULTS







Depth (mm)	Angle	Difference	*p* Value
2 & 3	20°	57%	0.002
2 & 5	20°	182%	<0.0001
3 & 5	20°	79%	<0.0001
2 & 3	40°	95%	0.0005
2 & 5	40°	194%	<0.0001
3 & 5	40°	51%	0.0004
2	20° & 40°	4%	0.7
3	20° & 40°	29%	0.09
5	20° & 40°	8%	0.1



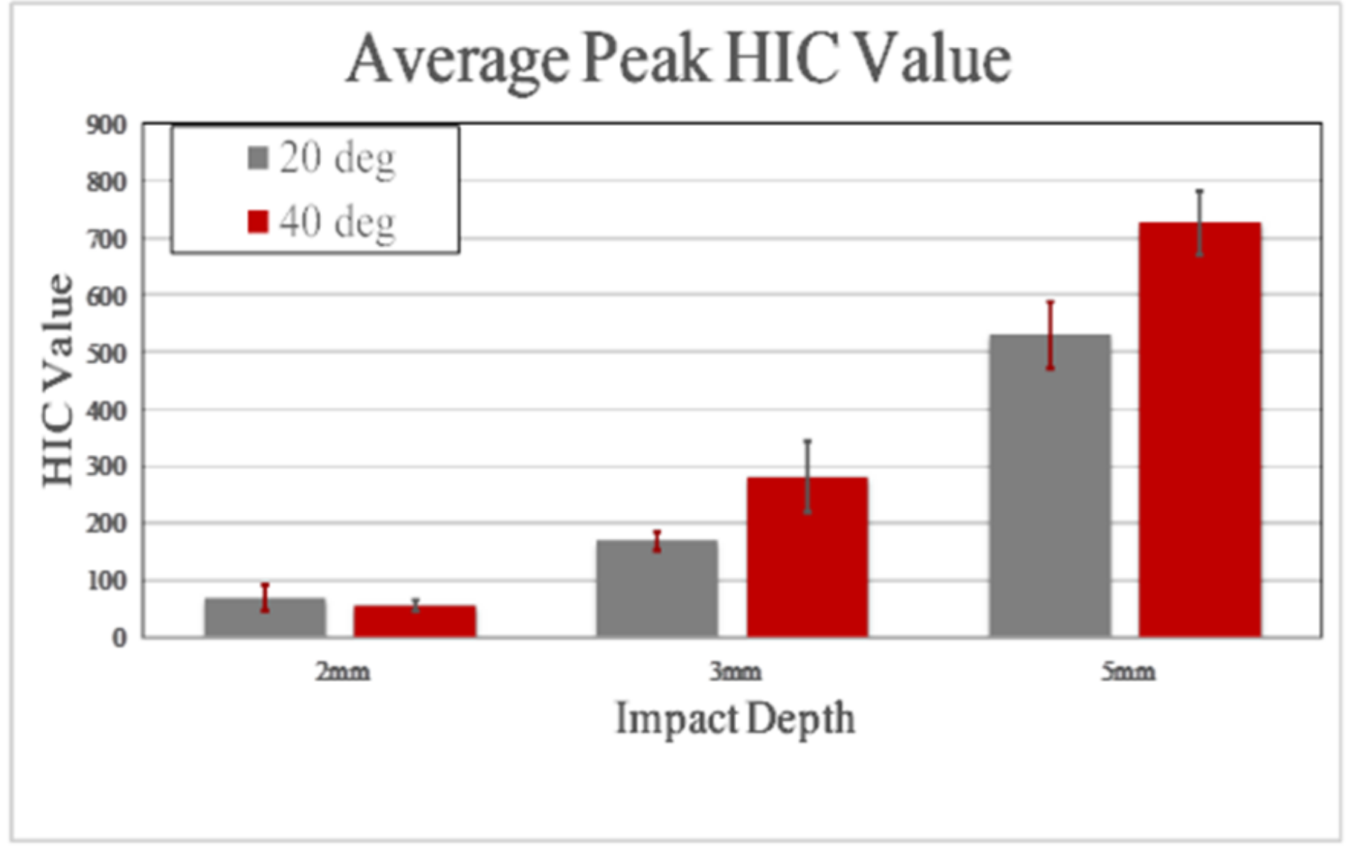
Depth (mm)	Angle	Difference	*p* Value
2 & 3	20°	48%	0.024
2 & 5	20°	124%	<0.0001
3 & 5	20°	51%	0.0015
2 & 3	40°	85%	0.002
2 & 5	40°	162%	<0.0001
3 & 5	40°	42%	0.005
2	20° & 40°	10%	0.5
3	20° & 40°	12%	0.37
5	20° & 40°	5%	0.4

Calculation of Head Injury Criterion (HIC)

HIC values were computed using the following empirical formula:

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

Where *t* represents time in seconds and a represents acceleration in g. HIC values were calculated for maximum time durations of 15 ms or HIC15.



Depth (mm)	Angle	Difference	*p* Value
2 & 3	20°	145%	0.14
2 & 5	20°	666%	<0.0001
3 & 5	20°	212%	<0.0001
2 & 3	40°	394%	0.017
2 & 5	40°	1169%	<0.0001
3 & 5	40°	157%	<0.0001
2	20° & 40°	17%	0.6
3	20° & 40°	67%	0.15
5	20° & 40°	37%	0.04

Comparison of Data with Human

While a number of mechanical and physiological variables exist, an impact resulting in a HIC value over 250 (Mackay, 2007) and acceleration over 80 g (Guskiewicz, 2011) are associated with an elevated risk of concussion in humans. Based on the geometric similitude between the brains of rats and humans, a length scale can be applied to approximate the differences in acceleration and HIC value needed to apply the same amount of stress to the brain tissue, producing a similar injury.

The acceleration and HIC scaling factors between two subjects can be calculated as $\lambda_A = \lambda_L/\lambda_E$ and $\lambda_{HIC} = \lambda_L^{1.5}/\lambda_E^{2.5}$, where λ_L is the length ratio of the brains, and λ_E is the ratio of the moduli of elasticity of brain tissue (Panzer, 2014). The length of an adult human brain is typically 10 times the length of a rat brain. While it is assumed that the modulus of elasticity of brain tissue remains constant between species, it can vary with factors such as age and sex.

Compared to a human, a rat model must experience linear acceleration of approximately 10 times the magnitude, and HIC value approximately 30 times as great, in order to experience a similar injury. Therefore, it can be concluded that the impacts performed in this study would correspond to a mild concussive (subconcussive) impact in human.

CONCLUSIONS

- The kinematics of rat head in a CHI model was characterized.
- The highest magnitudes of kinematics parameters measured for 5 mm depth were about 2.5 m/s linear velocity, 180 rad/s rotational velocity, 250 g linear acceleration and 200 krad/s^2 rotational acceleration.
- These values correspond to a mild concussive impact in human.
- Head velocity, acceleration and HIC were significantly dependent on the depth of impact and it was found that they increased linearly with depth (R^2 >0.95)
- Impacts from 40 degrees caused an average increase of 14% velocity, 3% acceleration and 29% HIC, but the differences were not statistically significant.
- The time of peak rotational velocity and rotational acceleration were slightly (about 0.5 ms) before the corresponding peak linear parameters.
- In the future, the effect of other experimental parameters, such as impactor velocity, will be studied.
- The results of this study can be used as the input to finite element models of rat head to study the biomechanics of TBI.

ACKNOWLEDGEMENTS

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