Validation of the GHBMC Small Female Head Model and Development of Crash Induced Injury Tolerance for Head Injury Prediction

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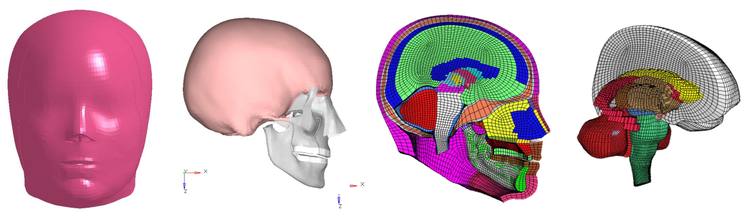
INTRODUCTION

Finite element (FE) modeming can serve as a powerful tool to study human head and brain injuries that is difficult to investigate experimentally. Recently, a detailed human head model, GHBMC M50 (Global Human Body Modelling Consortium), representing a 50th percentile male adult head has been developed and validated (Mao et al. 2013). A number of Crash Induced Injury (CII) criteria have also developed for predicting risk of various head injuries.

The objectives of this study were to 1) rigorously validate the GHBMC 5th percentile female (F05) head model which accounts for gender related size, geometrical and anatomical differences, and 2) determine CII values for head injuries to the skull, face, and brain of various regions.

METHODS

GHBMC F05 Head Model



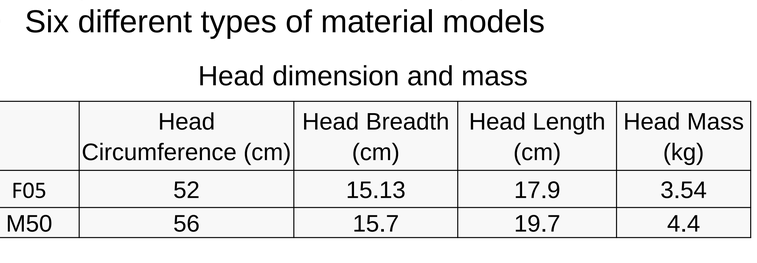
- GHBMC F05 head model: The FE mesh of the head model represents essential anatomical structures of the skull, brain, face and surrounding tissues
- 180,000 solid elements and 66,000 shell elements
- Six different types of material models

Head dimension and mass

	Head Circumference (cm)	Head Breadth (cm)	Head Length (cm)	Head Mass (kg)
F05	52	15.13	17.9	3.54
M50	56	15.7	19.7	4.4

Head Model Validation

Structure	Subregion	Validation Parameter	Experimental Study	Case No.
Brain	Frontal, occipital, ventricles	Intracranial pressure	Nahum et al., 1977, Hardy et al., 2007, Trosseille et al., 1992	9
	Various locations	Brain displacement	Hardy et al., 2001, 2007	6
Face	Nasal, Zygomatic, Maxilla	Force/deflection, stiffness	Nyquist et al., 1986, Allsop et al., 1988	8
Skull	Frontal, temporal, parietal, occipital	Force/deflection, stiffness	Yoganandan et al., 1995, Allsop et al., 1988, Allsop et al., 1991	8
TOTAL CASE				**31**

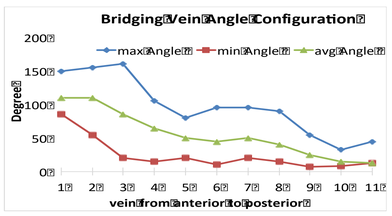


Example of validation cases

Crash Induced Injury (CII)

- Forty-four sets of head impact experiments with injurious and noninjurious conditions were simulated to develop CII values for various types of head injuries

Body Region	Body Subregion	CII Parameter	Case No.	Experimental Studies
Face	Nose, maxilla, zygoma	Fracture	8	Allsop, 1988, Nyquist et al., 1986
Skull	frontal, temporal, occipital, vertex	Fracture	8	Allsop, 1988, 1990, Yoganandan, 1995
Brain	Frontal, occipital	Contusion	10	Nahum et al.,76
Vessel	Bridging veins	ASDH	15	Depreitere et al., 2006
Brain	White matter	DAI	4	Franklyn et al., 2005*
		TOTAL CASE	**44**	



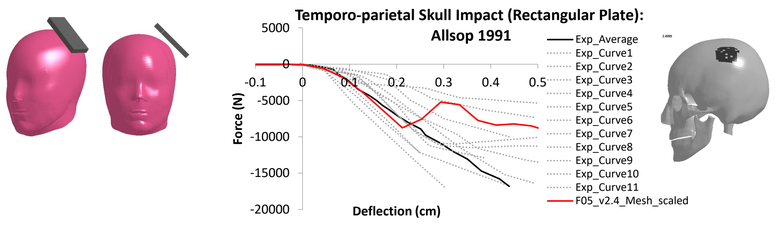
Bridging Vein Angle	Range	Average
frontopolar	85-150	110
anterior frontal	55-155	110
middle frontal	20-160	85
posterior frontal	15-105	65
precentral	20-80	50
central	10~95	45
vein of trolard	20-95	50
postcentral	15-90	40
anterior parietal	0-55	25
posterior parietal	0-32	15
occipital	0-45	10

(Oka et al., 1985)

Modeled bridge vein angles: max, min, average

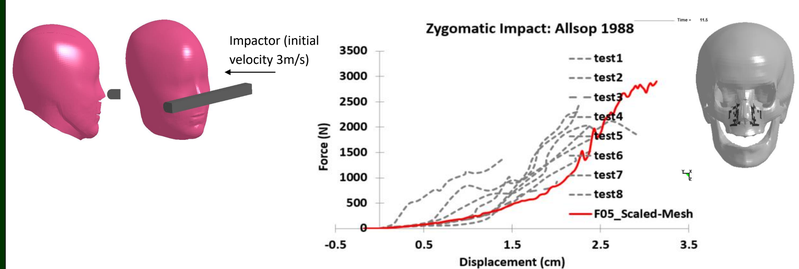
VALIDATION RESULTS

Force-Deflection of Skull Bone



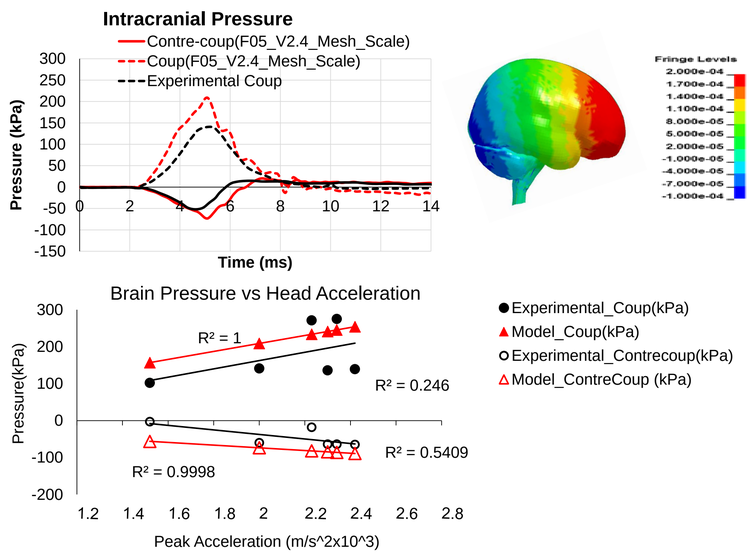
Comparison of force –deflection curves and predicted fracture location (Allsop et al., 1991)

Force-Deflection of Facial Bone

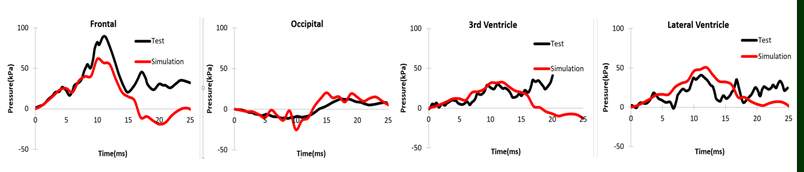


	Nasal	Zygomatic	Maxilla
Experiment	2.9± 0.67 kN	1.74 ± 0.504 kN	1.35 ± 0.356 kN
F05_v4.2 mesh scaled	2.2 ± 0.11 kN	1.39 kN	1.94 kN

Intracranial Pressure

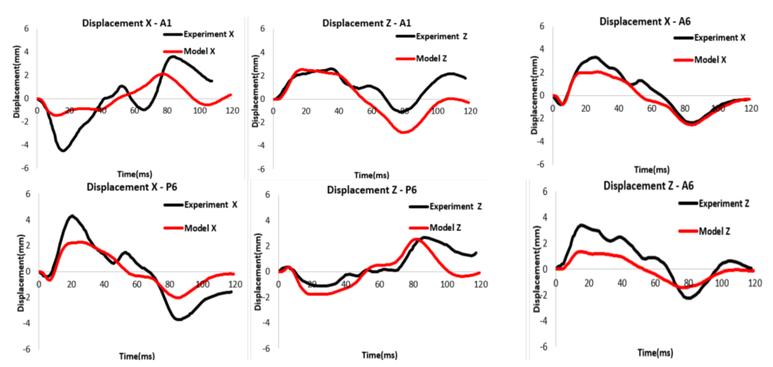


Intracranial pressure validation (Nahum et al., 1977)



Intracranial pressure validation (Trosseille et al., 1992)

Brain-Skull Relative Displacement



Brain-skull displacement - Case 383-T3 sagittal plane (Hardy et al.,2001)

CRASH INDUCED INJURY (CII) VALUE

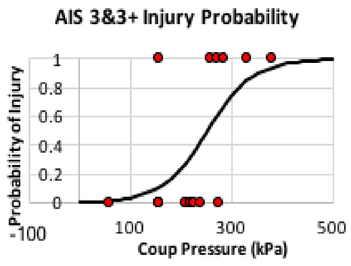
Body Region	CII Description		Tissue Level Based CII Parameters
	Primary	Secondary	
Head	**Skull Fracture**	Cortical Layer, Vault, Base	Maximum principal strain
		Diploe Layer, Vault, Base	Maximum principal stress
	Facial Bone Fracture	Nasal, Maxilla, Zygomatic, cortical, spongy bone	Maximum principal strain, stress
	Cerebral Contusion	Cerebral Injury, Haemorrhage	Intracranial pressure
	Acute Subdural Hematoma (ASDH)	Bridging Vein Rupture	Tensile strain
	Diffuse Axonal Injury (DAI)	White matter, mid-brain injury	Maximum principal strain, strain x strain rate, cumulative strain damage measure (CSDM)
	Brainstem Damage	Brainstem	
	Haemorrhage	Sub-arachnoid	Pressure, CSDM
		Cerebral	Strain, stress

CII for predicting Skull and Facial Bone Fracture

Structure	Injury Parameter	CII value
Cortical bone	Maximum principal strain	0.42%
Spongy bone	Maximum principal stress	20 MPa

CII for predicting Cerebral Contusion

- Contusion: AIS 1 vs AIS 3 and 4 by Nahum (1976, 77)



	Pressure (kPa) 50% Injury Probability	
	(AIS ≥3)	(AIS ≥4)
Coup	261	293
Contre-Coup	-89	-102

CII for ASDH

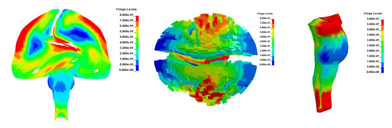
Summary of BV strain predicting 25%, 50% and 75% BV rupture risk

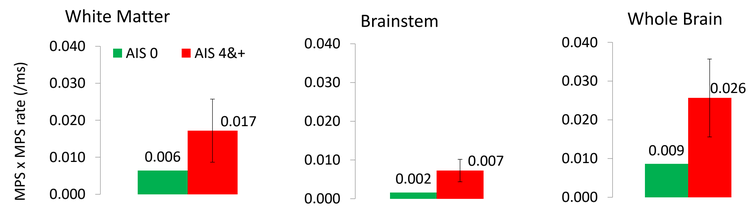
	N = 10			N = 15		
BV Angles	25% Injury Probability	50% Injury Probability	75% Injury Probability	25% Injury Probability	50% Injury Probability	75% Injury Probability
Average	0.243	0.285	0.328	0.22	0.395	0.57
Maximum	0.148	0.177	0.206	0.12	0.25	0.37
Minimum	0.178	0.22	0.26	0.155	0.31	0.46

*For simple size 15, the data also include the first impact test data (unusually at low impact energy without injury)

CII for DAI

MPS contour from AIS 4 case





Threshold values of product of maximum principal strain and strain rate for predicting AS4 &4+ DAI

DISCUSSION / CONCLUSIONS

- Model validated time histories of the force-deflection, intracranial pressure and brain/skull relative displacement data from thirty-one PMHS tests.
- Parametric studies of material properties, damping, and contact parameters improved overall CORA rating from 0.5 to >0.7.
- CII values for various head injuries have been developed and have achieved the following capability

Body Region	CII Description Primary	CII Capability	Comments
Head	**Skull Fracture**	**0**	Reasonably predictive
		0	Reasonably predictive
	Facial Bone Fracture	**0**	Reasonably predictive
	Cerebral Contusion	**0**	Predicted values lower than literature
	Acute Subdural Hematoma (ASDH)	**1**	Additional model improvement
	Diffuse Axonal Injury (DAI)	**2**	More human injury data and in vivo animal data is needed
	Brain Stem Damage	**3-4**	Detailed spinal cord model required
	Haemorrhage	**1-2**	More test data
		5-6	Injury mechanism requires some more investigation, SWI imaging

- The GHBMC F05 can be used to properly predict head injury risk sustained by this population.

Acknowledgement:

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