Far-side Struck Occupant Injury Patterns and Severities with Gender and Size

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ABSTRACT – This study was to better understand injury patterns and severities of far-side occupants of small size females and mid/large size males from vehicle crashes. 405 AIS 2+ injury incidents of 80 far-side struck occupants from 2004-current CIREN database were categorized into two groups of small size females and mid/large size males. 31 most often observed or most critical AIS 2+ tissue injuries were counted for 78.3% of the total incidents. The field data indicated that the far-side small size female occupants were more vulnerable to the chest and upper and lower extremities injuries than the mid/large size males. Far-side occupant simulations and injury analysis were conducted with a case re-construction for the compact size vehicle crashed in NHTSA FMVSS 214 right side pole impact test #210915, in which the GHBMC occupant models of the 5th%ile female, the 50th%ile male and 95th%ile male were represented as the drivers respectively with and without the passenger 50th%ile male occupant. The HBMs predicted AIS 2+ tissue injuries of the far-side occupants from the vehicle crash case were consistent with 58% of the mid/large males and 32% of the small females observed from the CIREN data, respectively.

INTRODUCTION

Earlier real-world vehicle crash studies on US NASS/CDS, Australia MIDS and other accident database found that far side struck occupants have a significant risk of serious and fatal injuries from various far-side impact environment (Digges et al. 2001, Gabler et al. 2005, Yoganandan et al., 2014).

The analysis by Carter et al. 2014 on NASS-CDS 2000-2010 database showed that older age increased AIS 3+ injuries in all frontal and side crash modes, especially thorax and head injuries. Higher BMI increased lower extremity and thorax injuries. Female gender was associated with more head, thorax, and extremity injuries.

The objectives of this study were to understand more specifically injury patterns and severities and the association between far-side struct occupant gender and sizes, and to evaluate predictiveness of GHBMC human body models (HBM) for the most common AIS 2+ tissue injuries from the far-side impacts.

METHODS

The technical approach was to conduct combined field data analysis and occupant simulation study.

CIREN Data Analysis

The US DOT CIREN database for the years 2004 to current were searched. The analysis was limited to the injured adult far-side occupants from vehicle planar crashes. Cases were selected with the filter criteria: 1) vehicle Damage Plane of Impact (DPI) on Front Right Side and Occupant Seat Position (OSP) on Front Left Side; 2) DPI on Front Left Side and OSP on Front Right Side; 3) 18+ years old and females height less than 165mm and males height more than 165mm. All the selected cases were classified into two groups—small size females and mid/large size males. For the selected CIREN cases all the occupants' AIS 2+ injuries to the head and face, thorax, abdomen, pelvis, spine, upper and lower extremity body regions were counted, each as an injury incident. The Harm metrics developed by Fildes et al. (2020) were calculated for each injury.

Occupant Simulation Study with HBMs

Six far-side occupant simulation cases in single-occupant (SO) and dual-occupant (DO) scenarios listed in Table 1 were performed. Three body sizes of the LHS occupants were represented respectively with the GHBMC detailed occupant models of the 5th%ile female (F05-O v5.1), the 50th%ile male (M50-O v6.0) and the 95th%ile male (M95-O v5.1). The opposite (near-side) occupant was with the GHBMC simplified 50th%ile male model (M50-OS v2.2).

Table 1. The far-side occupant simulation matrix

Case #	Case Name	LHS Occupant	RHS Occupant
C1	SO-F05	F05-O v5.1	None
C2	SO-M50	M50-O v6.0	None
C3	SO-M95	M95-O v5.1	None
C4	DO-F05	F05-O v5.1	M50-OS v2.2
C5	DO-M50	M50-O v6.0	M50-OS v2.2
C6	DO-M95	M95-O v5.1	M50-OS v2.2

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The case vehicle model represented the compact size vehicle crashed to a 75° oblique right-side rigid pole at 31.01 km/h (NHTSA FMVSS 214 test #210915), applied with the vehicle CG accelerations and rotation velocities measured from the crash test. The validated seatbelt and LHS and RHS FE seat models were integrated.

RESULTS

Field Data

80 CIREN cases satisfied the selection criteria were found out. There were 405 AIS 2+ injury incidents in total, out of which 200 (49.4%) incidents were from 43 small size females, and 205 (50.6%) incidents from 37 mid/large size males.

The occupant demographic statistics data for the mid/large size males as following. The height range were 1.65 m—1.88 m; the body mass range 59 kg—142 kg; the BMI range 19.3—46.4; the age range 18 years—82 years, respectively. For the small size females, the height range were 1.45 m—1.65 m; the body mass range 41 kg—70.9 kg; the BMI range 17.7—28.4; the age range 18 years—92 years, respectively.

Compared between the two occupant groups, the far-side injured small females had higher percentages of the tissue injury incidents and more societal cost harm on the neck, thorax, upper and lower extremities than the males while the mid/large males were experienced more harm on the head region, as shown in Figure 1.

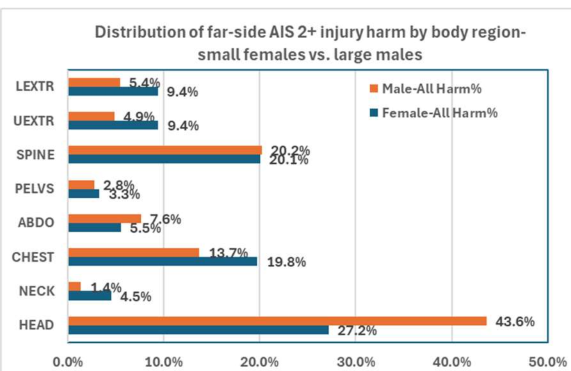

Figure 1. Comparison of distribution of far-side AIS 2+ injury harm by body region between the small size females and the mid/large size males

Out of the 405 AIS 2+ injury incidents, 31 AIS 2+ tissue injuries that were higher occurrence percentages (>2.5%) or critical incidents were counted as 78.3% of the total incidents. Table 2 in Appendix summarizes those 31 top AIS 2+ tissue injuries and their occurrence percentages for both the small females and mid/large males. Comparisons were made for the occurrence percentages of each tissue injury from the field and the yes/no prediction from the HBMs.

HBM Occupant Simulation Results

As shown in Figure 2, HIC for the far-side 5th%ile female in the dual-occupants case (DO-F05 in blue) significantly increased over the single occupant case (SO-F05 in yellow), while all her other injury measures remained about same between the two cases.

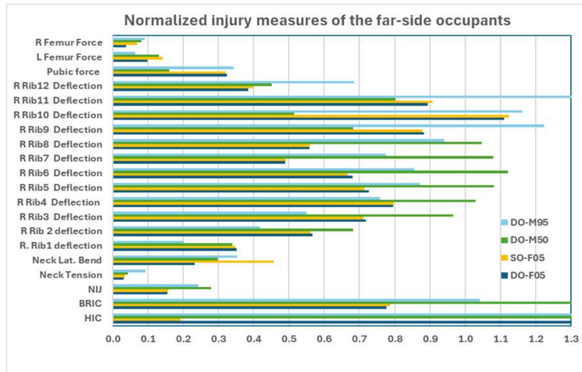

Figure 2. Comparison of the HBM predicted normalized global injury measures from the four simulation cases shown in Table 1. The normalization factors were in Table 3.

The rib deflections in Figure 2 indicated different patterns for different body sizes. Those that the normalized chest deflections exceeding 80% were located to the right ribs #9-11 for the 5th%ile female, #4-9 for the 50th%ile male and #5-6 & 8-11 for the 95th%ile male.

As occupant size increased, the head relative lateral displacements increased in general, the relative longitudinal displacements decreased in single far-side occupant case and increased in the dual-occupants case due to the head contact, as seen from Figure 3.

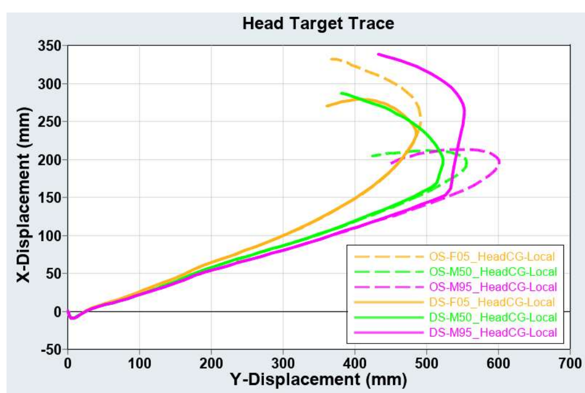

Figure 3. Comparison of the far-side occupants' head CG lateral and longitudinal displacements relative to the vehicle among the three body sizes in the two impact scenarios.

Table 4 in Appendix listed all the normalized injury measures for the HBM predicted tissue injuries of the far-side occupants for the six simulation cases. Those highlighted in red cells reached or exceeded the injury measure thresholds. 18 tissue injuries out of the 31 (58%) listed in Table 2 were predicted by the HBMs, involved 300 real-world incidents (about 74% of the total).

Compared each tissue injury of the CIREN data in Table 2 with the HBMs predicted tissue injuries in Table 4, we observed the following coincidences between the two data sets.

1) In Head region, there were higher local pressure on cerebrum for the small female and larger affected areas for the large male. The mid/large males suffered more risk of skull or facial bones fractures.
2) In Thorax body region, about same number of rib fractures and sternum fracture were estimated for the three far-side occupants (DO-F05: R. ribs #8/9/10/11 fractures; DO-M50: R. ribs #5/7/9/10/ 11, DO-M95: R. ribs #9/10/11/12). The small size female had higher severities of aorta injury than the mid/large males.
3) In Lower Extremities region, the small size female had same or higher risk of Femur/tibia/ fibula fractures than the mid/large males.
4) There were risk of liver injury and lumber fracture for the 5^{th}%ile female, pelvic bones fracture for the 50^{th}%ile male, spleen injury for the 95^{th}%ile male, cervical spine fractures for the mid/large males.

The most often observed tissue injuries from the CIREN data listed in Table 2 but not predicted by the HBMs are as follows: 1) fractures of clavicle, humerus, cervical spine and pelvic bones of the 5^{th}%ile female, 2) humerus and lumbar fractures and spleen injuries of the 50^{th}%ile male, and 3) humerus and pelvic bones and lumbar fractures and liver injury of the 95^{th}% male.

DISCUSSION

About 58% of the tissue injures of the mid/large size males listed in Table 2 were correctly predicted by the HBMs, while the 5^{th}%ile female model predicted about 32% of the risk of tissue injures of the small females in Table 2. There were 10% of the tissue injures of the mid/large size males and 35% tissue injuries of the small size females in Table 2 were not predicted by the HBMs. This could be due to either the simulated vehicle crash case did not generate such injuries or the HBMs had poor prediction capabilities for such tissue injuries.

This study investigated only driver far-side occupants in one vehicle right-side pole crash without considering near-side intrusion in vehicle model. Our next step is to investigate passenger far-side occupants in the vehicle left-side offset crash mode.

The CIREN data from this study indicated higher risk of head injury or harm to the mid/large size males than to the small size females from far-side impacts, which contradicted the findings from NASS/CDS by Carter et al. (2014). The causes could be due to differences of sampling criteria from the two database and a limitation of small size samples from this CIREN study.

CONCLUSIONS

The CIREN data and the far-side occupant simulation study indicated higher injury harms to small size female occupants than the mid/large size males in the chest and the upper and lower extremities body regions.

The CIREN data indicated that the mid/large size males suffered higher head injury harms than the small size female. The HBMs estimated higher risks of skull or facial bones fractures for the mid/large males and higher risk of cerebrum contusion for the small size females from the simulated far-side impact condition.

Further investigation is necessary on those tissue injuries not predicted by the HBMs from this case re-construction, especially on refinement of the human model tissue injury criteria and more vehicles crash far-side impact conditions.

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APPENDIX

Table 2. Comparisons of the most often observed or most critical tissue injuries of the far-side occupants from the real-world crashes (CIREN) and the HBMs predictions.

Body Region	Tissue Injury	AIS Severity Index	Total Incident	Mid/large Males incident Count %	Small Females Incident Count %	Mid/large HBMs Males Prediction	Small HBM Female Prediction
HEAD	Cerebrum hematoma/hemorrhage	AIS 3, 4, 5+	10	5.70%	0.63%	NE	NE
	Orbit fracture	AIS 2, 3	6	1.90%	1.89%	NE	NE
	Cerebrum subarachnoid hemorrhage	AIS 3, 4, 5+	4	1.27%	1.26%	NE	NE
	Base (basilar) fracture NFS; dura intact	AIS 2, 3	5	1.90%	1.26%	FAIL	NONE
	Mandible fracture	AIS 2	4	1.27%	1.26%	FAIL	NONE
	Cerebrum contusion-Bilateral	AIS 2, 3, 4	3	0.63%	1.26%	FAIL	FAIL
	Vault fracture comminuted; compound but dura intact	AIS 2, 3	3	1.27%	0.63%	NE	NE
	Cord laceration-thoracic spine	AIS 2, 3, 4	3	1.27%	0.63%	NE	NE
NECK	Cervical Spine fracture	AIS 2, 3	16	3.80%	6.29%	FAIL	NONE
CHEST	Rib case fractures without fail	AIS 2, 3	32	10.13%	10.06%	FAIL	FAIL
	Thoracic cavity injury Hemopneumothorax	AIS 2, 3	13	3.80%	4.40%	NE	NE
	Rib Cage fractures with flail	AIS 3, 4, 5+	8	2.53%	2.52%	NONE	NONE
	Sternum fracture	AIS 2	16	3.80%	6.29%	FAIL	FAIL
	Aorta laceration/rupture	AIS 5+	2	0.00%	1.26%	FAIL	FAIL
	Clavicle fracture	AIS 2	7	1.90%	2.52%	FAIL	NONE
	Lung contusion	AIS 2, 3, 4	10	4.43%	1.89%	NE	NE
	Scapula fracture	AIS 2	6	1.90%	1.89%	NE	NE
ABDO	Liver laceration	AIS 2, 3, 4, 5+	13	5.06%	3.14%	FAIL	FAIL
	Spleen laceration	AIS 2, 3, 4, 5+	7	3.16%	1.26%	FAIL	NONE
	Kidney Injury	AIS 2, 3, 4, 5+	3	0.63%	1.26%	NONE	NONE
PELS	Pelvis fracture closed	AIS 2, 3	10	1.90%	4.40%	FAIL	NONE
	Pelvis fracture open/displaced/comminuted	AIS 2, 3	10	3.80%	2.52%	FAIL	NONE
SPINE	Thoracic vertebra(e) fracture	AIS 2, 3	35	10.13%	11.95%	NE	NE
	Lumbar vertebra(e) fracture	AIS 2, 3	37	11.39%	11.95%	NONE	FAIL
UEXT	Ulna fracture	AIS 2, 3	12	3.80%	3.77%	NE	NE
	Radius fracture	AIS 2, 3	11	3.16%	3.77%	FAIL	FAIL
	Humerus fracture	AIS 2, 3	4	1.90%	0.63%	FAIL	NONE
	Carpus or metacarpus fracture	AIS 2, 3	4	0.63%	1.89%	FAIL	NONE
LEXT	Fibula fracture	AIS 2, 3	11	1.90%	5.03%	FAIL	FAIL
	Tibia fracture	AIS 2, 3	7	3.16%	1.26%	FAIL	FAIL
	Femur fracture	AIS 2, 3	5	1.90%	1.26%	FAIL	FAIL
TOTAL			317	1	1		

FAIL—Tissue Injury predicted by HBM; NONE— No Tissue Injury predicted by HBM: NE—Not Evaluated by HBM

Table 3. Normalization factors of the global injury measures for the three HBMs

Injury Measure	95th%ile Males Normalization Value	50th%ile Males Normalization Value	5th%ile Females Normalization Value
HIC	700	700	700
BRIC	1	1	1
NIJ	1	1	1
Neck Tension	2.9	2.8	2.0
Neck Lat. Bend	51.5	50.0	35.6
Pubic force	4.5	3.0	1.8
L & R Femur Force	5.2	4.0	3.0

Table 4. The HMBs CII tissue injury measures (reference values and normalized) for the predicted for the six cases.

Body Region	CII (Crash Induced Injuries)		Ref Value	SO-F05	SO-M50	SO	DO-F05	DO-M50	DO-M95
Head	Skull Fracture**	Cortical Layer	0.0042	0.43	1.26	0.50	0.17	2.19	0.64
	Facial Bone	Cortical Bone	0.0042	0.98	1.26	0.98	0.10	8.74	0.90
	Cerebrum Contusion***	Coup	194 kPa	0.17	0.65	0.19	6.86	2.73	3.37
		Contrecoup	-75 kPa	0.29	1.85	0.45	4.35	3.89	1.86
NECK	Cervical Vert.	Cortical Bone	0.0178	0.35	5.47	1.33	0.15	2.34	1.44
CHEST	Aorta Wall Rupture**		0.55	0.93	0.92	0.93	1.16	0.92	0.94
	Ribs Fracture*	Cortical Bone (R. Rib 5)	0.018	0.14	1.48	0.37	0.14	1.46	0.37
		Cortical Bone (R. Rib 7)	0.018	0.03	1.01	0.98	0.23	1.03	0.97
		Cortical Bone (R. Rib 8)	0.018	1.00	1.41	0.52	1.00	0.93	0.77
		Cortical Bone (R. Rib 9)	0.018	1.00	1.42	1.00	1.00	1.59	1.00
		Cortical Bone (R. Rib 10)	0.018	1.00	10.51	1.00	1.00	11.21	1.00
		Cortical Bone (R. Rib 11)	0.018	1.00	8.92	1.00	1.00	9.24	1.00
		Cortical Bone (R. Rib 12)	0.018	0.68	0.57	1.00	0.67	0.87	1.00
	Clavicle Fracture**	Cortical Bone	0.03	0.25	3.13	0.22	0.09	0.31	0.12
	Sternum Fracture**	Cortical Bone	0.02	0.99	1.47	0.96	0.95	1.46	0.98
		Cancellous Bone	0.4	1.47	0.15	1.04	1.47	0.15	1.06
ABDO	Spleen Injury****	Strain Energy Density	0.6	0.07	0.20	4.03	NE	0.18	0.11
	Liver Injury****	Strain Energy Density	0.7	1.11	0.75	0.08	NE	0.72	1.96
	L-Spine Fracture*	Cortical Bone	0.025	0.92	0.28	0.56	1.02	0.28	0.67
PELS	Coxal Fracture**	Cortical Bone	0.025	0.79	2.96	0.99	0.91	2.87	1.00
		Cancellous Bone	0.25	0.56	0.37	1.00	0.54	0.35	0.90
	Sacral Fracture**	Cortical Bone	0.025	0.13	2.61	0.93	0.07	2.32	0.94
UEXT	Humerus Fracture*	Cortical Bone (Right)	0.015	1.00	0.00	0.00	1.00	0.00	0.00
LEXT	Femur Fracture**	Cortical Bone (Right)	0.015	1.29	2.06	1.46	1.61	1.45	1.19
		Cortical Bone (Left)	0.015	0.92	2.74	1.88	6.89	2.81	1.17
	Tibia/FibulaFracture**	Cortical Bone (Right)	0.015	0.98	2.01	0.83	1.45	1.99	0.83
		Cortical Bone (Left)	0.015	0.97	2.16	0.80	1.49	2.15	0.79
	Calcaneus Fracture**	Cortical Bone (Right)	0.02	0.54	1.16	0.81	0.10	1.12	0.85
		Cortical Bone (Left)	0.02	0.41	1.68	0.86	0.08	1.63	0.88
	Knee Ligament	PCL (Right)	0.3	0.52	0.65	0.36	1.03	0.65	0.36
	*	Effective Plastic Strain	**	Maximum Principal		NE; Not Evaluated			
	***	Pressure	****	Strain Energy Density					