OCCUPANT DYNAMICS AND INJURIES IN NARROW-OBJECT SIDE IMPACT

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ABSTRACT

Side impact tree/pole crashes can have devastating consequences. A series of 49 CIREN cases of narrow-object side impacts were analyzed. 26 of 49 had serious chest injury and 26 had serious head injury. Of the head trauma patients, 10 had skull fractures, out of which seven were basilar skull fracture. Seventeen of the head trauma patients had some kind of internal bleeding such as subdural or subarachnoid hemorrhage; three were coded as having diffuse axonal injury. Of the chest injuries, 17 occupants had lung contusions and 19 had rib fractures. Of those with rib fractures, 15 of 17 had unilateral rib fractures. Examining crash test data of side pole crashes, it was evident that in tests where the pole caused intrusion at the middle of the occupant's thigh, a high degree of oblique chest loading occurred. The hypothesis was that this oblique chest loading from the door induces unilateral rib fractures, lung contusions, and possible aortic rupture. Additional testing was done in a sled laboratory to induce oblique chest loading to PMHS. A modified side impact sled buck induced oblique loading at 20 and 30 degree angles to the chest. PMHS subjects experienced unilateral rib fracture patterns. Additional dummy tests in this same configuration were also conducted. Chestband data revealed better biofidelity in the WorldSID dummy than the NHTSA-SID for oblique chest loading. These dummies however, are not currently equipped to measure oblique chest deformations. Narrow-object side impacts are realistic crash environments that can induce oblique chest loading. Because the human may be more vulnerable in this type of crash scenario, dummy biofidelity and measurements, as well as a re-examination of side injury criteria may be necessary to design appropriate injury-mitigating safety devices.

INTRODUCTION

Side impact crashes in general have received more attention recently. Despite a lower overall incidence rate, side impact crashes can result in more serious injuries to occupants compared to frontal crashes [NHTSA Traffic Safety Facts, 2005]. Side impact crashes may result from vehicle to vehicle configurations as well as single vehicle crashes. Most single vehicle side crashes result when the driver loses control and collides with a fixed object. Often the fixed object is a tree or pole. Recently the US federal government has proposed a side impact crash into a rigid pole as part of the regulatory test requirements. It has long been presumed that these single vehicle side impacts into narrow objects result in devastating consequences to the occupants on the near side of the crash. There are very few studies however, that have described occupant injury patterns in sufficient detail to assist designers of vehicle safety systems and to assist in the interpretation of dummy response measures. The purpose of the present investigation therefore, was to characterize occupant injury patterns in side pole/tree crashes using detailed real world data and to develop a laboratory sled test to verify occupant injuries and examine dummy biofidelity.

METHODS

The Crash Injury Research and Engineering Network (CIREN) database contains a wealth of detailed information on real world crashes. The CIREN database is populated with a sample of real world crashes from eight centers around the US. To enroll a case occupant in the CIREN database, the injuries sustained by the occupant must be at least AIS=3, or moderate to severe trauma. The case vehicle must also be within eight model years of the crash date.

For the current study, the database was queried for single vehicle side impacts resulting in collision with a tree or pole. The vehicle collision direction was 2-4 or 8-10 o-clock, and only near side occupants were included in the analysis.

To understand occupant responses in narrow object side crashes, the deformation patterns of the vehicles involved in real world crashes were examined. The oblique door deformation pattern to the occupant compartment was simulated in the sled environment by inducing an oblique load wall configuration. A previously established load wall configuration [Pintar et. al. 1997] was modified to include an angled wall configuration for thorax and abdomen plates (Figure 1). Preliminary PMHS and NHTSA-SID dummy tests were run at 6.7 m/s change in velocity (Table 1). The human surrogates were instrumented with head, T1, T12, and sacrum triaxial accelerometer packages. Rib and sternum accelerometers were also mounted. The load wall was instrumented with uniaxial load cells to measure interaction forces. PMHS were examined for injury with a complete autopsy following testing.

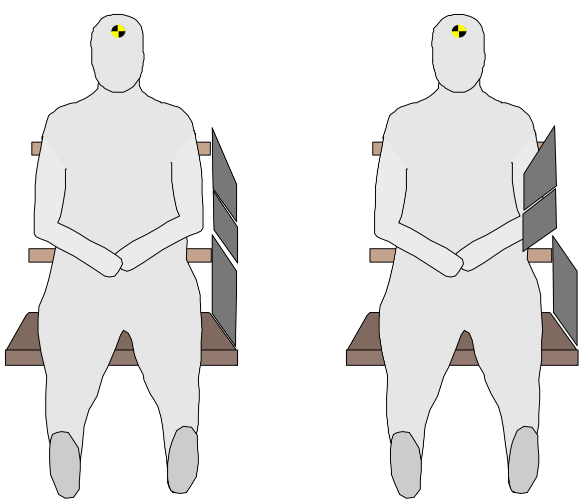

Figure 1. Schematic diagram depicting original flat wall configuration on the left and the modified configuration with angled thoracic and abdominal load plates on the right.

Table 1: Experimental sled tests

Test ID	Config-uration	Gen der	Age (yrs)	Height (cm)	Weight (kg)
PMHS 102A20	20-deg wall	M	46	186	73
NHTSASID 102A20	20-deg wall	---	---	175	75
WorldSID 112A20	20-deg wall	---	---	175	75
PMHS 103A30	30-deg wall	M	52	179	75
NHTSASID 105A30	30-deg wall	---	---	175	75
WorldSID 108A30	30-deg wall	---	---	175	75

RESULTS

For the CIREN analysis, a total of 49 cases were examined. Of the 49, 25 were male, 24 were female; 15 were in the age range from 10-18 years old, while 34 ranged in age from 19-63. There were 34 drivers and 15 passenger occupants. Out of the total occupants, 38 (78%) were belted. The severity of the crash was rated by delta-V calculations based upon deformations using the WINSMASH software program that is standard for CIREN crash reconstruction analysis. Delta-Vs ranged from 17 to 58 km/h with a preponderance of crashes in the range from 24 – 48 km/h (Figure 2). The majority of the case vehicles (28) were model year 1998 or newer (Figure 3).

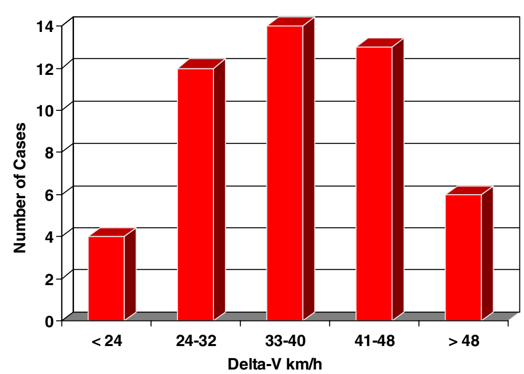

Figure 2. Bar graph representation of the number of CIREN cases analyzed by delta-V range.

Occupant injuries were broadly separated by body region (Figure 4) with at least half sustaining chest and head trauma. Occupants with chest trauma, also had head trauma 73 % of the time. In contrast, pelvis and lower extremity trauma were present in the chest trauma patients only 35 % and 8 % of the time, respectively. Of the head trauma patients, 10 had skull fractures, out of which seven were basilar skull fracture. Seventeen of the head trauma patients had some kind of internal bleeding such as subdural or subarachnoid hemorrhage; three were coded as having diffuse axonal injury. Of the 26 chest trauma patients, 19 had rib fractures and 17 had lung contusions. Ten of the 17 patients had unilateral lung contusions, and 15 of the 19 patients had unilateral rib fractures. Only four of the 26 occupants with chest trauma had isolated injuries.

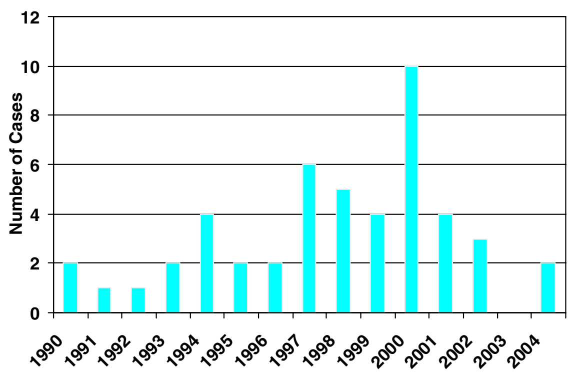

Figure 3. Bar graph representation of the number of CIREN cases analyzed by vehicle model year.

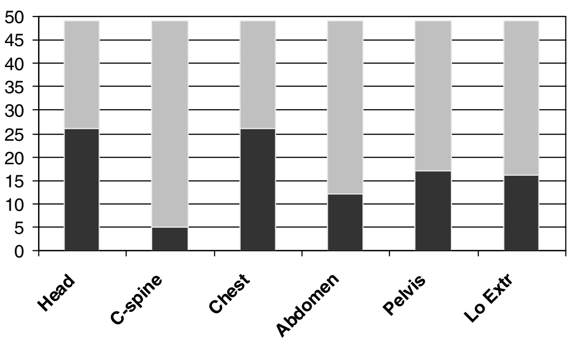

Figure 4. Bar graph representation of the number of CIREN case occupants with trauma by body region. Note that each occupant may sustain multiple trauma.

For the sled studies, a matching test series was done with PMHS, NHTSA-SID, and WorldSID at 20 and 30 degree offset wall conditions. The PMHS that was tested at 20-degrees endured 12 rib fractures that resulted in flail chest. Diaphragm rupture and lung contusion was also present. The PMHS tested at 30 degrees resulted in no skeletal or organ injuries. As an initial assessment of dummy biofidelity, the PMHS load wall responses were scaled to a 50th percentile male (75 kg) and compared to the dummies. For the 20-degree load wall condition (Figure 5), the thorax and pelvis loads of the WorldSID are comparable in magnitude and time duration to the PMHS. The NHTSA-SID thorax and pelvis forces are greater in magnitude and shorter in duration than the PMHS. For the 30-degree load wall condition (Figure 6) the WorldSID thorax response is comparable in magnitude to the PMHS. Both dummies exert a greater force into the pelvis than the PMHS. For the abdomen forces in either configuration the PMHS loads are greater and the time durations are longer than for the dummies.

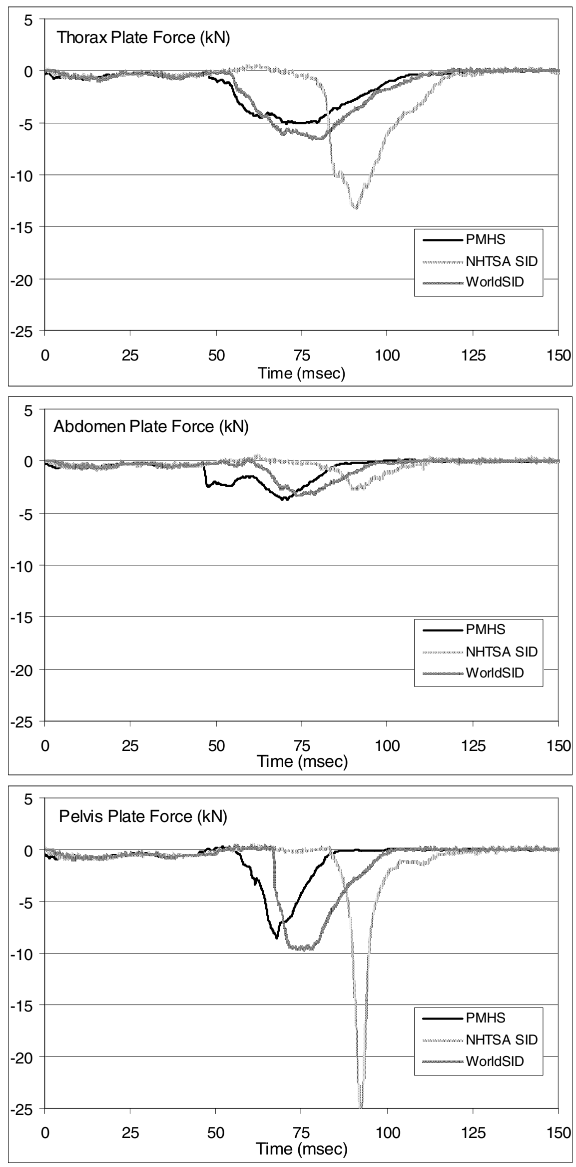

Figure 5. Force response curves from 20 degree oblique load wall sled tests at 6.7 m/s.

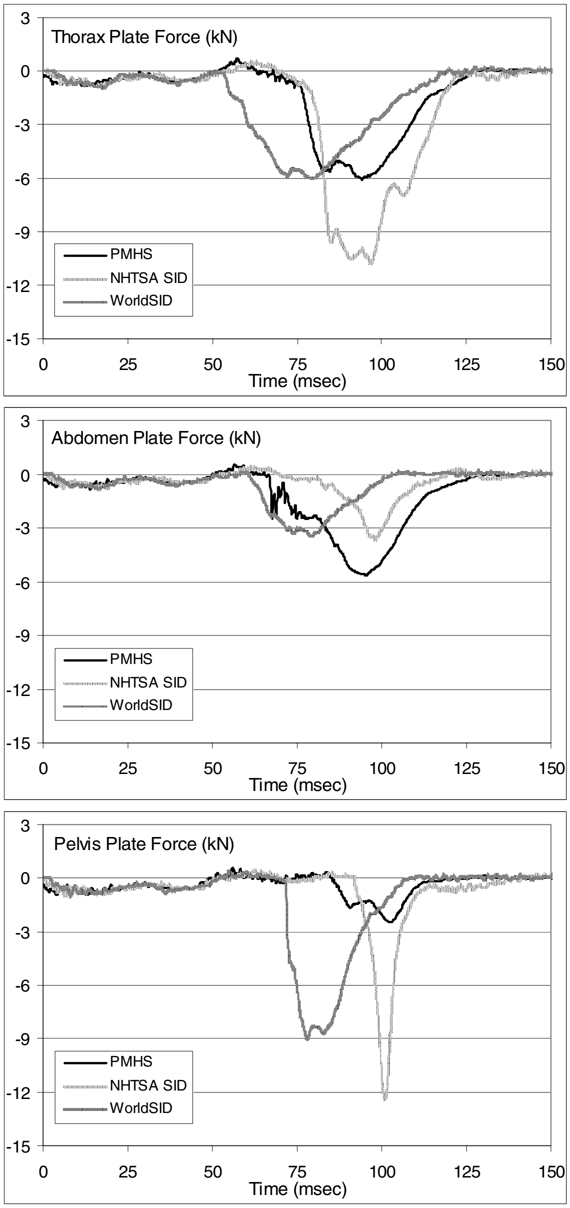

Figure 6. Force response curves from 30 degree oblique load wall sled tests at 6.7 m/s.

DISCUSSION

A side impact into a pole or tree can result in devastating injuries to the near side occupant. A CIREN investigation of 49 cases was undertaken to characterize injury patterns in these types of crashes. The real world data that is collected for CIREN cases results in over 900 data points for each case. The medical images and injury identification documentation is excellent. A prerequisite for inclusion in the CIREN database is that the injuries sustained by the occupant be at least moderate to severe (AIS = 3). The 49 CIREN cases examined in the current study revealed distinct injury patterns. In more than half the cases, head trauma and chest trauma occurred, most often in combination. It is important to note that in only four of the cases were there side airbags present. None of these four cases resulted in head injuries, however two cases resulted in chest or abdomen trauma. The effectiveness of side airbag technology is, as yet, not fully evaluated [Mcgwin et.al., 2003; Yoganandan et.al., 2005].

The focus of this presentation was chest trauma due to the difference in mechanism of injury in these narrow object impacts. It was observed from the vehicle deformation photos that the door intrusion into the occupant space resulted in oblique (antero-lateral) chest loading. This was evident by the occupant chest injury patterns; often unilateral rib fractures and unilateral lung contusions resulted on the struck side. An oblique load to the chest results in a different injury mechanism to the rib cage due to difference in arm position and direct exposure of the rib cage to the load with no protection from the shoulder. The internal organs may also receive a more severe load exposure as the lungs and heart are clearly in line with the impact.

To reproduce these injuries in the laboratory, a unique load wall was designed with inclined plates at the thorax and abdomen regions. The pelvis plate was not oriented obliquely due to the practical constraint of inflicting a focal point of loading to the lower legs. It was also noted in the real world that pelvis and lower extremity injuries occurred only about 30 % of the time and in greater isolation when the impact was located forward on the vehicle. The PMHS test at 20 degree oblique wall configuration resulted in a similar injury pattern as seen in the real world occupants: unilateral rib fractures and unilateral lung contusion.

The NHTSA-SID and the WorldSID were tested in the same load wall configurations as the two PMHS. Neither NHTSA-SID nor WorldSID were designed to be biofidelic in oblique side loading conditions. The WorldSID however, seemed to offer greater biofidelity in the pelvis and thorax under oblique loading conditions. A report on a test series that used the WorldSID in a far side impact scenario also concluded that the dummy was valuable for testing outside of its originally intended design [Pintar, et.al., 2006]. The instrumentation to measure chest deflection in both dummies is directly lateral. It is recommended that the dummy chosen for this type of testing be modified to measure deflections in an oblique direction.

CONCLUSIONS

Narrow-object side impacts are realistic crash environments that can induce oblique chest loading. Because the human may be more vulnerable in this type of crash scenario, dummy biofidelity and measurements, as well as a re-examination of side injury criteria may be necessary to design appropriate injury-mitigating safety devices.

This study has also demonstrated that a trend exists between seatbelt geometry and pretension on the level of restraint provided to occupants in far-side impacts. It has also been highlighted that human anthropometry has a major effect on the restraint provided by the seatbelt in far-side impacts.

ACKNOWLEDGEMENTS

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