INJURY PATTERNS IN SIDE POLE CRASHES

Frank A. Pintar, PhD
Dennis J. Maiman, MD, PhD
Narayan Yoganandan, PhD
Medical College of Wisconsin and VA Medical Center
Milwaukee, Wisconsin

ABSTRACT

Side impact pole/tree crashes can have devastating consequences. A series of 53 CIREN cases of narrow-object side impacts were analyzed. Twenty-seven of 53 had serious chest injury and 27 had serious head injury. Unilateral chest trauma led to the examination of residual crush pattern that often demonstrated oblique door intrusion into the occupant thorax space. It was hypothesized that unilateral chest trauma was caused by antero-lateral chest loading. This hypothesis was evaluated by conducting two (PMHS and ES2) vehicle side impact tests into a rigid pole. The PMHS test produced an oblique chest deformation pattern with injuries very similar to the real world trauma: unilateral rib fractures, spleen laceration, pelvic fracture, and a basilar skull fracture. Narrow-object side impacts are severe crash environments that can induce oblique chest loading and unique head trauma. Because the human may be more vulnerable in this type of crash scenario, dummy response and measurements, as well as a re-examination of side injury criteria may be necessary to design appropriate injury-mitigating safety devices.

Side impact crashes in general have received more attention recently. Despite a lower overall incidence rate compared to frontal impacts, 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 pole or tree. A recent study using US DOT NASS and FARS data indicated that the overall distribution by crash delta-V of vehicle-to-vehicle side impacts was approximately equal to narrow object impacts. However, when MAIS=3+ injuries were examined, narrow object side crashes produced more injuries at lower delta-V [Zaouk et al., 2001]. 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 validate injury mechanisms in controlled full-vehicle laboratory tests.

**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. In the past, there were up to 12 centers that contributed to the database. There are currently almost 3,000 cases with detailed information. 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. There are some exceptions that include children (minimum AIS=2 trauma) and some adults with multiple AIS=2 trauma. The abbreviated injury scale (AIS) as incorporated by the NHTSA into their standard crash analysis routines was used to document all injuries sustained by the case occupant. 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 a collision with a pole or tree. The vehicle collision direction was 2-4 or 8-10 o’clock, and only near side occupants were included in the analysis. Major occupant injuries were evaluated for their association with trauma to other body regions. Vehicle characteristics including deformation patterns, center of maximum deformation, and occupant seat deformations were examined from photo documentation.

As a supplement to the examination of the real world data, two laboratory full-vehicle crash tests at 32 km/h into a 10-inch diameter pole were conducted. One test was done with a post mortem human subject (PMHS) and the second was done with a EuroSID-2 (ES2) dummy. The results from the examination of the CIREN data were used to design the test conditions of the vehicle crash tests to induce maximum head and chest loads to the test occupants. Vehicles were mid-sized sedans without side airbag systems. The center of the pole was aligned with a point 10 cm forward of the occupant H-point. The principal direction of force was 285 degrees, or 15 degrees off a direct 9 o’clock impact to the driver. The vehicles were instrumented with a tri-axial center of gravity (CG) accelerometer and door accelerometers in front and rear aspects recording in the lateral direction. Each of the human surrogates was instrumented with head, T1, T12, and sacrum triaxial accelerometer
packages. In addition, a nine-accelerometer package (NAP) was used to derive head angular accelerations. For the ES2, an internal NAP system from the dummy manufacturer was used, and for the PMHS, a custom-designed pyramid NAP (PNAP) was mounted as described and validated previously [Yoganandan et al., 2006]. Rib and sternum accelerometers were also mounted. Each surrogate was instrumented with a 59-channel chestband device to record chest deflection contours. On the PMHS, the chestband was placed just under the axilla such that rib-4 laterally was directly under the chestband; on the ES2, the chestband was placed over the upper rib [Pintar et al., 1997]. The PMHS was examined for injury with a complete autopsy following the test.

RESULTS

For the CIREN analysis, 53 cases met the inclusion criteria. The age of the occupants were generally younger with 26 (49%) in the range 16-25 (Figure 1). There were 38 drivers and 15 passenger occupants. Out of the total occupants, 40 (75%) 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 15 to 58 km/h with a preponderance of crashes in the range from 31 to 45 km/h (Figure 2). The majority of the case vehicles (32) were model year 1998 or newer (Figure 3). Forty-eight of the case vehicles were passenger cars, three were SUVs and two were pickup trucks.

![Figure 1 - Distribution of occupant age from the 53 CIREN cases.](image_url)
Occupant injuries were broadly separated by body region (Figure 4) with at least half sustaining severe (AIS=3+) chest or head trauma. All of the following comparisons and associations of trauma refer only to AIS=3+ trauma. Occupants with chest trauma also had head trauma 70% of the time (Figure 5). In contrast, lower extremity trauma was relatively isolated with the strongest association (38%) to pelvis injury (Figure 6). Of the head trauma patients, 11 had skull fractures, out of which eight were basilar skull fracture. Eighteen 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 and five
had brain stem trauma. Of the 27 chest trauma patients, 19 had rib fractures and 17 had lung contusions. The lung contusions were not always documented by CT (many by plain film) but when CT images were available, it was evident that the locations of contusion were generally lateral, but some were antero-lateral and some were postero-lateral. Ten of the 17 patients had unilateral lung contusions, and 15 of the 19 patients had unilateral rib fractures. Without exception, unilateral multiple rib fractures and unilateral lung contusion were on the side of the body closest to the intrusion. Only four of the 27 occupants with chest trauma had isolated injuries.

Because the associations between injuries followed some unique trends, it became evident that trauma to various body regions might be dependent on location of maximum damage (i.e., center of pole intrusion on the vehicle). A classification scheme was developed to assess maximum damage location with respect to the center of the wheelbase of the vehicle (Figure 7). This resulted in 19 class-1 impacts, 19 class-2 impacts, and 11 class-3 impacts. There were not enough class-4 impacts to analyze as a group.
Figure 5 - Bar graph representation of the percentage of CIREN case occupants with a given AIS=3+ injury that also had serious head trauma.

Figure 6 - Bar graph representation of the percentage of CIREN case occupants with a given AIS=3+ injury that also had serious lower extremity trauma.
Examining the occupant injury patterns based upon the maximum damage classification developed, resulted in further specification. For class-1 impacts, there was a preponderance of serious lower extremity trauma (Figure 8). Occupant trauma was almost balanced between pelvis, thorax, and head injuries for class-2 impacts (Figure 9), and there was more head and thorax trauma for class-3 impacts (Figure 10).
Because of the high percentage of unilateral chest trauma, the case occupant vehicle damage pattern and interior was examined further. The residual crush pattern often demonstrated that the door was intruded in an oblique manner into the case occupant space. This was especially evident in class-2 and class-3 impacts. It was hypothesized that unilateral chest trauma was due to the oblique door loading during the impact that caused antero-lateral chest loading instead of direct lateral loading through the arm or shoulder. From the interior compartment photos, it was noted that there was a number of twisted, or torqued, seatbacks (Figure 11). A torqued seatback was evident in 11 of the 15 cases that resulted in unilateral chest trauma.
For the two experimental vehicle tests, the CIREN data revealed that a class-2 impact might be the most injurious to a driver occupant. The experiments demonstrated that the chest in this crash configuration does experience oblique loading. The chestband contours demonstrate that the antero-lateral aspect of the thorax was loaded so severely that the chestband demonstrated a kink as the PMHS was squeezed between the door and the seatback (Figure 12). The main difference between the PMHS test and the ES2 test was the delay in the head strike to the pole (Figure 13). This was verified by the onboard high-speed camera that showed the PMHS head translated laterally for a longer time than the ES2 dummy. The PMHS head struck the pole on the lateral aspect of the face whereas the ES2 dummy head struck the pole on the temporo-parietal aspect of the head. The thorax of both the dummy and the PMHS struck the door at about the same time.
Figure 12 - Chestband contours of the PMHS (left) and the ES2 dummy (right) tests in the laboratory vehicle pole tests.
Figure 13 - Recorded and derived results from the experimental tests for the PMHS test and the ES2 dummy test.
The PMHS experienced severe injuries in the vehicle crash test. There were unilateral rib fractures (six left-sided rib fractures), a left clavicle fracture, a spleen laceration, a pelvic ramus fracture, and a comminuted femur fracture. The head strike to the pole caused a zygomatic bone fracture to the face and a temporal bone fracture that extended through the base of the skull.

**DISCUSSION**

A side impact crash into a pole or tree can result in devastating injuries to the near side occupant. A CIREN investigation of 53 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 53 CIREN cases examined in the current study revealed distinct injury patterns. In almost 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; three were seat-mounted head-chest combination bags and one was a seat-mounted torso-only bag. 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 although limited case series are available [McGwin et al., 2003; Yoganandan et al., 2005].

A classification scheme to describe location of maximum damage was developed to identify the specific location on the vehicle that might produce the most severe injuries. A previous study surveyed US DOT NASS and FARS data and determined that the middle one/third (occupant compartment accounts for 42% of narrow object side impacts and 61% of the MAIS=3+ injuries [Zaouk et al., 2001]). This was verified in the current examination of CIREN cases that identified 30 class-2 and class-3 impacts out of 53 cases with AIS=3+ injuries. It was further specified that class-2 impacts produced almost an equal distribution of severe injuries between pelvis, chest, and head body regions. Thus, the laboratory crash test was designed to replicate this type of impact by aligning the center of the rigid pole along a line 10 cm forward of the occupant H-point. This impact location maximized the oblique door loading to the occupant chest, produced hip and thigh trauma, and allowed for direct head contact to the pole.

Chest trauma in the CIREN case series demonstrated a unique injury pattern. It was observed from the vehicle deformation photos that the door intrusion into the occupant space resulted in oblique (anterolateral) 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 a 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. There was also evidence of a torqued or twisted seatback in many of these cases. It can be presumed that the chest is squeezed between the intruding door and the seatback. It is unknown, however, if a torqued seatback may be produced by the intruding pole placing an eccentric load on the vehicle chassis. In either case, the evidence of a torqued seatback may be enough of an implication to first-responders that severe chest trauma is likely.

The unique chest deformation pattern was verified in a PMHS test in an actual vehicle crash into a rigid pole. The PMHS in the experimental test experienced a very similar injury pattern as in the real world cases. There were unilateral rib fractures, a spleen laceration, hip fractures, and a basilar skull fracture. These injuries were indicative of the class-2 pole crashes in the real world CIREN case series. In the CIREN case series, there were eight basilar skull fractures. The PMHS laboratory test revealed the mechanism of this type of skull fracture. It was evident that the head translates laterally and strikes the pole in almost an upright configuration. The severe lateral head strike produces focal loading on the lateral skull that produces a linear fracture pattern extending from the temporal bone inferiorly through the base of the skull. This results in a “hinge”-type fracture through the skull base.

Both the PMHS and the ES2 dummy were tested in the same type of side pole crash configuration. Despite the two different vehicles, the CG accelerations and the velocities were remarkably similar (Figure 14). The door velocity in the front and rear portions produced 5-10 m/s intrusions into the occupant compartment. This is on the order of the speed of the vehicle (8.9 m/s) but certain parts of the door may actually move into the occupant compartment at slightly higher velocities because of the unique deformation pattern induced into the door by the pole. This implies that the chest is subject to antero-lateral loading at very high rates of speed. High-rate chest loading in these impacts may be the cause for the increased probability of severe trauma in a narrow object side impact compared to vehicle-to-vehicle side crashes [Zaouk et al., 2001]. Augenstei identified twice the risk of AIS=3+ injuries in near side crashes when the crash was into a narrow object [Augensten et al., 2003]. The results from this analysis and laboratory testing corroborate these findings.
Figure 14 - Vehicle CG accelerations and velocities in the lateral direction and door velocities in front and rear portions recorded from lateral axis accelerometers.
CONCLUSIONS

Pole/tree side impacts are realistic crash environments that can induce severe injuries to the occupant. The mechanisms of injury are unique to this unusual environment. The antero-lateral chest is loaded in an oblique configuration because of the intruding door. The head translates laterally to often strike the intruded pole/tree producing linear skull fractures, commonly through the skull base. Because the human may be more vulnerable in this type of crash scenario, it is imperative that the dummy models used for injury mitigation design mimic the antero-lateral chest loading response seen in this study.

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REFERENCES


