COMPARISON OF HIGHER SEVERITY SIDE IMPACT TESTS OF IIHS-GOOD-RATED VEHICLES STRUCK BY LTVS AND A MODIFIED IIHS BARRIER WITH THE CURRENT IIHS SIDE TEST AND REAL-WORLD CRASHES

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ABSTRACT

Since 2003, the Insurance Institute for Highway Safety (IIHS) has rated side impact crashworthiness based on tests involving a 1,500 kg moving deformable barrier (MDB) with the geometry of pickups and SUVs (LTVs) striking the side occupant compartment of a stationary vehicle with driver and rear passenger SID-IIs dummies. Previous examinations of real-world side crashes revealed that one quarter of 2016 side crash fatalities were in good-rated vehicles, suggesting that more improvements in side crashworthiness may be necessary. Research focused on injured occupants suggests that a higher severity test in a similar configuration may be the most effective at driving continued crashworthiness improvements relevant in real-world crashes. This study investigates how well the IIHS MDB impact and injury patterns replicate those observed in modern striking LTVs in a higher severity laboratory test.

Four recently designed good-rated vehicles were impacted by an MDB, a pickup, and an SUV at 50 km/h and 60 km/h. Two vehicles, the Toyota Camry and Volkswagen Atlas, were chosen because they had very low structural intrusion measures at the B-pillar in the current (or established) IIHS test, with 22 and 32 cm of survival space for the driver, respectively. Two vehicles, the Honda Accord and Infiniti QX50, were chosen because their survival space measures were on the borderline of a good/acceptable rating, with 14 cm and 15 cm of survival space, respectively.

Data collection included external and internal measurements along the side structures of the vehicles. All other measures and test setup were conducted according to the current IIHS side test protocol. Observations from the crash tests were compared with real-world higher severity crashes involving good-rated vehicles with configurations like the IIHS test to understand the potential real-world benefit of a new crash test configuration.

The MDB produced vehicle kinematics, deformation, and injury patterns that were not representative of striking LTVs. LTVs loaded the struck vehicles with force concentrations at the striking vehicle’s front longitudinal structures while MDBs loaded vehicles more uniformly, both vertically and laterally. Dummy injury patterns were consistent with the deformation patterns; elevated pelvis/femur injury risk was present when struck by the LTVs and elevated head and chest injury risk was present when struck by the MDB.

The four good-rated vehicles exhibited a range of performance when struck by the LTVs, suggesting that a different test configuration, speed, or crash partner may highlight those differences in performance among the current good-rated vehicles. Additionally, MDB tests at 60 km/h revealed dimensional limitations of the barrier that must be addressed prior to further higher speed barrier research.

The current research suggests that increases in severity – mass or speed – of the current MDB would not necessarily encourage vehicle countermeasures that would confer benefit to occupants in real-world side impacts. To encourage relevant real-world design changes, the MDB must be redesigned to replicate the damage and injury patterns of current LTVs in a field-representative impact condition. This test configuration could potentially address an additional 10% of real-world, injury-causing side crashes.

BACKGROUND

The Insurance Institute for Highway Safety (IIHS) began its side crashworthiness evaluation program in June 2003 [1]. SID-IIs dummies are placed in the driver and left rear seating positions of the subject vehicle, and a perpendicular moving deformable barrier (MDB) strikes the left side of the vehicle at 50 km/h [2].

The IIHS MDB was designed to represent the front end of a midsize SUV or large pickup truck, but with a mass (1,500 kg) closer to a small SUV or midsize car. The test evaluation criteria include assessments of dummy injury measures, head protection (which was especially important when few vehicles had standard head-protecting side airbags), and structural intrusion of the occupant compartment as assessed by driver survival space. Vehicles are assigned an overall rating based on a combination of assessment criteria in one of four categories ranging from best to worst protection: good, acceptable, marginal, or poor.

The IIHS side crash test was more challenging to vehicle structures than other regulatory and consumer information tests that were being conducted in 2003. The MDB was heavier, had a higher ride height (compared with the NHTSA and Euro NCAP MDBs), and had a chamfered front end. The combination resulted in B-pillar loading and intrusion that was more severe and matched real vehicle-to-vehicle crash deformation better than other MDBs in use at the time [3]. Although the IIHS test was considered very severe for its time, an early comparison of the IIHS side test with real-world vehicle-to-vehicle side crashes indicated that 70% of serious injury (MAIS 3+) crashes and 90% of fatal side crashes exhibited more intrusion than the average IIHS crash test configuration [4] (Figure 1).

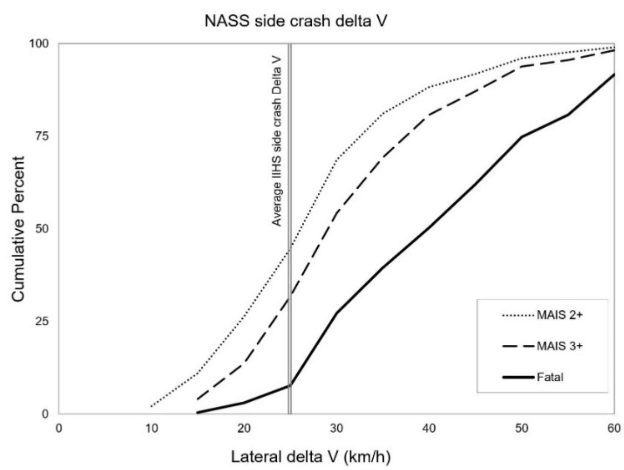

Figure 1. Delta V of side crashes causing injury and fatalities (from "Delta Vs for IIHS side impact crash tests and their relationship to real-world crash severity" by R.A. Arbelaez, B.C. Baker, and J.M. Nolan [2005])

The IIHS side crash test configuration also encouraged the installation of head-protecting side airbags, shown to reduce death risk in near-side crashes [5], which prior to 2003, were not available on most vehicle models or only available as an optional safety feature. The IIHS test encouraged fitment of these airbags because in vehicles without head-protecting side airbags, the front of the MDB often struck the dummy's head, a result of the smaller statured SID-IIs dummy combined with the higher front end of the MDB. To improve ratings, vehicle manufacturers strengthened vehicle side structures and fit head-protecting side airbags, initially as optional equipment and eventually as a standard safety feature by 2009. Since 2014, over 95% of new vehicles rated by IIHS earned a good side crash rating. In 2016, 40% of registered vehicles had a good rating, and this proportion of good-rated vehicles will continue to increase as older vehicles are retired from the fleet. Driver fatality rates in 1–3 year old vehicles have dropped from 22 per million registered vehicles in 2005 to 7 per million in 2017 [6] and declines may be largely attributable to improvements in vehicle crashworthiness [7, 8] (Figure 2). Despite the improvements made in side crash protection and the continued increase of good-rated vehicles in the fleet, side crash fatalities have increased slightly in recent years, leaving open the possibility that modifications to the existing side impact test could further real-world crashworthiness improvements.

Figure 2. Trends in side crash fatalities in the United States from 2000–2016 (data retrieved from NHTSA's Fatality Analysis Reporting System [FARS])

Using methods analogous to the Teoh and Lund study [9], a 2019 analysis by Teoh and Arbelaez was conducted with the latest years of available crash data (2000–2016) but focused on the effects of crash test measures rather than component ratings [10]. Table 1 shows that reductions in crash measures are strongly associated with reductions in real-world death risk, indicating that the level of each measure matters, not just achieving a certain ratings threshold. B-pillar intrusion (survival space) showed the most promise in terms of both risk reduction and room for improvement among rated vehicles on the road. Results demonstrate that one way to improve vehicle performance in side crashes is to change the minimum criteria for good component ratings, even without changing the fundamentals of the crash test.

Table 1.
Percent changes in real-world left-side impact death risk associated with the IIHS side crash test

Test measure	Reduction in measure	Reduction in death risk
B-pillar intrusion	10 cm	25%
HIC-15	100	8%
Maximum shoulder deflection	10 mm	10%
Average rib deflection	10 mm	12%
Maximum rib deflection	10 mm	12%
Maximum rib deflection rate	1 m/s	9%
Maximum rib V*C	0.5 m/s	14%
Acetabulum force	1 kN	7%
Iliac force	1 kN	9%
Combined pelvic force	1 kN	8%

Note. All values are statistically significant at the 0.01 level.

Evaluation crash tests should be based on real-world crash conditions to best develop effective countermeasures against real-world injuries. A 2015 IIHS study focused on crashes that produced serious or fatal injuries to occupants in vehicles with good ratings [11]. Queries of the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) and Crash Injury Research and Engineering Network (CIREN) identified 109 occupants in crashes from 2005–2012. Differences between the real-world crashes and the IIHS test were categorized through in-depth analysis of each case. Table 2 shows the potential for various changes to the IIHS test configuration to affect the injury outcome for the study population. No single change to the current test configuration would have been relevant to more than approximately 25% of the occupants. When considering combinations of two changes, a more severe test combined with a forward-shifted impact point (relative to the existing IIHS configuration), assessment of far-side occupant injuries, or modified injury criteria had the greatest potential relevance. Upon further examination of the far-side occupant cases, configurations included a large number of unbelted and out-ofposition occupants and a variety of alignments and crash severities, which would be difficult to capture in a single test configuration.

Another IIHS study [12] explored whether the occurrence of real-world injury in a crash with an impact location forward of the current IIHS test can be identified in the laboratory, how injury risk in such a configuration compares with the current IIHS test, and whether current vehicle designs already offer improvements over the vehicles in the real-world cases (median model year was 2007). The laboratory tests were successful in replicating the damage and injury patterns seen in the real-world case. It also determined that the risk factors observed in this configuration were mitigated in the newer generation of the vehicle with more recent crashworthiness improvements. This test series further concluded that a higher severity crashworthiness evaluation would be more likely to encourage improvements in the current fleet than one with a forward-shifted impact point.

Table 2.
Potential relevance of test changes to real-world cases

Change or combination of changes	Case occupants affect (%)
Adjust injury criteria	9
Include a far-side occupant	9
Increase severity	17
Shift the impact location forward	28
Increase severity and adjust injury criteria	26
Increase severity and include a far-side occupant	37
Increase severity and forward impact location	62

OBJECTIVE

Currently, IIHS is exploring potential modifications to the side impact crash test to address real-world injuries occurring in vehicles with good performance in the existing test. Previous examinations of real-world side crashes with injured occupants suggest that a higher severity test in a similar configuration may be the most effective at achieving this aim. This study investigates how well the IIHS MDB impact and injury patterns represent those observed in modern pickup and SUV striking vehicles in a laboratory test.

METHODS

Laboratory crash tests

Four recently designed IIHS-good-rated vehicles were impacted by various crash partners at 50 km/h and 60 km/h (Table 3). Two vehicles, the Toyota Camry and Volkswagen Atlas, were chosen because they had very low structural intrusion (greater survival space) measures at the B-pillar in the ratings test, 22 and 32 cm respectively. Two vehicles, the Honda Accord and Infiniti QX50, were chosen because their structural intrusion measures were on the borderline of a good/acceptable rating, 14 cm and 15 cm, respectively.

Striking vehicles were chosen from popular modern vehicles with a focus on pickups and SUVs (LTVs), which the MDB was originally designed to best represent. In addition, one midsize car partner was chosen to understand how cars compare with the MDB. The MDB mass was increased to 1,900 kg, the registration-weighted mass of midsize SUVs in the U.S. market (Figure 3). Registration-weighted mass was calculated based on curb mass from the vehicle information databases maintained by the Highway Data Loss Institute [13] and vehicle registration data from IHS Automotive. The test speed for the striking vehicles was either 50 km/h or 60 km/h. All data were compared with results from the baseline IIHS side test in the 50 km/h, 1,500 kg MDB configuration. Data for comparison included high speed video analysis, dummy sensor measures, and pre- and postcrash static measurements on the vehicle.

Table 3. Test Matrix

	Striking Vehicle					
	60 km/h				**50 km/h**	
	F-150	Pilot	Camry	MDB	MDB	F-150
	2,200 kg	1,900 kg	1,500 kg	1,900 kg	1,500 kg	2,200 kg
Camry	X	X	X	X	X	X
Accord				X	X	X
Atlas	X	X		X	X	
QX50				X	X	

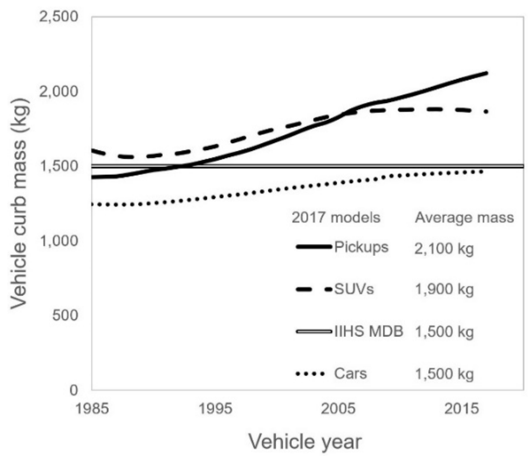

Figure 3. Vehicle curb mass over time based on weighted vehicle registrations (data provided by the Highway Loss Data Institute)

Vehicle tests were setup following the IIHS side impact crash test protocol [2] with the following modifications:

- For striking vehicle partners, a Hybrid III midsize male dummy was installed in the driver and pre- and postcrash measurements of the bumper bar were taken.
- For tests with the MDB, pre- and postcrash measurements of the honeycomb profile were taken at the bumper, mid-barrier height, and top of the barrier.

Adding the extra 400 kg on the MDB resulted in a new center of gravity location and moments of inertia, as shown in Table 4. Striking vehicles were positioned so that the vehicle's centerline aligned with the calculated impact reference distance (IRD) from the front axle to MDB centerline in the test protocol (Table 5).

Table 4. MDB Characteristics

Characteristics	1,500 kg MDB	1,900 kg MDB
CGx rearward of front axle (mm)	990	1,056
CGy from vehicle centerline (mm)	0	0
CGz (mm)	566	530
Ix (kg-m^2)	542	572
Iy (kg-m^2)	2,471	2,560
Iz (kg-m^2)	2,757	2,870

Table 5. Impact reference distance (IRD) from front axle to striking vehicle centerline

Vehicle	IRD (mm)
Camry	1610
Accord	1614
Atlas	1648
QX50	1597

For the struck vehicle, setup followed the IIHS side impact test protocol and UMTRI ATD Positioning Procedure [14] with the addition of pre- and postcrash measurements taken along the side of the vehicle to compare deformation patterns (Figure 4).

Figure 4. Measurement locations for external crush

In addition, pre-and postcrash measurements were taken vertically along the driver-door trim at locations matching the UMTRI ATD Positioning Procedure H-point positions of the Hybrid III 5th female and Hybrid III 50th male dummies [14] to compare localized loading for different-sized occupants (Figure 5).

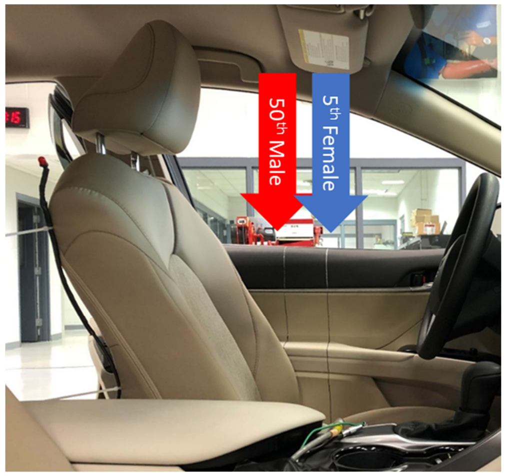

Figure 5. Door trim vertical measurements of crush at the location of dummy H-points

Real-world higher severity crashes

NASS and CIREN cases from Brumbelow et al. [11] categorized as higher severity crashes with similar impact locations as the IIHS side impact test were further examined to relate real-world crash observations to this study's laboratory tests. A list of cases is shown in Appendix C.

RESULTS

Laboratory crash tests

High-speed video footage indicated different vehicle dynamics between vehicle partners and the MDB. The struck vehicles rolled away from the MDB (positive roll, as defined by SAE [15]), while struck vehicles rolled toward (negative roll) all three of the striking vehicle partners. This pattern was observed in all four struck-vehicle models in this study. An example of these kinematic differences is shown in Figure 6 with the Toyota Camry.

Figure 6. Vehicle dynamics comparison between Toyota Camry struck by the MDB (left) and Ford F-150 (right) at 60 km/h during maximum roll

Vehicle deformation patterns were compared using measurements along the outside and inside door and B-pillar structures of struck vehicles. Appendix A has a summary of structural measurements for the striking and struck vehicles. Striking LTVs created a distinct "M" shape in the sides of struck vehicles when compared in a plan view (Figure 7). Whether the striking vehicle was a pickup, an SUV, or a car, they all produced the characteristic 'M' shape deformation pattern to varying degrees. The test configuration aligns the stiffer frame rails with the middle of the struck vehicle doors and the comparatively less stiff bumper center with the B-pillar.

In contrast, the uniform shape and stiffness of the MDB center section created relatively evenly shaped loading into the sides of the struck vehicles (Figure 7). For the MDB impacts, the maximum crush measured at the mid-door height varied by only 6 cm from the crush measured at the B-pillar, compared with a 12- to 19-cm differential in the LTV impacts. Vertically, the MDB resulted in only 2 to 5 cm less crush at the beltline than mid-door, while the LTV and car partners produced 9 to 17 cm less crush. The greater crush at mid-door height aligns with the striking vehicle's frame rails. These trends in vertical deformation patterns are shown in Figure 8.

Survival space measured relative to the driver seat centerline, near the theoretical H-point positions of a 50th male and 5th female dummy was less than at the B-pillar in all tests, with the lowest survival space measures recorded at the 5th female location, the furthest from the B-pillar (Figure 9). The largest differences were seen with LTV partner vehicles, with 7 to 19 cm more intrusion at the 5th female location than measured at the B-pillar. For the four vehicles in this study, the B-pillar is located, on average, 41 cm rearward of the 5th female driver dummy's H-point line. The difference between the measurement and occupant location becomes even more pronounced in two-door vehicles, where the B-pillar was an average of 57 cm rearward of the vehicle occupant being evaluated in a sample of two-door vehicles tested at IIHS. While repeatability of measuring door-trim deformation is suspect, consideration should be made for new test rating criteria to capture the magnitude of intrusion directly at the occupant location to better relate to real-world injuries.

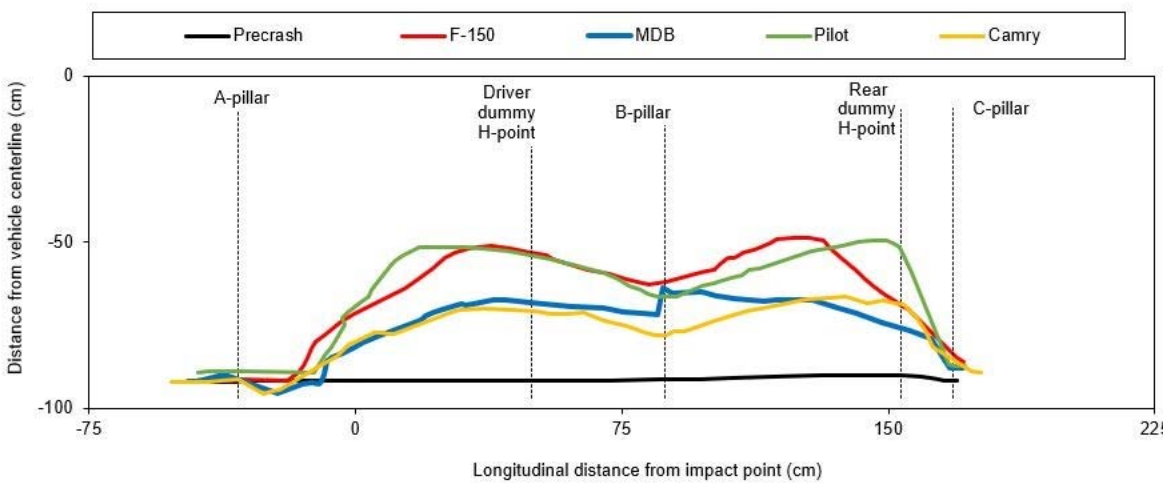

Figure 7. Comparison of external crush along the struck vehicle doors for the Toyota Camry struck by different vehicle partners at 60 km/h

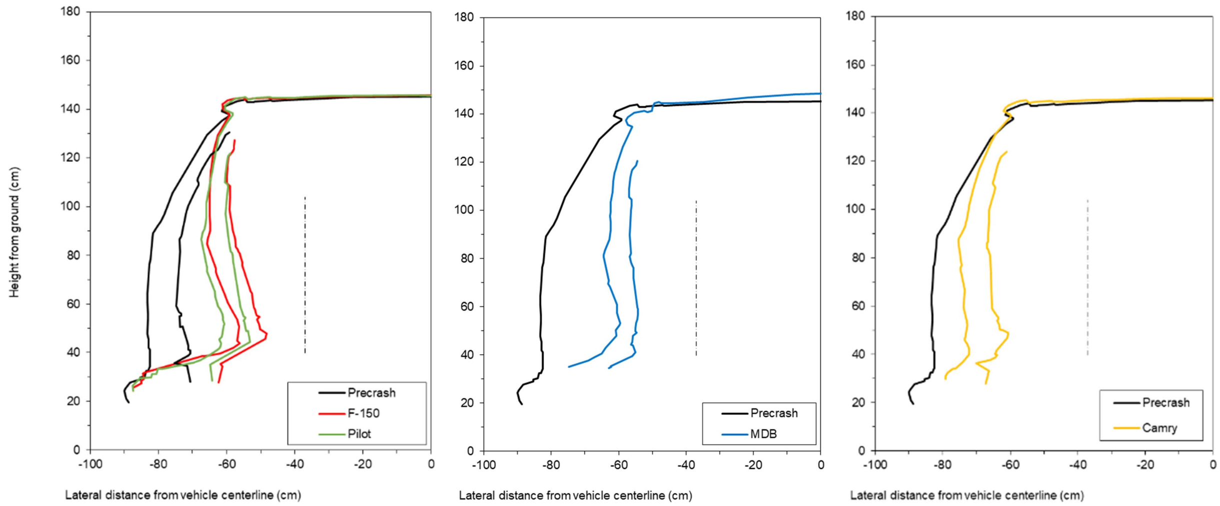

Figure 8. Comparison of B-pillar vertical deformation in Toyota Camry tests

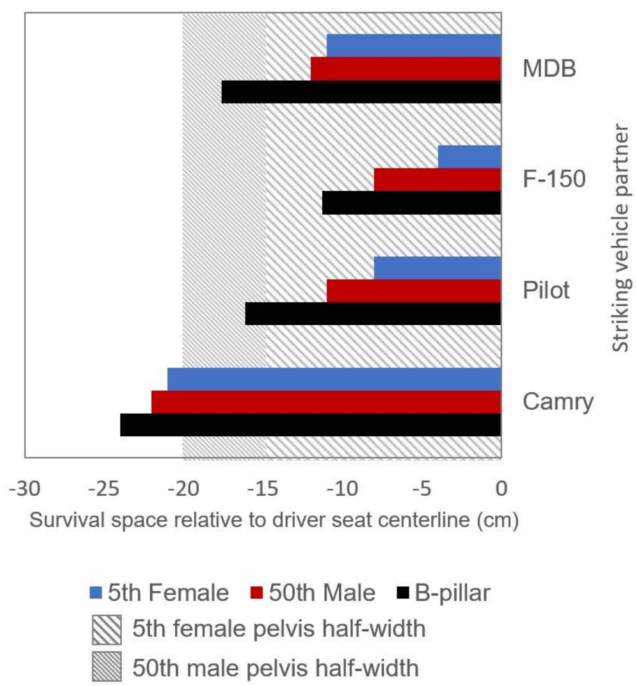

Figure 9. Comparison of occupant survival space measurements for 60 km/h striking vehicles against the Toyota Camry

The effects of crash energy on performance for the Toyota Camry when struck by the F-150 and MDB are shown in Figure 10. The 10 km/h increase in speed for the F-150 test pair represents a 44% increase in energy and resulted in a 50% increase in intrusion on the Camry. In comparison, increasing the MDB mass and speed represented an 82% increase in energy yet resulted in only a 20% increase in intrusion. These specific comparisons highlight the observations that the MDB distributes loading over a broader area of the side structure than the striking LTV.

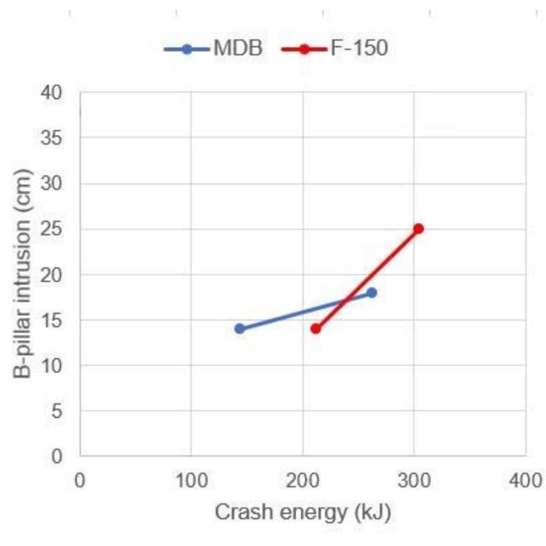

Figure 10. Crash energy and vehicle structural performance for Toyota Camrys struck at 50 km/h and 60 km/h

Peak injury measures from the driver and rear passenger SID-IIs dummies are summarized in Appendix B. General injury patterns in the Toyota Camry tests are illustrated in Figure 11. Striking vehicle partners caused vertically lower structural intrusions and dummies recorded elevated pelvic and femur injury measures, while dummies in the MDB partner tests had elevated head and chest measures.

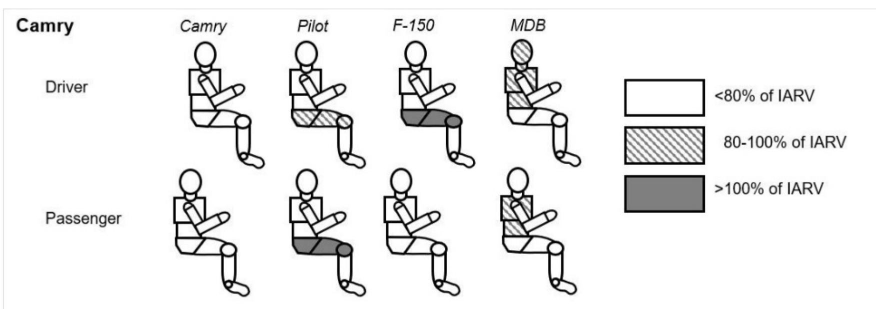

Figure 11. Injury patterns in Toyota Camry tests conducted at 60 km/h

Real-world higher severity crashes

Laboratory test results of impact and injury patterns were compared with observations from field data. NASS and CIREN cases from Brumbelow's 2015 study (Appendix C) that may benefit from vehicle countermeasures designed for a 60 km/h test were identified. Pockets of localized deformation observed in the laboratory tests with striking LTVs were also observed to varying degrees in more than half of the field cases. Maximum crush in real-world crashes was typically higher than measured in this series of laboratory tests (Figure 12). This suggests either that the real-world crashes involve speeds higher than 60 km/h or that the vehicles in this sample, which were older than those in the test series, had weaker side structures. The latter possibility is suggested by the field-study vehicles having lower structural ratings in the standard IIHS evaluations than vehicles chosen for laboratory tests. Dummies in the laboratory LTV-striking vehicle tests had pelvic injury measures suggesting a high risk of injury, consistent with the occurrence of pelvic injury seen in the majority of the field cases. However, the laboratory LTV tests did not reveal high chest injury risk, which was sustained in more than half of the field cases. Laboratory LTV tests did not predict high risks of head injury, consistent with the low frequency of head injuries observed in the field. For the two field occupants with head injuries, it is suspected that curtain airbags were not fully effective in preventing head contact with the striking pickups, resulting in contact through the airbag.

Laboratory MDB-striking-vehicle tests showed mixed trends when compared with field data. Relatively uniform loading across the struck vehicle's side was seen in about half of the field cases, but vertically, intrusion patterns were more consistent with LTV laboratory tests, with maximum crush concentrated at mid-door height and significantly less at higher locations. Dummies in the MDB tests did not reveal high pelvic injury risk, despite the large frequency seen in field cases. Conversely, the MDB tests typically predicted high risks of head injury, but the field cases typically did not. Dummies in the MDB tests were consistent with field observations for chest injury risks.

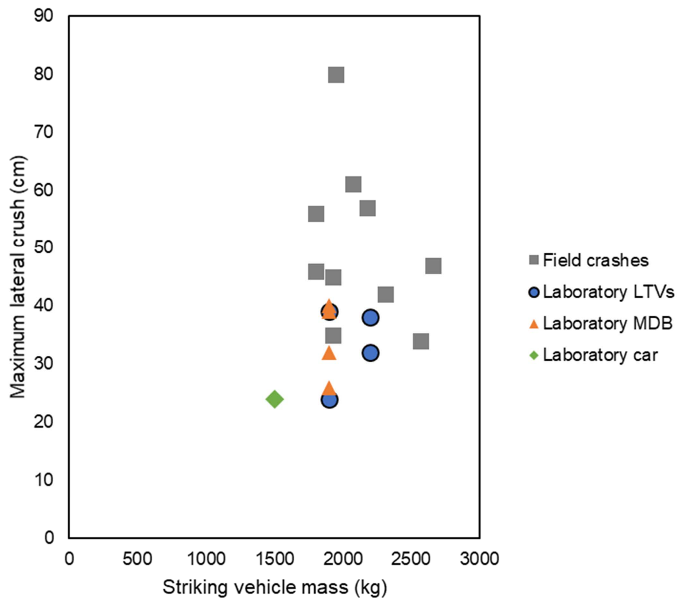

Figure 12. Vehicle maximum crush for seriously injured real-world occupants in side crashes with a striking LTV that may benefit from a higher severity ratings test compared with laboratory tests conducted at 60 km/h

DISCUSSION

In the 1990s, field evidence was clear that occupant injury risk in side-struck vehicles was significantly higher when the striking vehicle was a pickup or an SUV. IIHS developed its side barrier to mimic this elevated risk and encourage automakers to improve occupant protection. The structural changes, plus the fitment of side head-protecting airbags that resulted, have been very effective at reducing side impact fatalities.

The efforts in the current study suggest that the simplistic barrier design conceived in the late 1990s is no longer replicating the deformation and injury patterns of current striking LTVs. Design requirements in regulatory and consumer information tests in the 1990s did not necessitate structural improvements of vehicle sides to perform well, but current testing requirements require consideration for stronger vehicle structures. Consequently, the lack of fidelity of the IIHS MDB to real LTV front structures was not as apparent as the present tests show. Current side designs now tend to fend off the MDB by carrying large loads through the B-pillar, door sill, and roof rail. However, the fronts of modern vehicles are stiffer at the frame rail locations while sections outside and in the middle are softer, contrasting with the MDB's uniform stiffness. Thus, the strongest parts of vehicles' sides do not align with the stiffer portions of the striking vehicles' fronts, so less load can be carried by the B-pillar, door sill, and roof rail than is apparently the case when struck by the IIHS MDB. Additionally, the MDB is loading A-pillars and lower rear door frames of the struck vehicles, which is not seen with LTV striking vehicle comparisons (Figure 13).

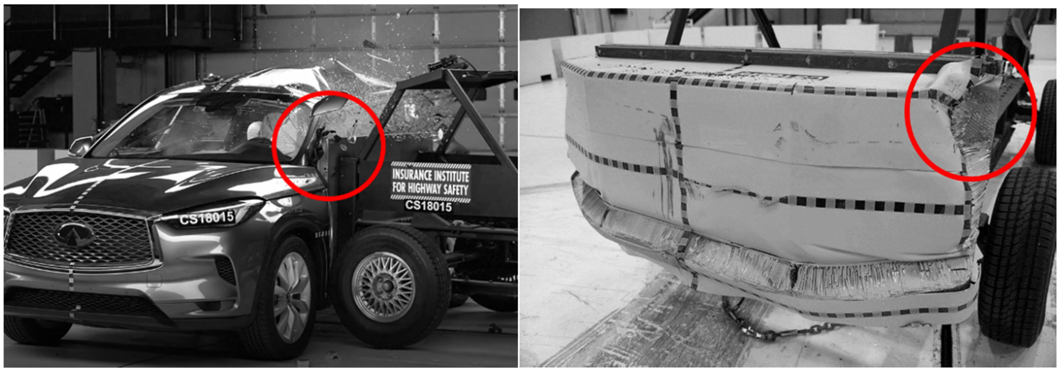

Figure 13. Barrier crush in the 60 km/h Infinity QX50 test highlights significant loading at the barrier's edges that do not occur in laboratory LTV tests

Vehicles in this study had a range of performance in higher severity tests. The two vehicles with the strongest B-pillar structures (Camry and Atlas) performed appreciably better than their borderline good B-pillar structure comparison vehicles (Accord and QX50) in comparative tests with real striking vehicles. Differences were more dramatic in the 60 km/h MDB configuration, where the Camry had an additional 9 cm of survival space compared with the Accord and also, the Atlas had 17 cm more survival space compared with the QX50. The higher levels of intrusion in the Accord and QX50 tests corresponded to much higher risks calculated for head and chest injuries compared with the Camry and Atlas. The 50 km/h F-150 tests, with a crash severity closer to the IIHS ratings test, did not differentiate vehicle structural performance between the Camry and the Accord, but indicated that these vehicles provide different levels of pelvic protection for occupants, with pelvic injury risks up to 115% of the good-acceptable boundary for the Camry and 165% for the Accord. In comparison, for the IIHS ratings tests, neither vehicle indicated deficiencies for pelvic protection, where dummies in both vehicles measured pelvic injury below 70% of the good-acceptable boundary. A different test configuration, speed, or crash partner may capture that modern vehicles with good IIHS side impact ratings have a range of occupant protection in higher severity side crashes.

A future IIHS side crash test must be able to replicate real-world damage and injuries to encourage effective crashworthiness improvements beyond those developed for the current evaluation. IIHS is investigating barrier modifications that will better replicate common LTV crash partners in terms of mass and front-end structure. Damage patterns and injuries from real-world crashes correspond to results from 60 km/h tests with LTV partners better than tests with the current MDB. The localized pockets of door deformation observed in all LTV partner tests were seen to varying extents in about half of the real-world cases with LTV partners. Cases with more uniform loading typically had torn B-pillars, suggesting weaker B-pillar structure (many of the real-world vehicles had acceptable-rated B-pillar structure) or that these crashes had significantly more energy than the laboratory tests. Serious pelvic injuries occurred in 70% of the real-world cases (Figure 14), and LTV laboratory tests indicated risks to this body region while MDB tests did not. In contrast, the incidence of real-world chest injuries was better reflected by MDB test results. However, this may indicate that the current injury criteria can be further improved, as Teoh and Arbelaez [10] showed a 10-mm reduction in peak deflection related to a 12% increase in survivability. Additionally, rating criteria should include considerations for an elderly risk curve to provide benefit for chest-injured occupants over 60 years old. Low head injury risks from the LTV tests better agreed with the low number of real-world observations of head injury than the higher head injury risks observed in the MDB tests. A higher speed test with the current MDB could encourage countermeasures targeting body regions where the fewest amount of injuries are occurring while potentially ignoring areas of greater concern. An MDB that better replicates modern LTVs is needed to appropriately address real-world injuries. A higher speed test with a redesigned MDB could potentially address an additional 10% of real-world injury-causing side crashes. Vehicle design changes made in response to such a test would need to be evaluated for their potential to reduce protection in the more common lower severity crashes where much improvement already has been achieved.

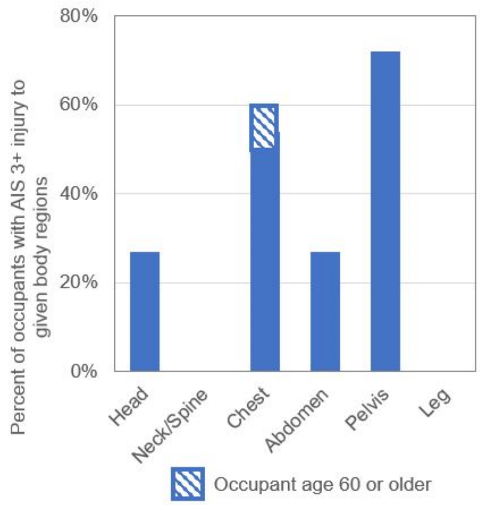

Figure 14. Injured body regions for seriously injured real-world occupants in side crashes with striking LTV partners that may benefit from a higher severity ratings test

CONCLUSIONS

The current IIHS side impact test, developed in 1999–2002, has encouraged side crashworthiness improvements that have significantly reduced driver fatality rates in side impact crashes. Findings from this research suggest that further improvements could be encouraged. Options such as a higher severity crash test show promise. To achieve this, the IIHS MDB needs modifications to better replicate the deformation and injury patterns caused by LTVs.

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APPENDIX A: VEHICLE DEFORMATION

Table A1. Measurements of external crush along the struck vehicle side profile (cm)

	Lower door			Mid-door				Upper door			
	Driver H-point	B-pillar	Passenger H-point	Driver H-point	B-pillar	Passenger H-point	Max	Driver H-point	B-pillar	Passenger H-point	Max
F150	23	21	15	31	16	20	34	14	20	13	20
Pilot	13	12	16	23	12	20	31	7	6	16	14
MDB	12	16	17	33	28	17	33	27	25	15	30
F150	2	2	1	39	30	20	43	17	15	18	27
Pilot	2	2	1	37	25	38	42	25	13	27	33
MDB	0	2	4	24	28	14	28	21	17	15	23
Camry	9	9	4	22	14	21	25	3	7	9	13
50km/h F150	18	7	12	31	20	20	38	11	10	16	25
MDB	5	9	9	39	36	31	39	37	29	23	37
50 km/h F150	18	6	28	35	19	24	37	20	8	20	27
MDB	14	12	9	39	35	31	41	38	38	28	38

Table A2. Struck vehicle survival space comparison at interior locations relative to the driver seat centerline aligned longitudinally with the theoretical 5th female H-point, 50th male H-point, and centerline of the B-pillar structure as used for rating vehicles (cm)

		5th Female	50th Male	B-pillar
Camry	50 km/h MDB			-22
	F-150	-4	-8	-11
	Pilot	-8	-11	-16
	MDB	-11	-12	-18
	Camry	-21	-22	-24
	50 km/h F150	-13	-23	-22
Atlas	50 km/h MDB			-32
	F-150	-7	-11	-26
	Pilot	-22	-23	-32
	MDB	-6	-9	-21
Accord	50 km/h MDB			-15
	50 km/h F150	-16	-17	-21
	MDB	-5	-7	-9
QX50	50 km/h MDB			-14
	MDB	-4	-5	-4

APPENDIX B: DUMMY INJURY MEASURES

Table B1. Peak driver dummy injury measures

		Camry						Atlas					Accord		QX50	
		60 km/h				50 km/h		60 km/h			50 km/h	60 km/h	50 km/h		60 km/h	50 km/h
	Reference	F150	Pilot	MDB	Camry	MDB	F150	F150	Pilot	MDB	MDB	MDB	50 F150	MDB	MDB	MDB
Resultant acceleration (g)		70	69	82	36		56	32	21	109		110	42		88	
Resultant acceleration (3ms clip, g)		66	66	80	36		54	29	20	92		106	38		84	
HIC15	779	412	434	723	107	334	276	65	26	696	63	1291	116	316	791	159
X shear force (kN)		-0.4	-0.4	-0.6	-0.3		-0.3	-0.4	-0.2	-0.5		-0.8	-0.4		-0.4	
Y shear force (kN)		0.5	0.4	-0.4	0.3		0.3	0.5	0.3	0.6		-0.4	-0.3		0.4	
Tension (kN)	2.1	1.4	1.4	1.5	0.8	0.9	0.8	1	0.6	1.6	0.7	1.4	1	0.9	2	1.4
Compression (kN)	2.5	0.5	0.9	0.1	0.2	0.2	0.3	0.2	0.1	0.6	0.4	0.1	0.2	0.1	0.4	0.3
X moment (Nm)	±67	-58	-45	-35	-18		-38	34	-10	29		-39	-46		-27	
Z moment (Nm)	±39	-22	-25	-18	16		-21	24	15	-17		-32	-11		-23	
Lateral deflection (mm)	60	30	39	53	15	29	19	24	24	49	23	61	13	53	61	42
Lateral force (kN)		1.6	1.6	2.1	1	1.2	1.3	1.4	1.4	2	1.1	4.8	0.8	1.5	5.2	1.7
Rib 1 deflection (mm)	34	25	29	46	9	27	15	12	11	32	21	58	17	42	58	33
Rib 2 deflection (mm)	34	23	30	40	12	28	14	17	14	31	19	54	18	37	57	36
Rib 3 deflection (mm)	34	29	35	42	16	30	20	22	18	36	17	52	20	34	56	37
Rib 4 deflection (mm)	32	33	37	36	21	28	25	23	21	46	17	43	17	29	45	32
Rib 5 deflection (mm)	32	38	40	34	25	29	33	23	22	40	16	37	21	28	35	27
Maximum Rib Deflection		38	40	46	25	30	21	23	22	46	21	58	19	42	58	37
Average rib deflection (mm)		29	34	41	16	28	21	19	17	37	18	49	21	34	50	33
Rib 1 deflection rate (m/s)	8.2	1.97	1.55		0.74	2.8	1	1.48	1.18	1.85	1.82	6.27	1.28	4.12	5.98	4.86
Rib 2 deflection rate (m/s)	8.2	2.22	1.36	3.94	0.76	2.4	1.14	1.82	1.52	2.04	1.75	6.23	1.12	3.63	6.58	4.21
Rib 3 deflection rate (m/s)	8.2	2.42	1.91	3.82	1.5	2.4	1.34	2.4	2.15	2.68	1.84	5.32	1.4	3.18	6.14	3.89
Rib 4 deflection rate (m/s)	8.2	3.11	2.12	3.1	1.63	2.1	2.13	2.25	2.37	2.98	2.14	3.32	1.98	3.08	3.56	3.75
Rib 5 deflection rate (m/s)	8.2	2.82	2.42	2.93	1.66	3.6	2.47	2.25	2.52	2.39	1.89	4.33	3.63	5.03	3.2	3.65
Rib 1 VC (m/s)	1	0.27	0.28	0.85	0.02	0.33	0.08	0.08	0.07	0.33	0.17	1.6	0.12	0.59	1.16	0.61
Rib 2 VC (m/s)	1	0.22	0.27	0.78	0.04	0.33	0.07	0.17	0.11	0.31	0.17	1.68	0.1	0.56	1.35	0.6
Rib 3 VC (m/s)	1	0.37	0.33	0.82	0.09	0.34	0.12	0.3	0.18	0.48	0.16	1.51	0.17	0.54	1.41	0.54
Rib 4 VC (m/s)	1	0.55	0.41	0.61	0.16	0.28	0.28	0.27	0.27	0.72	0.11	0.67	0.11	0.32	0.69	0.28
Rib 5 VC (m/s)	1	0.58	0.44	0.58	0.19	0.31	0.42	0.22	0.29	0.48	0.1	0.46	0.13	0.31	0.42	0.25
Lateral acceleration (g)		152	52	54	66		96	29	9	74		33	148		79	
Iliac force (kN)	4	0.5	3	0.3	2	1.3	1.9	2.9	1.6	0.4	1.2	1.7	1.7	1.1	2.4	1.2
Acetabulum force (kN)	4	3.2	2.6	1.6	1.8	1.4	2.7	3	3.1	2.4	2.3	1.5	4.5	0.9	1.4	1.2
Combined Acetabulum and Ilium force (kN)	5.1	3.7	5.2	1.9	3.7	2.6	4.6	5.6	4.6	2.8	3.5	2.7	5.3	1.3	3.7	2.3
Distal femur Y force (3ms clip, kN)	±3.9	-3.6	-1.1	-0.7	-0.5	-0.4	-0.4	-1.2	-0.5	-1.1	0.5	-0.9	-0.6	0.8	-1.3	-0.6
Distal femur X moment (3ms clip, Nm)	±356	563.7	199.1	103.6	147.9	50	247.8	138.1	52.7	120.1	40	130.9	386.7	53	186.2	94
Distal femur Y moment (3ms clip, Nm)	±356	-74.4	85.5	62.3	34.9	122	52.9	-28.1	-13.4	38.8	16	71.1	53	137	51.9	32

Table B2. Peak passenger dummy injury measures

		Camry						Atlas				Accord			QX50	
		60 km/h				50 km/h		60 km/h			50 km/h	60 km/h	50 km/h		60 km/h	50 km/h
	Reference	F150	Pilot	MDB	Camry	MDB	F150	F150	Pilot	MDB	MDB	MDB	50 F150	MDB	MDB	MDB
Resultant acceleration (g)		46	49	66	45		47	53	49	51		66	51		72	
Resultant acceleration (3ms clip, g)		43	48	65	44		46	53	48	48		63	51		70	
HIC15	779	171	226	425	176	151	176	258	206	199	57	379	233	111	463	90
X shear force (kN)		-0.1	0.1	0.3	0.1		-0.1	-0.3	-0.3	-0.2		0.3	0.3		-0.2	
Y shear force (kN)		-0.5	-0.4	-0.2	-0.2		-0.3	-0.2	0.3	0.3		0.4	-0.3		-0.4	
Tension (kN)	2.1	0.4	0.6	0.2	0.2	0.1	0.2	0.7	0.8	0.3	0.1	0.9	0.4	0.3	0.6	0.4
Compression (kN)	2.5	0.5	0.3	0.5	0.5	0.5	0.5	0.3	0.4	0.5	0.5	0.2	0.6	0.5	0.9	0.6
X moment (Nm)	±67	-23	-31	-28	-17		-14	-42	-48	-50		-48	-30		-37	
Z moment (Nm)	±39	-21	-25	-23	-17		-18	-13	16	-19		-20	-24		-20	
Lateral deflection (mm)	60	22	23	38	25	22	22	31	21	25	17	52	43	36	38	25
Lateral force (kN)		1	0.7	1.7	1.2	0.9	0.9	1.4	1	1.5	1	1.7	0.9	0.9	2.4	1.5
Rib 1 deflection (mm)	34	24	27	34	31	24	25	23	19	21	15	57	45	41	31	17
Rib 2 deflection (mm)	34	23	27	38	31	26	21	20	17	18	11	49	33	30	22	14
Rib 3 deflection (mm)	34	24	29	39	33	24	23	32	21	15		38	16	15	13	14
Rib 4 deflection (mm)	32	22	24	38	29	20	21	48	48	42	23	25	5	17	32	33
Rib 5 deflection (mm)	32	24	27	28	30	21	25	54	57	52	34	26	7	15	56	46
Maximum Rib Deflection		24	29	39	33	26	23	54	57	52	34	57	45	**41**	56	**46**
Average rib deflection (mm)		24	27	35	31	23		35	32	29	21	39	21	**24**	31	**25**
Rib 1 deflection rate (m/s)	8.2	1.4	1.62	2.12	1.4	1.4	0.93	2.62	3.54	2.43	2.04	6.36	3.49	2.95	2.92	1.73
Rib 2 deflection rate (m/s)	8.2	1.45	1.6	2.2	1.76	1.6	0.97	2.56	3.38	2.42	1.98	5.56	2.37	2.44	2.64	1.64
Rib 3 deflection rate (m/s)	8.2	1.61	1.84	2.15	2.27	1.3	1.27	2.49	2.69	1.68		4.35	1.95	1.56	1.85	1.52
Rib 4 deflection rate (m/s)	8.2	1.69	1.92	2.19	2.03	1.1	1.45	4.09	3.34	3.5	2.05	3.48	1.15	3.48	2.63	2.39
Rib 5 deflection rate (m/s)	8.2	1.69	1.93	1.84	2.1	3.9	1.52	5.5	4.91	4.23	2.73	4.97	0.93	2.22	3.7	3.19
Rib 1 VC (m/s)	1	0.19	0.22	0.38	0.26	0.19	0.14	0.23	0.3	0.21	0.16	2.06	0.76	0.51	0.35	0.12
Rib 2 VC (m/s)	1	0.2	0.23	0.49	0.24	0.22	0.1	0.21	0.26	0.17	0.09	1.39	0.3	0.32	0.18	0.1
Rib 3 VC (m/s)	1	0.22	0.29	0.45	0.3	0.18	0.14	0.35	0.32	0.08		0.78	0.14	0.12	0.06	0.1
Rib 4 VC (m/s)	1	0.19	0.27	0.49	0.23	0.12	0.14	0.82	0.92	0.73	0.22	0.45	0.02	0.2	0.38	0.42
Rib 5 VC (m/s)	1	0.21	0.28	0.29	0.23	0.14	0.18	1.01	0.97	0.96	0.49	0.38	0.04	0.13	0.8	0.59
Lateral acceleration (g)		137	165	76	83		105	95	88	73		110	77		74	
Iliac force (kN)	4	1.2	1.7	0.9	1.1	0.9	0.6	0.5	0.4	1.6	0.3	0.7	0.1	0.1	0.5	0.7
Acetabulum force (kN)	4	2.3	6.1	1.6	2.4	1	4.6	5.8	5.3	1.8	1.8	0.7	2.9	0.5	1.7	0.5
Combined Acetabulum and Ilium force (kN)	5.1	3.4	7.8	2.4	3.5	1.7	5.1	6.1	5.6	2.9	1.9	1.3	2.9	0.6	2.1	1
Distal femur Y force (3ms clip, kN)	±3.9	1.2	-0.5	0.4	0.8	0.2	-0.7	-0.5	-0.9	-0.4	0.6	-2.3	1.1	0.7	-1.8	-1.3
Distal femur X moment (3ms clip, Nm)	±356	232.4	143.3	106.9	111.8	-31	168.6	187.9	85.9	105.6	29	636.5	420	28	205.9	140
Distal femur Y moment (3ms clip, Nm)	±356	-160.3	52.8	25.8	30.9	89	-85	-39.8	43.9	-21	16	-269.5	-193.7	206	19.2	32

APPENDIX C: NASS AND CIREN CASE LIST

Table C1.
Crashes that may benefit from a higher speed crash test

Case ID	Crash partner	AIS 3+ injured body regions
781136585	LTV	Abdomen, pelvis
2011-73-024	Heavy vehicle	Chest (elderly)
2007-81-048	Fixed object	Leg
133129	LTV	Abdomen, pelvis
352203868	Car	Chest, pelvis
338071752	LTV	Chest, pelvis
2007-48-216	LTV	Pelvis
2010-75-043	LTV	Chest, pelvis
2009-12-289	Car	Chest (elderly)
842005511	LTV	Head, chest, abdomen, pelvis
2012-73-118	LTV	Chest
2012-78-139	LTV	Chest, pelvis
852153529	LTV	Chest (elderly)
2011-09-091	LTV	Head
554160123	LTV	Head, pelvis

Table C2.
Crashes too severe to benefit from a higher speed crash test

Case ID	Crash partner	AIS 3+ injured body regions
160151944	LTV	Pelvis
2009-79-003	Fixed object	Head, spine, chest
2009-11-180	Fixed object	Head, spine chest, abdomen
2007-09-135	Fixed object	Head
2009-09-185	Fixed object	Chest, abdomen, pelvis
2011-81-080	Fixed object	Head, chest
2009-79-180	Car	Chest
2006-09-173	Car	Head, neck, chest
2009-43-041	Fixed object	Chest
2007-74-123	Fixed object	Chest
2007-11-067	Heavy vehicle	Head, chest, abdomen
2007-45-174	Fixed object	Head
2011-11-187	Heavy vehicle	Chest
2012-48-109	Heavy vehicle	Head, chest, abdomen
2012-49-052	Fixed object	Head