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Claire Laberge-Nadeau
François Bellavance
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Bureaux de Montréal :
Université de Montréal
C.P. 6128, succ. Centre-ville
Montréal (Québec)
Canada H3C 3J7
Téléphone : 514 343-7575
Télécopie : 514 343-7121

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Université Laval
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Québec (Québec)
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Occupant Injury Severity from Lateral Collisions: A Literature Review

Claire Laberge-Nadeau[1,2], François Bellavance[1,3,*], Stéphane Messier[1], Lyne Vézina[4], Fernand Pichette[4]

[1] Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT)

[2] Department of Social and Preventive Medicine, Université de Montréal, 1420, boulevard Mont-Royal, Montreal, Canada H2V 4P3

[3] Department of Management Science, HEC Montréal, 3000, chemin de la Côte-Sainte-Catherine, Montreal, Canada H3T 2A7

[4] Société de l'assurance automobile du Québec (SAAQ), 333, boulevard Jean-Lesage, Québec, Canada G1K 8J6

Abstract. *Problem*: Side-impacts are a serious automotive injury problem; they represent about 30% of all fatalities for passenger vehicle occupants. This literature review focuses on casualties resulting from lateral crashes. It takes stock not only of vehicle, occupant, and crash characteristics but also of severity and types of injuries. It highlights what is known on the subject and what questions remain unanswered. *Method:* We reviewed publications identified by searches in several electronic data bases. Though our search had no date limitations, the 1996-2006 period did receive closer scrutiny, the focus being on real crashes and injuries. *Results:* Studies on the Primary Direction of Force (PDOF) have revealed that fatal crashes occur most frequently when the PDOF is at 3 or 9 o'clock. The risk of serious injury is 2 to 3 times higher for the near-side occupant than for the far-side occupant. Head injuries predominate in oblique impacts and thoracic injuries in perpendicular ones. A few results are also reported on side airbag protection. *Conclusions:* This literature review presents an overall picture of the injuries caused by lateral collisions, though each of the papers or articles examined focuses mostly on some particular aspect of the problem. The incidence of specific injuries depends on the data source used. Very few population-based analyses of lateral collision injuries were found. New studies are needed to evaluate new protective devices: e.g., lateral air bags, inflatable curtains. Without interfering with their care duties, emergency medical technicians could be systematically trained to observe the collision's specific characteristics and to report all their relevant observations to the emergency physicians to increase the likelihood of prompt diagnosis and proper care.

Keywords. Side impact, side air bags, type of injury, injury prevention.

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* Corresponding author: Francois.Bellavance@cirrelt.ca

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1. Problem

Side impacts are a serious automotive injury problem. They come second only to frontal impacts, in terms of the severe injuries and fatalities occurring on US roads: lateral impacts to passenger vehicles result in some 9,400 deaths each year, about 30% of all the fatalities for passenger vehicle occupants (Insurance Institute for Highway Safety [IIHS], 2002). Also, according to the National Highway Traffic Safety Administration [NHTSA] (2002), about 3.18 million U.S. drivers per year are involved in police-reported crashes characterized by side impacts. Anon (2002), cited in Chipman (2004), found that in British Columbia side-impact collisions accounted for 29.6% of all fatal and injury-producing crashes attended by police. Bédard, Guyatt, Stones and Hirdes (2002) have reported that 31% of the crashes recorded in the US Fatal Accident Reporting System (FARS) are side-impact crashes. What is more, older studies report almost the same proportion of side-impact collisions: an Australian study (Fildes, Digges, Carr, Dyte & Vulcan, 1995) have revealed that side-impact crashes account for 25% of all injury crashes and 40% of serious injury crashes where an occupant was either hospitalized or killed. In their literature review, Miltner and Salwender (1995) indicate that between 15% to 40% of all passenger vehicle crashes involve side-impacts; Huelke and Campton (1992) report that, according to the NHTSA database, side-impact collisions accounted for 30% of fatal crashes in 1978. In their review of fatality data, Viano, Culver, Evans, Frick and Scott, (1989) found that 31.8% of passenger car fatalities occur in crashes where the primary direction of force is lateral to the vehicle. Two-thirds of the fatalities in such crashes are due to multi-vehicle collisions and the rest to the impact of a single vehicle with a fixed object. Multi-vehicle crashes frequently involve victims over the age of 40. Foret-Bruno, Hartemann, Tarriere, Got and Patel (1983) state that younger motorists are over-represented in impacts against rigid objects and older motorists, in car-to-car collisions. In her literature review, Chipman (2004) reports that the only driver factor significantly associated with side impact is driver age. Older drivers are at higher risk of being involved in crashes at intersections and side-swipe than in any other types of crash. They also tend to drive at lower speeds. On the other hand, younger drivers are known to drive at higher speeds and are less experienced which put them at higher risk for single vehicle crashes in loosing control of the vehicle and getting off the road.

Informing trauma surgeons or emergency clinicians of non-clinical risk factors observed at the crash scene might help them detect the presence of severe injuries. For example, lateral collisions might cause aortic injury, particularly when unbelted occupants are involved in a crash of high-impact severity (Fitzharris, 2004). Reiff, McGwin Jr and Rue III (2001) have shown that a diagnosis of diaphragmatic rupture is highly suggestive if specific motor vehicle crash characteristics combined with patient injuries have been identified because often there is a lack of an accurate test demonstrating the injury.

This paper's in-depth review of the literature on injuries resulting from lateral collisions is an attempt to synthesize what is already known on the subject and what questions remain to be answered. It takes stock of vehicle, occupant, and crash characteristics and of specific injuries as well. This research is part of the Automobile of the 21st Century (AUTO 21) research projects funded by the Canadian Network of Centers of Excellence.

2. Method

Several electronic publication databases were used to select the papers and articles included in this literature review: Elsevier, over 2,000 Journals on line); Pubmed, a service that includes over 16 million citations from MEDLINE and other life sciences journals and National

Center for Biotechnology Information, National Library of Medicine, and the National Institutes of Health); National Highway Traffic Safety Administration [NHTSA], Department of Transportation, U.S. The search engine Google.ca was also used to find general articles or Web sites and to validate references for paper copies. We used the University of Montreal's "Ovid Online" to access 15 medical databases, including MEDLINE, PsycINFO and EBM Review. Our search had no date limitations but did focus mainly on the 1996-2006 publication period and on real crash data. We have taken NHTSA and Transport Canada regulations into account but have not fully reviewed the biomechanics of test crashes.

The key words and phrases used in the search were the following: *side impact crashes, side impact collisions, lateral crashes, lateral collisions, injury, car accident, vehicles compatibility*. Our literature review paid special attention to studies on side-impact crashes involving two vehicles. However, side collisions of a single vehicle with a fixed object or side-swipes can be severe and they are also considered.

3. Results

Primary direction of force (PDOF)

Various in-depth studies show that vehicle occupants sustaining serious or even fatal injuries from side-impact collisions represent a large proportion of road crash victims. In their study, Thomas, Lanson, Griffiths, and Breen, (1981) reveal that, for fatal crashes, the most frequent direction of primary impact is at 9 o'clock, while, for all side collisions, the most frequent direction of impact is at 2 o'clock. Their study also shows that in three-quarters of fatal crashes the PDOF ranges between 2 and 4 o'clock and between 8 and 10 o'clock. These results are based on an in-depth investigation of the situation in France. Also in France, Hartemann et al.

(1976a) and Hartemann et al. (1976b) have noted that for most of the lateral impacts causing occupant injury the trajectory angle was between 45° and 75° from the longitudinal vehicle axis. In their examination of Daimler-Benz crash files, Reidelbach and Zeidler (1983) found that the primary direction of force (PDOF) was at 3 or 9 o'clock (51%). A German study (Danner & Langweider, 1976) found that impacts at 2 and at 10 o'clock accounted for 60% of all side impacts. The analysis of the PDOF done by Banglmaier, Rouhana, Beillas and Yang, (2003), using the NASS/CDS database for the 1993-2000 period, suggests that a large proportion of the lateral impacts occurred obliquely, at approximately 2 and 10 o'clock, with a rearward component of force. Otte, Suren, Appel, and Nehmzow, (1984) found that 43% of the vehicles in their study had sustained perpendicular impacts, whereas 55% had taken oblique impacts. In Great Britain, Riley and Radley (1976) documented that 55% of British side-impact crashes were oblique and frontal, while 31% were perpendicular. They reported a slight difference in injury severity between perpendicular and oblique impacts. Their findings differ from those of Thomas et al. (1990) who indicate that there is a greater risk of moderate injury when the PDOF is at 9 o'clock.

As seen in the previous paragraph, the definition of side-impact crashes varies from study to study. For example, McGwin, Metzger & Rue III, (2004), in their research on near-side collisions, have defined such collisions as those where the PDOF is between 2 and 4 o'clock for the driver and between 8 and 10 o'clock for the passenger. Moreover, in the literature, the PDOF crash angle may be defined either in terms of o'clocks or angles. Transport Canada (1996), this country's vehicle safety standards regulator, focuses mainly on a 45° angle of impact with passenger and driver compartments in its in-depth investigations of side-impact crashes. In January 1973, the U.S. adopted Federal Motor Vehicle Safety Standard 214 on side-door strength as a protection against side impacts. And Transport Canada has since adopted its own section 214 "Side Door Strength regulation (on July 1st 1973), accompanied by a specified test for the new standard. Several amendments have subsequently been adopted by the NHTSA (1990), and by Transport Canada. In summary, these measures are designed to increase door strength (thus reducing intrusion into the car) and to strengthen latches and hinges (thus lowering the risk of doors opening and occupants being ejected). Equivalent to those in the U.S., these Canadian requirements would provide an adequate level of protection and facilitate trade between Canada and the U.S. Full implementation of a crash test requiring that all doors in the struck vehicle must remain shut became effective for all new vehicles in 1996 (Transport Canada, 1996). From their study of a large GES (General Estimates System) sample of a side-impact occupant population (6,223 occupants unweighted 1997-2000), McGwin, Metzger, Porterfield, Moran and Rue III, (2003) observed that ejection was uncommon— both for those occupants protected by side airbags and for those who were not; their sample did not include pre-1998 vehicle models. McGwin et al. finding differs from older publications reporting several ejections.

Near-side versus far-side, belted versus unbelted, and passenger compartment damage (PCD)

Near-side occupants are at high risk in side-impact collisions. Three studies (Fildes, Lane, Lenard & Vulcan, 1994 ; Frampton, Brown, Thomas & Fay, 1998 ; Digges, & Dalmotas, 2001) report that near-side occupants account for more than 70% of all side-impact injuries. Still, far-side occupants are involved in 30% of these injuries and account for up to 40% of occupant. Monk, Burgett and DeLarm (1977) note that at any given Delta-V, near-side occupants register a much higher Delta-V than do their far-side companions, which means that the former are the most vulnerable in lateral crashes.

Lestina, Gloyns and Rattenbury (1990) were interested in the relationship between lateral-collision injuries received by occupants and their position in the vehicle. They drew their data from coroners' reports on 140 victims killed by such crashes in the United Kingdom. According to their study, in 85% of the cases, near-side victims received injuries to the chest. These victims also frequently received serious injuries to multiple parts of the body. And far-side victims sustained more severe head injuries (82% of the cases) than did near-side victims (64%). On the other hand, 54% of the near-side victims killed in the impact were belted as compared with 43% of the far-side victims. Furthermore, the non -restrained victims suffered more serious injuries than those who were restrained. Jones (1982) and Jones and Shaibani (1982) studied the effect of occupant restraints on serious injuries in frontal and lateral collisions. A sample of 1,100 crashes was used to make an in-depth analysis. The results obtained are similar to those observed by Lestina et al. (1990): occupants on the struck side are injured more often and more severely than occupants seated on the opposite side and that, regardless of restraint use, the level of injury is higher for occupants on the struck side. Danner and Langweider (1976) noted that unbelted far-side occupants (those often thrown about in the car's deformed interior) could largely avoid serious injury by wearing a safety belt. They also noted that the risk of head injury was 20% lower for near-side belted occupants than for near-side unbelted occupants, even though belted occupants in their series were in crashes significantly more severe than their unbelted companions. Monk et al. (1977) observed that, as regards thoracic injuries, seat belts did benefit far-side occupants, but were of no significant benefit to near-side occupants. Jones (1977) discovered that restrained occupants were at lower risk for moderate or serious injuries than were unrestrained occupants, especially if the former were far-side occupants. Mills and Hobbs (1984) have shown that safety belts do protect far-side occupants in lateral impacts. Shimoda, Akiyama and Nishida (1989) conducted a Japanese study to simulate side impacts, using cadavers restrained by 3-point seat belts and seated in near- and far-side positions. They report that the restraint system did not offer effective thoracic protection to near-side occupants. The restraint system was of only slight use in preventing projection of the head and failed to protect the near-side occupant from contact with the vehicle's interior or exterior frame. However, the restraint system did offer effective protection to the far-side occupant. Otte et al. (1984) note that seat belts may be of benefit in oblique impacts (64% of near-side belted occupants were not injured), but not in perpendicular impacts (only 30% of near-side belted occupants were not injured). Therefore seat belt wearing is effective but cannot be regarded as completely satisfactory in lateral impacts. Hartemann et al. (1976a), Hartemann et al. (1976b) and Thomas et al. (1981) state that the safety belt's main advantage is preventing ejection during lateral impacts.

Fildes, Gables, Fitzharris and Morris (2000) and Partyka and Razebek (1983) found that, in real-world side impact crashes, the risk of serious or fatal injury to near-side occupants was 2 times higher than for far-side occupants and that the risk of injury was 2 times higher with passenger compartment damage (PCD) than without. Similar results were found in other studies. Riley and Radley (1976) state that the risk of serious injury to a near-side occupant is twice that of a far-side occupant and that PCD also increases the risk of injury to the occupant. Reidelbach and Zeidler (1983) note that the risk of serious injury for near-side occupants at the site of the PCD is twice that for far-side occupants directly opposite the PCD. Hartemann et al. (1976a) and Hartemann et al. (1976b) note that, when there is intrusion, the risk of injury to far-side occupants is lower than that for near-side occupants. They also show that, with PCD, the risk is 2 to 3 times higher than without PCD. Norin, Nilsson-Ehle and Gustafson (1982) state that, with passenger compartment damage, occupants closer to the damage are more at risk of serious injuries than those on the far side.

Danner and Langweider (1976) looked at differences in risk for restrained and unrestrained occupants in crashes with PCD. Without PCD, the risk was equal for near- and far-side occupants. With PCD, near-side occupants were 2 to 3 times more likely to receive a serious injury than far- side occupants. Among belt-wearers, near-side occupants ran a 4 times higher risk of serious injury than did far-side occupants when there was PCD and twice the risk when there was no PCD. Otte et al. (1984) have observed that, in impacts without PCD, 90% of belt-wearers were not injured as compared with 35% of near-side unbelted occupants and 83% of far-side unbelted occupants. They note that an impact penetrating the compartment region seems to be more dangerous, and the risk posed to unbelted occupants on the near side versus those on the far side is 2 to 3 times greater.

Danner and Langweider (1976) report that the main deformed zone is situated between the A-Pillar and the B-Pillar. Because lateral collisions have a more direct impact on occupants than frontal ones, they cause more violent, varied, and complex injuries. Miltner and Salvender (1995) note that the more serious injuries are caused by contacts with: door panels; A-Pillar; B-Pillar; Roof-rails; lateral windows; and window frames. Rouhana and Forste (1985) observed that, in a lateral collision, an occupant's most likely point of contact with the car's interior would be a function of the occupant's position relative to the collision's side, location, and primary direction of force (PDOF). For near-side occupants, the most frequent point of contact would be the interior of the side door, whereas far-side drivers would most often come into contact with the steering wheel and the instrument panel. Kahane, Smith and Tharpe (1976) noticed that serious injuries to near-side occupants are usually caused by contact with interior side structures, while far-side occupants are usually thrown against interior front structures. Otte et al. (1984) state that the major points of contact for near-side occupants would be side interiors and for far-side occupants, the instrument panel. Hartemann et al. (1976a) and Hartemann et al. (1976b) observed that, with AIS 4+, occupants were most often thrown against the inside door panel. Reidelbach and Zeidler (1983) observed that the side door was the most frequent interior contact point. Jones (1982) and Jones and Shaibani (1982) observed that near-side occupants come into contact with interior side structures and far- side occupants, with inside front structures.

Injuries in side impacts

Acierno, Kaufman, Rivara, Grossman and Mock (2004) analyzed 200 Seattle CIREN database cases and observed the following injury distribution for occupants of passenger vehicles involved in side-impact collisions (percentage of patients with AIS 2+ injury to designated body regions): head (53%), chest (73%), abdomen (33%), pelvis (53%), and lower extremities (13%). Other vehicle compatibility studies (Gabler & Hollowell, 1998 ; Summers, Hollowell & Prasad, 2003) indicate similar percentages for the body regions most frequently injured in target-vehicle occupants during side-impact crashes. Chipman, Lebovic, Desapriya and Gane (2006) studied all crashes reported by police in British Columbia in 2002. From these data, all two-vehicle crashes coded by police as intersection right-angle crashes were selected if both vehicles were passengers vehicles licensed in British Columbia and the age of both drivers was recorded in the report. Thus, a total of 4032 crashes were analyzed. Approximately 25% of occupants in both vehicles were injured. The distribution of injuries is similar for occupants of target and bullet vehicles in T-type crashes (damage to the front of the bullet vehicle and to the left or right side of the target vehicle). The distribution of the “most serious” injuries of occupants in the target vehicles is neck (31%), head (23%), upper extremities (15%), lower extremities (13%), chest (8%) and abdomen (4%).

Lower extremity injuries are commonly reported in side-impact collisions. Though usually ranging from minor to serious (AIS 1 to AIS 3), such injuries may, however, result in long-term disability and impairment. To examine the incidence of lower extremity injuries in lateral collisions, Banglmaier et al. (2003) undertook a retrospective analysis of the NASS/CDS database for the 1993-2000 period. The results of this study show that, in side impacts ranging from 2 to 4 o'clock and from 10 to 8 o'clock, the incidence of AIS 2 and AIS 3 pelvis/hip injuries was higher in near-side (70.4%) as opposed to far-side occupants (38.3%). The opposite trend was observed for injuries to the thigh (2.8% versus 4.5%), knee (6.2% versus 16.7%), leg (10.1% versus 19.5%), and foot/ankle (5.6% versus 14.7%).

Hassan, Morris, Mackay and Haland (1994) have shown that the most severe AIS 3+ injuries in side collisions are chest injuries. However, Reidelbach and Zeidler (1983) note that 53% of the AIS 3+ injuries observed were to the head and neck and only 30% to the thorax, whereas Hartemann et al. (1976a) and Hartemann et al. (1976b) note that the abdomen, thorax, and head were at equal risk when AIS 4+ injuries were considered. In Japan, Igarashi, Ehama and Sunabashiri (1998) note that, in side impacts with AIS 3+, the occupant on the struck side is most likely to sustain an injury first in the head area, second in the thorax, third in the pelvis, and fourth in the abdomen. They added that, if combined, head and thorax injuries would represent more than 50% of the AIS 3+ category. Lister and Neilson (1969) noted that fatal head injuries were just as likely to occur in near-side as in far-side occupants. Similarly, Danner and Langweider (1976) and Otte et al. (1984) observed no difference in the risk of head injury for near-side as compared with far-side occupants. Morris, Hassan, Mackay and Hill (1993) found that 60% of AIS 2+ head injuries in side impacts were of the diffuse brain injury type. Diffuse brain injuries originate mainly from contact with the car's interior, especially with the side window.

Tencer, Kaufman, Mack and Mock (2005) have studied US-NCAP, NASS, and CIREN data (165 separate tests, 1999-2003) to look for factors affecting pelvic and thoracic forces in near-side impact crashes. Their results coincide with other previously discussed studies: greater side -door intrusion also increases the AIS; bilateral pelvic injuries were significantly more frequent for subjects in CIREN crashes when their vehicle had a center console—but only if door intrusion was greater than 15 cm.

Newgard, Lewis, Krauss and McConnell (2005) analyzed 15,160 persons involved in lateral motor vehicle crashes drawn from NASS/CDS for the 1995-2003 period. The authors found seating position to be a significant factor in thoracic-abdominal injuries: higher mean probability of injury for near-side and middle-seat occupants as compared to far-side occupants and probability of thoracic injury approximately 4 times higher than that of abdominal injury for all seat positions. Danner and Langweider (1976) state that thoracic injuries from contact with side structures were over-represented for near -side occupants. In their Swiss analysis, Walz, Niederer, Zollinger and Renfer (1977) noted that head injuries were predominant in oblique impacts and thoracic injuries in perpendicular impacts. Lateral impacts also cause pelvic ring fractures in 10-14% of near-side occupants (Cesari, Ramet & Clair, 1980).

Reiff, McGwin Jr and Rue III (2001) have studied the effect of occupant restraints on mortality and splenic injury caused by side-impact collisions. NASS data was used to identify drivers involved in side-impact collisions during the 1996-1998 period. Overall results indicate that restraint use was associated with a significantly reduced rate of mortality (OR: 0.4, $p<0.0001$) and splenic injury (OR: 0.76, $p<0.0001$). However, drivers of smaller vehicles had higher incidences of splenic injury in both minimal lateral intrusion < 30 cm and severe intrusion > 30 cm. For mid-size (2,500-3,000 lb) and large (> 3,000 lb) vehicles, restraint use was associated with a lower risk of splenic injury, regardless of the magnitude of the crush.

Franklyn et al. (2002) examined the incidence of aortic injuries in the US and the UK, using real-world crash data: 11,125,106 injured occupants in the US and 16,738 in the UK were analyzed; 20,036 (US) and 290 (UK) were occupants with aortic injuries. Results indicate that the risk of sustaining an aortic injury is greater for near-side occupants than for those on the far side. The Delta-V was also higher in crashes where occupants did sustain an injury to the aorta than in crashes where they did not. With these data, Fitzharris et al. (2004) assess the risk of traumatic rupture of thoracic aorta (TRA) associated with impact direction, seat belt use (unbelted RR=3), force of impact, SUV versus passenger vehicle. The incidence was 1.5% in the US and 1.9% in the UK. Katyal et al. (1997) reviewed 97 patients with TRA resulting from motor vehicle crashes and found that 50% were involved in lateral crashes. Moreover Bertrand et al. (2008) studied 15,074 occupants with individual detailed autopsy reports and analysed TRA types as a function of car crash conditions. They found that TRA occurred in 1.2% of all accidents but caused 21.4% of all fatalities; 2.4% were side impacts and 1.1% front ones. Although aortic injury had been known to be associated with frontal impacts, emergency physicians should be aware that occupants of side-impact crashes are at greater risk for this injury.

Vehicle characteristics

Passenger vehicle occupants struck in the side by another vehicle are more likely to sustain serious injuries when the striking vehicle is a pickup truck or sport utility vehicle (SUV) than when it is a car (Farmer, Braver & Mitter, 1997). There is an increase risk of thorax and intra thoracic organ injuries, more severe traumatic brain injury and a smaller risk of lower extremity injury (Siegel et al., 2001). Thus, to protect the occupant, the vehicle has to be conceived so that the habitacle preserves its integrity (will not deform) in crashes and will contain no components likely to injure the passengers. The passenger compartment must also be equipped with device of restraint to prevent occupants being ejected from the vehicle or being tossed about inside, risking injury to themselves and the other passengers.

Thomas et al. (1990) highlight the influence of vehicle aggressiveness on the force of impact, pointing out that it is difficult to assess the respective roles played by the vehicle's structure and rigidity. The authors show that some makes known for the protective interior they offer their own occupants turn out to be particularly dangerous for occupants of the vehicles whom they enter in lateral collision.

Improving compatibility in lateral collisions would mean achieving a better match between structural characteristics (dimensions, architecture, and rigidity) and the particularly complicated technical problems this poses have been receiving special attention since the 90s. To reduce the incompatibility between vehicles, the structure of small cars would need to be made relatively stiffer than that of larger vehicles, but without compromising the safety of the occupants in heavier cars. However, even if car weights are controlled, pickups and SUVs would still cause more severe injuries in side impacts because their higher front-end geometry increases the risk of direct head strikes and other injuries to occupants in struck vehicles.

Structural reinforcements are needed to lower the velocity of the intruding side structure in car-to-car impacts and to provide a satisfactory base for interior padding. Introduction of the SIPS (Side Impact Protection System) a first step was taken in offering occupants greater protection against side impacts by reinforcing many of the car's systems, including doors, B-pillars, the floor, the floor tunnel, the roof, and the seats (Mellander, Ivarsson, Korner & Nilsson, 1989).

Side air bag systems and seating position

Airbags installed in doors or seats are designed to attenuate and redistribute forces exerted on the chest and abdomen by the intruding side of the vehicle; they were conceived and validated by Volvo (Olsson, Skötte & Svensson, 1989) and first introduced in its 1995 models. Brambilla, Kallina and Tschäschke (1998) describe the window bag system developed for Mercedes cars—first installed in the 1999 E-Class Sedan and continued in the new S-Class. The window air bag was validated using car-to-pole crash tests. Results showed this protective device to be effective in test crashes and thus capable of providing good protection in real-world side impact crashes. Öhlund, Palmertz, Korner, Nygren, and Bohman (1998) have shown that inflatable curtains (mounted on roof rails) considerably reduce the risk that occupants will receive heavy blows to the head from objects outside of the vehicle (30% decrease). These authors add that the inflatable curtain is specifically useful in reducing risks of serious or fatal head injuries, especially in side collisions with rigid and/or heavy objects.

Several side impact air bag systems providing thoracic and head protection have appeared in new models and are projected to become prevalent automotive features. However, as side airbags are still not standard equipment, their effectiveness has not yet been widely studied in real impacts, owing to lack of data. Nonetheless, few recent studies analyzing side air bags were found. According to McGwin et al. (2004) occupants in vehicles equipped with head protection side air bags had a 75% lower risk of head injury (p=0.008) after near-side collisions. As for thoracic injury, side air bags providing thoracic protection reduce the risk of injury to this part of the body by 68% (p=0.01). Kompass, Digges and Malliaris (1998) found that the Inflatable Tubular Structure (ITS)—an innovative head-protection system introduced by BMW in its 1997 model— was estimated to reduce fatalities by 33%; AIS 3+ injuries by 45%; and AIS 2+ injuries by 33% . They also report that 51% of the reductions in fatalities were attributable to the mitigation of head impacts with this component. Braver and Kyrychenko (2004) and McCartt and Kyrychenko (2007) found that side air bags which typically combine head protection with torso protection have significantly reduced car driver death risk by a factor a 45% and 37% respectively. Torso-only side airbags generally have been less effective in protecting drivers.

Prasad, Samaha and Louden (2001) describe the NHTSA program set up to evaluate side air bag systems for out-of-position (OOP) occupants. They also provide a status report on current research. The industry's Side airbag OOP Injury Technical Working group has recommended test procedures for 3- and 6-year- old occupants, in order to assess injuries to OOP children. There is ongoing NHTSA research evaluating adult OOP dummies, roof mounted air bag systems, and the repeatability of test procedures for occupants of different sizes. This report reflects NHTSA's increasing interest in studies on side air bags systems. The entire industry is also stepping up its research in this field, especially with regard to the development of new systems and tests standardization.

The effectiveness of airbags in both frontal and side-impact crashes is moderated by the occupant seating position. The Australian study on seating positions presented in Dinas and Fildes (2002) observes the on-road seating and limb positions of front-seat occupants on the side of the car, based on a representative sample of occupants during straight road driving and turning maneuvers. In this study, a video camera captured over 650 front-on images of passenger car occupants in Metropolitan Melbourne. The results obtained show that a significant number of occupants were seated OOP while on the road and especially when the car was making a turn (a maneuver common in many side impacts): up to 23% of passengers rested their arm on the door itself—a potentially dangerous move both in terms of airbag deployment and side impacts.

4. Discussion

Side-impact crashes are a serious problem in terms of their incidence : they represent about one-third of all vehicle crashes, 30 % of fatal and 40 % of serious injury crashes. Two-thirds of the fatalities are due to multiple vehicle crashes, the remainder involves the impact of a single vehicle with a fixed object (Viano et al., 1989) Studies vary in their assessment of the frequency of injuries, but all agree that it is high.

Table 1 summarizes the main results of this literature review. It brings out the relationship between injury patterns and collisions characteristics in real crashes. It shows that many results from different studies confirm findings. However other results differ depending on study’s data sources and objectives. Even the definition of lateral crashes differ: some publications will specify what they consider in their data in terms of o'clock or angles, others like Canada's Motor Vehicle Safety Standard 214 will focus on a 45° angle of impact for tests; other authors consider side-impact from 0° to 180° degree, oblique and perpendicular. Several publications emphasize the effect of the occupant position and the side-crash characteristics to the severity and the complex pattern of injury.

Among the possible measures for protecting occupants involved in side collisions, we may suggest: 1) decrease the rigidity of the striking vehicle's front-end; 2) increase the lateral rigidity of the struck vehicle; and 3) insure the compatibility of the structures of striking vehicle and struck vehicle (weights, heights, stiffness geometry, etc.).

Besides what is known, what questions remain to be answered and what can we foresee to improve future studies for the prevention of these injuries? Accurate and pertinent data are lacking and might explain different results obtained. Banglmaier et al. (2003) estimate the incidence of lower extremity injuries to be 22 % of those to all anatomic regions, whereas Acierno et al. (2004), using 200 Seattle CIREN cases, had a much lower estimate of 13 % probably because CIREN databank focuses on severe injuries: it may underestimate the frequency to lower extremities (AIS $\leq$ 2). These frequent injuries may lead to long term disability that needs further studies.

However CIREN crashes have more complete data on injuries and crash characteristics; Tencer et al. (2005) found an original result, a significant higher frequency of bilateral pelvic injuries for subjects in a vehicle with a center console, but only if door intrusion was greater than 15 cm. Curently it is fashionable on new vehicle to have a center console. A good evaluation of a preventive measure requires taking into account several variables in order to distinguish its effects between other variables. Authors complain about the lack of database in studying real crashes for evaluation. The USA amended its “Side Door Strength” regulation for passenger cars (standard 214) to upgrade its test procedures and requirements. Full implementation of this standard was made effective for all new cars in September 1996: were these door-strength regulations successful in preventing ejections? Several older publications have reported that most severe injuries were caused by ejection. But a more recent study conducted by Mc Gwin et al. (2004) observed on a large sample that ejections were uncommon; his series included only 1998-2000 passenger car models built in compliance with the new standard. Although these publications were not aimed to this kind of evaluation and the fact that individual seat belt wearing was not analyzed, the development of good longitudinal data might help in assessing the benefit of a standard regulation in real crashes.

Wearing a seat belt does reduce injuries in lateral collisions, but more protection is needed for the near-side impact occupant where the seat belt wearing is not sufficient if there is intrusion. Some car-makers have equipped their new vehicle models with lateral airbags, inflatable curtain or inflatable tubular structures, but they have not yet become standard equipments. Their effectiveness still remains to be studied based on large databanks drawn from real crashes. A few recent studies showed a reduction of head/thoracic injuries and fatalities for cars equipped with this emerging technology. However some researchers anticipate perverse effects for frequent out-of-position occupant and for the potential aggressiveness of airbags particularly for the aging population because of the frailty of elderly occupants. It has to be documented by new researches.

To improve future studies, Event Data Recorders (EDR) can lead to objective data into the crucial seconds before and during crashes on vehicle speed, braking, belt use, impact severity (Status Report [IIHS], 2006). The information EDR is collecting varies by automaker and data retrievability is mixed. New U.S. Federal rules, effective for 2011 passenger vehicle models standardize the data collected in a uniform format and register specified data about crash severity, vehicle dynamics and safety systems. The rules also specify the format and time period if EDR records more information. The rules do not compel to require EDR in all new passenger vehicles, estimating that 64 % already have it and forecasting 85 % by the 2010 model year. These federal rules ask also to make it easier for researchers, law enforcement persons and others to download the information.

Judging from its low incidence in both the UK and the USA, aortic injury appears to be a rather rare event. When it does occur, it is often lethal and known to be caused by frontal impacts. However, a recent and well documented study has shown that traumatic rupture of aorta is twice more at risk in lateral impact than frontal ones. They found also that 79% had rib fractures, mostly bilateral and more than half of them were associated with liver and lungs injuries; third of them were spleen and pelvis injury. Near-side occupants involved in lateral collisions with a higher Delta-V are sometimes victims of aortic trauma. Though such cases are rare, surgeons know that their prompt diagnosis and proper surgical treatment can sometimes result in a complete recuperation without sequel. The chances of prompt diagnosis and proper care might be enhanced if emergency medical technicians (EMT) were trained to provide an accurate crash-scene report when the injured patient is brought to the emergency room. Without interfering with care duties, proper pre-hospital care might thus include a protocol for accurate observation of just a few crash-scene characteristics: side-impact collision, vehicle models, primary direction of force, near-side occupant, far-side, belted or unbelted, passenger compartment damage.

We may foresee new results if the quality of the data collected on side collisions are improved. This can be done by getting more objective and accurate data with EDR and by linking them with health insurance data on physicians' diagnostics and treatments and autopsy reports. With more accurate data on crash-scene characteristics and occupants on a large number of cases, it would also be possible to use other data analysis techniques, such as classification trees, to automatically detect the important interactions between the different factors and therefore have a better understanding of the injury mechanisms involved in motor vehicles crashes.

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Table 1
Lateral collision characteristics and injury patterns: literature review

Side-collision and occupant characteristics	Main observations on side-collision	References*	Notes
Generalities	20% to 40% of all fatalities and injury-producing crashes	2, 4, 17, 29, 31, 75	
	2/3 of fatalities are multi-vehicle and 1/3 single vehicle against fixed object	75	
	occupant of struck vehicle are more likely to sustain severe injuries when the striking vehicle is a pickup truck or SUV than a car	16, 68	
	younger drivers are over-represented in single vehicle against fixed object	21	
	older motorists are more frequently involved in car to car collisions	9, 21, 75	
PDOF (Primary Direction of Force)	3/4 of fatal crashes, PDOF is between 2-4 o'clock and 8-10 o'clock	73	
	51% of PDOF at 3 and 9 o'clock	62	
	43% perpendicular and 55% oblique	56	
	31% perpendicular and 55% oblique and frontal; slight difference in injury severity between perpendicular and oblique	65	might the larger number of roundabouts in UK explain part of the difference in % of perpendicular collisions with references #24 and 27?
	head injuries were predominant in oblique impacts and thoracic injuries in perpendicular impacts	76	
Belted versus unbelted	belted prevents ejection during lateral impacts	26, 27, 73	
	seat-belt significantly reduces rate of mortality (OR = 0.4) and of splenic injury (OR = 0.76)	63	incidence of splenic injury was higher for drivers of smaller vehicles
Passenger Compartment Damage (PCD)	risk of injury is 2 to 3 times higher with PCD	18, 26, 27, 58	
	PCD increases the risk of injury	65	
Injuries	Most frequent severe injuries are to head, neck, chest, thorax, pelvis and abdomen	1, 24, 26, 27, 28, 62, 70	injury distribution varies according to data sources
	Traumatic rupture of thoracic aorta (TRA) occurred in 1.2% of all accidents but caused 21.4% of all fatalities; 2.4% were side impacts and 1.1% front ones.	5	
	10% to 22% of injuries are to lower extremities	1, 3, 40	usually AIS 1 to 3: research needed to assess long term disability

Injuries of near-side (ns) versus far-side (fs) occupants	ns have serious injuries to multiple parts of the body; 85% of ns had injury to chest; 64% of ns had serious injury to the head versus 82% for fs	38	coroners' report on 140 victims killed in lateral collisions
	no difference in risk of head injuries between ns and fs	11, 39, 56	
	ns account for more than 70% of all side-impact injuries	12, 19, 22	
	risk of serious or fatal injury is 2 times greater for ns	18, 58, 65	
	higher probability of thoracic-abdominal injury for ns as compared to fs	52	
	side impacts with AIS 3+, ns is most likely to have injury to head, thorax, pelvis, abdomen (in that order); head + thorax represent more than 50% of AIS 3+ category	30	
	risk of aortic injury is higher for ns	23	Delta-V was higher in crashes with aortic injury
	pelvic ring fractures in 10-14% of ns	8	
ns, fs and seat-belt	ns are injured more often and more severely than fs regardless of restraint use	33, 34	lower risk of injury for both ns and fs belted occupants; belted fs benefits much more than ns; more protection needed for near side
	54% of ns killed were belted versus 43% for fs	38	
	risk of head injury was 20% lower for ns belted than for ns unbelted	11	
	belted benefits fs from thoracic injuries, but no significant benefit to ns	47, 67	
	belted are at lower risk for moderate or serious injuries than unbelted, especially for fs	32, 45	
ns, fs and PCD	when intrusion the risk of injury is higher for ns compared to fs	11, 26, 27, 53, 62	
	greater side intrusion increase AIS for ns	56, 71	
ns, fs, seat-belt and PCD	belted ns benefits in the absence of significant intrusion	34	
	impact without PCD, 90% of belted were not injured versus 35% for unbelted ns and 83% for unbelted fs	56	
	when PCD and belted, risk of serious injury is 4x higher for ns than fs; the risk is 2x higher when no PCD	11	
Side air bag or curtain protection	75% lower risk of head injury and 68% lower risk of thoracic injury for ns	41	
	reduce fatalities by 33%, AIS 3+ by 45% and AIS 2+ by 33%	37	
	head/torso protection side airbags reduces risk of death by 37% to 45%	7, 40	

** The numbers correspond to those indicated in references, see the number written at the end of each reference.*

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