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Patterns of injury sustained by car occupants with relation to the direction of impact with motor vehicle trauma – evidence based review

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Motor vehicle collisions (MVCs) have been reported as the leading cause of major trauma and subsequent morbidity and mortality, for people under 20 and those between 20 and 64 years of age. Crash fatalities have significantly reduced in number since the introduction of appropriate seat belt restraints and air bags for drivers and front seat passengers. Other factors which have positively influenced the outcome of MVCs include information from pre-hospital personnel at the crash scene, regarding the vehicle's exterior and interior damage, in addition to the direction of impact. The patterns of injury sustained by car occupants during a collision depend upon the direction of impact. We provide an up to date review of the key literature regarding injury patterns sustained to occupants of light passenger vehicles (passenger cars, vans, utility vehicles and pickup trucks) in correlation with the direction of impact. We strongly believe that this knowledge can allow pre-hospital personnel and clinicians in the emergency department to gain foresight when suspecting and identifying the injuries sustained by car occupants during a motor vehicle collision.

Key words: Motor vehicle collisions (MVCs); direction of impact; front; rear; lateral; near oblique; far oblique; rollover; adult; paediatric

Introduction

Motor vehicle collisions (MVCs) were reported by the Canadian Institute for Health in 2002 to account for 60% of all severe injuries in people aged between 20 and 34 (http://secure.cihi.ca/cihiweb/dispPage.jsp?cw). They were also recorded as the leading cause of major trauma for people under 20 and those between 35 and 64 years of age, accounting for 52 and 46%, respectively of all severe injuries (http://secure.cihi.ca/cihiweb/dispPage.jsp?cw).

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In 2001, the National Highway Traffic Safety Administration in the US reported 10 669 fatalities from motor vehicle crashes and 992 000 persons injured (Smith and Cummings, 2004). Side impacts in adults are the cause of the majority of fatalities in MVCs (Dischinger *et al*., 1993; Mikhail 1995; Reiff *et al*., 2001).

Crash fatalities have significantly reduced in number since the introduction of appropriate seat belt restraints and air bags for drivers and front seat passengers (FSPs) (Trinca and Dooley, 1975; Murphy RX *et al*., 2000; Rehm and Goldman, 2001; Estrada L *et al*., 2004; Jernigan, 2004; Maclennan *et al*., 2004). The widespread availability to hospital personnel of information from the accident scene regarding the vehicle's exterior and interior damage, in addition to the direction of impact has also had a positive effect of outcome. Training of pre-hospital personnel to make such observations has allowed hospital staff to suspect and detect

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occult injuries in the accident and emergency department (Biomechanics of injury, 2004).

The majority of vehicular trauma to car occupants is blunt. Three types of collisions have been described; first, between the patient and the interior of the vehicle; second, between the patient and a stationary object outside the vehicle during ejection, and third, a collision between the patients' viscera and the external framework of their body (organ compression) (Biomechanics of injury, 2004).

The pattern of injury sustained by car occupants during a collision depends upon the direction of impact. Five general patterns have been described – frontal, lateral, rear, angular (front- quarter and rear-quarter), and rollover (Biomechanics of injury, 2004).

We provide an up to date review of the key literature regarding injury patterns sustained by occupants of light passenger vehicles (passenger cars, vans, utility vehicles and pickup trucks) in correlation with the direction of impact. Only Adult motor vehicle trauma will be addressed.

The Evidence

General studies

Dischinger *et al*. (1993) collected crash data for a total of 2804 frontal and 376 lateral MVCs using available police reports in the US. They compared the patterns of organ injury incurred by occupants in frontal and lateral collisions. Statistically significant differences between the means of the frontal and lateral impact groups were determined by *t*-tests and proportional variations between them were tested using Chi-square and Fisher's exact methods. There was no significant variation between the two groups in mean Injury Severity Score; however those involved in side-on collisions had a significantly higher mortality rate. In patients aged 55 years and over, side impacts were found to be more frequent ($P<0.05$). The study revealed that frontal MVCs) had a significantly higher proportion of facial trauma ($P<0.0001$). In car occupants who were seat belted, no difference was seen in the incidence of skull fractures; they were significantly greater for unrestrained patients involved in frontal collisions. No difference was observed for brain injuries with relation to the direction of impact. All trauma to the lower extremity was noted to be significantly greater with frontal than lateral impacts ($P<0.0001$). This analysis included fractures of the femur, patella, tibia/fibula, foot, and ankle in both groups. The authors observed femoral fractures to be significantly more frequent in belted drivers and no difference was seen with the direction of impact in those who were unrestrained.

Lower limb injuries

Injuries to the lower leg have been reported as the second most common injury from automobile accidents and foot and ankle injuries can account for 28–34% of car occupant trauma (Pattimore *et al*., 1990; Letsina *et al*., 1992). Although the exact mechanism of injury to this area remains unclear, Morgan *et al*. (1991) described different mechanisms of injury associated with MVCs: knee-leg-foot entrapment, intrusion, whole body deceleration and foot entrapment by the pedals. Cadaveric studies have shown that foot and ankle fractures occur due to ankle dorsiflexion and inversion/eversion forces at the time of impact (Bergman and Prasad, 1987; Parenteau *et al*., 1996).

Parentau *et al*. (1996) studied the influence of crash location, seating position, and age on the incidence of foot and ankle injuries (categorized using the Abbreviated Injury Score, AIS). There were 805 cases (AIS 2–3), from a total of 57 949 car occupant injuries. Only occupants in cars with models dating from 1985 or later were included. Based on left hand drive vehicles they described the directions of impact for front seat occupants using a clock face. (1) They described fontal collisions as crash location 12 (12 o'clock). (2) Drivers in impact location 11 and FSPs in site 1 formed a near oblique-frontal group. (3) Drivers in impact location 1 (1 o'clock) and FSPs in site 11 (11 o'clock) formed a far oblique-frontal group (4) Drivers in impact locations 8, 9, and 10 and FSPs in impact locations 2, 3, and 4 formed a near side group. (5) Far side group was defined where the driver and FSPs were in the opposite impact location to those described in (4). (6) Drivers and FSPs in crash locations 5, 6, and 7 formed the rear impact group. They described the overall incidence of AIS 2–3 foot and ankle injuries as 13.9/1000 injuries and the rate as 24.7/1000 injured. The authors found that near side occupants i.e., drivers involved in a left sided impact and passengers in a right sided impact had a similar injury frequency for foot-ankle injury, with an incidence reported as 9–11/1000 injuries. On analysing frontal impacts, categorized by the 11, 12, and 1 o'clock positions for drivers and FSPs the incidences of AIS 2–3 ankle fractures and sprains were significantly higher in the near oblique-frontal collisions ($P<0.05$). For drivers the greatest incidence of foot and ankle injuries were in crash location 11 and for FSPs, this was found to be the case for crash location 1 (near oblique-frontal), with an overall incidence of 27.8/1000 ($P<0.01$). Crashes occurring in the 12 o'clock position had an overall incidence of 17.5/1000 and for the far oblique position an incidence of 15.5/1000 was reported. Ankle fractures were the most frequent injury followed by ankle sprains and fractures involving the midfoot. The incidence of foot and ankle injuries for rear impact and rollover crashes were 1.8/1000 and 12.1/1000, respectively.

Pelvic injuries

Pelvic fractures account for approximately 2% of all injuries sustained by occupants during MVCs (Ryan, 1971). About 10–14% of these fractures are of the acetabulum (Mayo, 1994; Guillemot, 1997). Overall MVCs are the most common cause of acetabular fractures, accounting for 66–76% of treated cases (Matta, 1996; Dakin *et al.*, 1999). While fractures to the pelvic ring are strongly associated with lateral impact MVCs, acetabular fractures are predominantly linked to frontal collisions and femoral shaft axis loading Dakin *et al.*, 1999). An exception to this is the central acetabular fracture with dislocation, resulting from side impact and loading through the greater trochanter. Dakin *et al.* (1999) stated following their study involving 83 acetabular fractures from the US that the direction of impact strongly correlated with these types of fractures. During a frontal collision it is perceived that a force is initiated along the femur when the flexed knee strikes the dashboard. This can either occur when an unrestrained driver slides forward or when the compartment intrudes upon a restrained driver. In a side impact the greater trochanter strikes the door when inertial forces throw unrestrained occupants laterally or the door collapses under the force of the oncoming vehicle.

Aortic injuries

High velocity frontal impact MVCs have been reported as the commonest cause of blunt traumatic aortic rupture. The mechanism of injury has been described as a combination of rapid deceleration and direct chest compression (Parmley *et al.*, 1958; Greendyke, 1966; Ochsner, 1992; Maggisano *et al.*, 1995; Hunt *et al.*, 1996). However there is mounting evidence that side impact collisions are not only associated with a higher mortality rate than with frontal crashes, but also a greater incidence of serious thoracic injury (Dischinger *et al.*, 1993; McLellan *et al.*, 1996). Katyal *et al.* (1997) found side impact crashes to be a significant cause of traumatic rupture of the aorta. Their study consisted of 97 patients who had sustained a traumatic aortic rupture, of which 48 (49.5%) cases were the result of a lateral impact. They found that in both the lateral and nonlateral group of patients the peri-isthmic region of the aorta was the most common for site of injury. Their findings were not statistically significant however the figures highlighted the need to suspect and detect such an injury associated with a lateral direction of impact.

Neck injuries

With rear end collisions the impact commonly occurs when the vehicle is stationary and is struck from behind by another. The vehicle and the occupant are accelerated forward away from the point of impact. The occupant's torso travels forward along with the vehicle, however, without a functional headrest, the head often does not, leading to a hyperextension injury of the neck (Biomechanics of injury, 2004). Current evidence suggests that whiplash injuries occur more often in rear end collisions (Deans *et al.*, 1986; Sturzenegger *et al.*, 1994; Berglund *et al.*, 2003). Berglund *et al.* (2003) studied crash related factors associated with the risk of sustaining a whiplash injury with data from 6581 subjects in Sweden. They compared frontal, side, rear-end, and other directions of impact for the incidence of this soft tissue injury to the cervical spine. Of their 6581 patients included in the study, 3704 (56%) had sustained this injury; of these subjects 55% were female and 45% male. Rear-end collisions were associated with the highest relative risk of whiplash when compared with side impacts (RR 1.82, CI 1.68-1.96). They found that females were at a higher risk of sustaining whiplash (RR 1.20, 95% CI 1.16−1.25). When the authors considered the influence of seating position, they found that in both sexes, the risk was more pronounced for drivers (adjusted RR 1.78. 95% CI 1.60−1.97) and lowest for passengers in the rear seat. Although whiplash injuries most commonly occurs with rear-end collisions, it is important to remember that it can occur with all directions of crash impact (Deans *et al*., 1986; Jakobsson *et al*., 2003). Berglund *et al*. reported that 2272 whiplash injuries occurred with rear impact, 1674 cases were the result of frontal collisions and 1513 cases secondary to a side impact. With regard to mechanism of injury with whiplash in rear-end collisions, there is a consensus that in the early phase after impact, the cervical spine compresses and forms an S shaped curve, with flexion of the upper segments and extension of the lower segments. During compression the lower cervical segments exceed the physiological limits of extension. It remains to be shown whether this described mechanism is the same or different for other directions of impact (Berglund *et al*., 2003).

In addition to whiplash, fractures of the posterior elements of the cervical spine have been reported; fractures to the laminae, pedicles, spinous processes have been reported (Biomechanics of injury, 2004).

Injuries associated with rollover accidents

A varied pattern of injuries is described in association with vehicle rollover and the clinician therefore requires a high index of suspicion and a methodical approach when managing the injuries of patients involved in such crashes. Injuries *may* be predicted from impact points on the patient's skin. In general, this mechanism of injury is associated with more severe injuries and mortality because of its violent nature (Biomechanics of injury, 2004). Three key factors contribute to fatality for patients in rollovers. First, occupant ejection (partial ejection) is the leading cause of death in rollover accidents Herbst *et al*. (2005). In fatal passenger car crashes involving ejection, 34% were expelled from the vehicle through the side windows (Berglund *et al*., 2003). It has therefore been suggested that side window glass retention during rollover is likely to significantly reduce occupant ejections. Secondly, roof crushes occur during such accidents and this contributes to serious or fatal occupant injury in 26% of rollovers (Berglund *et al*., 2003). Drop tests with hybrid III dummies have shown that a reduction in roof crush as a result of reinforcement resulted in a direct reduction in neck loading and therefore increased occupant protection (Herbst *et al*., 2005). Third, restraint systems, in particular the lap belt component of seat belts, have been shown to significantly reduce occupant movement in a rollover, during experimental dynamic spit testing with hybrid III dummies (Sances *et al*., 2005).

Direction of impact	Common patterns of injury
Frontal/ Near-Oblique/ Far- Oblique	Maxillofacial injuries
	Skull fractures (unrestrained drivers)
	Traumatic brain injury
	Cervical spine injury
	Lower extremity fractures
	Foot and ankle fractures (ankle fracture, sprain, mid tarsal fractures, ankle dislocation)
	Pelvic and acetabular fractures associated with femoral axis loading
	Posterior hip dislocation
	Traumatic rupture of aorta (commonly peri-isthmic region) associated high velocity impact
Lateral/Side	Chest wall injuries (flail chest, rib fractures)
	Pulmonary contusions
	pneumothorax
	diaphragmatic rupture
	liver and splenic contusions
	traumatic rupture of aorta
	lateral compression injuries to pelvic ring
	central acetabular fractures associated loading onto the greater trochanter
	traumatic brain injury
REAR	Whiplash injury to cervical spine
	Fractures to posterior elements of cervical spine
Rollover/Ejection	All of the above injuries possible due to multiple and varied points of impact during this mechanism

Note: It is important to note that this table is a guide to common trauma sustained with relation to impact direction and that other injuries are possible with each type of collision.

Causes of death

Deaths in the frontal group were frequently secondary to delayed complications such as ARDS, sepsis, and respiratory infections. Occupants injured in lateral collisions are more likely to die as a result of injuries to the brain, lung, and upper abdomen. Dischinger *et al*. (1993) reported thoracic trauma, which included the chest wall, diaphragm, and lungs to be more frequent with side impacts ($P < 0.0001$), as were injuries to the abdomen, in particular the spleen ($P < 0.0001$). The infrequent intestinal and mesenteric injuries were not seen to vary significantly by direction of collision force. Dischinger *et al*. (1993) reported the incidence of pelvic injuries as higher in lateral collisions ($P < 0.0001$). In keeping with lateral compression forces to the pelvis during a side impact, injuries to the bladder were significantly greater in lateral collisions (Dischinger *et al*., 1993).

Mitigating factors

The stiffness of the lateral aspect of cars and the use of restraints by the occupants are perceived to influence the patterns of injuries incurred during a side impact (Reiff *et al*., 2001). Reiff *et al*. (2001) evaluated the role of restraint use, vehicle size, and compartment intrusion on the incidence of splenic injury. Overall, they found that the use of seatbelts was associated with a reduced mortality rate (OR 0.40, $P < 0.0001$) and splenic injury (OR 0.76, $P < 0.0001$). However, restrained drivers in smaller vehicles (<2500 lb) had a higher incidence of splenic injury in crashes associated with minimal (lateral intrusion <30 cm, OR 60.1, $P < 0.0001$) and severe (lateral intrusion >30 cm, OR 4.0, $P < 0.0001$) compartment intrusion on the drivers side. This study supported the necessity for automobile manufacturers to improve the lateral impact crashworthiness of light vehicles, with the use of airbags and stiffer side collision bars.

Conclusions

There can be no doubt that the use of seat belts and airbags reduces the mortality risk during frontal and side impacts. A number of injury patterns can be clearly identified in conjunction with particular impact pictures:

- Lateral impacts are associated with a higher incidence of multiple injuries to the thorax and abdomen and statistically have a higher mortality rate when compared with frontal impacts.
- Frontal impacts are associated with a higher incidence of facial and lower extremity trauma, especially to the foot and ankle when the direction of impact is a near-oblique frontal.
- Traumatic blunt aortic rupture is more common in frontal high speed collisions however they can occur with side impact.
- Whiplash injuries to the neck most frequently occur with FSPs involved in rear-end collisions. However they can also occur with other directions of impact.
- There is a varied pattern of injuries sustained during rollover crashes. The severity of injuries and risk of fatality are closely linked with the use of lap restraints, roof crushing, and occupant ejection from the vehicle.

This literature review has highlighted the above key points. Like many who express interest in this field, we strongly believe that this knowledge can allow pre-hospital personnel and clinicians in the emergency department to gain foresight when suspecting and identifying the injuries sustained by car occupants during a motor vehicle collision.

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