ABDOMINAL INJURIES ASSOCIATED WITH THE USE OF REAR-SEAT LAP BELTS IN REAL-WORLD COLLISIONS

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ABSTRACT

In a number of motor vehicle collisions, occurrences of severe abdominal injuries to rear seat occupants have been identified as resulting from high loads imposed by lap belt restraints. Misuse of the available lap-belt restraint system in terms of excessive slack being present, or improper placement of the lap belt over the abdomen prior to the collision, has been shown to be a primary causal factor for the occurrence of such injuries. These incidents underline the need for improvements in the design and collision performance of rear seat belt systems, and the seats in which these devices are installed. Public education is also required to highlight the correct manner in which current restraint systems must be used if optimal collision performance is to be achieved.

INTRODUCTION

In general, the use of occupant restraints has been shown to provide substantial crash protection to vehicle occupants. By contrast, in some collisions, severe abdominal injuries to rear seat occupants have been identified as resulting from high loads to this vulnerable area imposed by lap belt restraints.

These instances are generally associated with some form of misuse of the restraint system by the involved occupant. Such misuse can take the form of excessive slack in the system, and/or improper placement of the lap belt prior to the collision event.

There are several factors which contribute to occupants wearing seat belt restraint systems incorrectly, including unawareness and carelessness. Many occupants have no knowledge of the importance of proper positioning of the lap belt, and some occupants who are aware of the significance of lap belt placement neglect to ensure that the seat belt webbing is properly positioned. Individuals who show some degree of obesity must make a special effort to ensure that the lap belt is correctly placed.

Seating position is important; the occurrence of slouching tends to position the lap belt over the abdomen rather than low on the pelvic girdle. Occupant stature can be a factor in this regard. Tall occupants may have their head touch the roof or rear window, their knees contact the front seat back, and thus a slouched position must be assumed. Finally, the wearing of bulky or heavily padded clothing provides a mechanism whereby the lap belt can easily be mis-positioned, or a significant amount of slack introduced into the system.

Not all of the problems associated with rear-seat lap belt use can be attributed to the action, or inaction, of the occupants. Often, the geometry of lap belt restraints installed in the rear seat, and the design of the rear seat assembly itself, tends to promote the misuse of the restraint systems rather than providing comfortable and convenient operation, and optimal levels of protection.

In Canada, a considerable effort is mounted to increase the levels of seat belt usage by vehicle occupants; however, seldom is much attention paid to promoting the correct manner of use of seat belts. On an individual basis, seat belt misuse can have disastrous consequences. Such instances, occurring in collisions receiving widespread media attention, can also have a substantial negative impact on promotional programmes. It is imperative, therefore, that the correct usage of occupant restraints be vigorously promoted.

Some of the problems associated with the use of lap belts by rear seat occupants are highlighted by studies of real-world collisions which have been investigated by the authors.

CASE STUDIES

Case Study No. 1

The case vehicle, a 1981 Toyota Corona, was travelling northbound on a two-lane, undivided highway. A 1952 Ford pick-up truck was travelling in the opposite direction on the same roadway and was approaching a sharp curve to the right. The truck's driver lost control while attempting to negotiate the curve on the wet roadway surface. The truck crossed the roadway centre line and the two vehicles collided in an offset, head-on impact.

There was direct contact across 81 cm of the left-front end of the passenger car, the maximum crush being measured as 99 cm at the vehicle's left-front corner. The barrier equivalent velocity for this vehicle in the collision was estimated to be in the range 32 to 48 km/h.

The driver of the Toyota and the right-front passenger were both fully-restrained, 63-year-old males. The driver sustained multiple fractures of the extremities (MAIS 3); the right-front passenger received only minor bruising (MAIS 1).

A 63-year-old female in the left-rear seating position was 152 cm tall, with a mass of 40 kg. She was wearing the available lap belt and sustained a sprained ankle and minor bruising (MAIS 1).

The right-rear passenger was a 68-year-old female. She was 183 cm in height, and had a mass of 72 kg. This passenger was also wearing the available lap-belt restraint. She received fatal, abdominal injuries (MAIS 6) as a result of loading impressed by the restraint system.

At autopsy, the abdomen showed a transverse area of bruising extending from the right to the left iliac crest, and areas of abrasion, measuring 8 cm x 5 cm, over the iliac crest. There was a fracture-dislocation at L3-L4, a torn abdominal aorta, massive retroperitoneal and peri-renal haemorrhage, and extensive mesenteric haemorrhages. The occupant also received a laceration in the inferior surface of the liver, a lacerated spleen, multiple contusions to the lungs with bilateral haemothorax, an extensive subarachnoid haemorrhage, and multiple abrasions to the forehead and extremities. There were no indications of bruising over the pelvic girdle.

Both lap belt restraint systems were removed from the outboard rear seating positions of the case vehicle for examination and testing. The vehicle sensitive, emergency locking retractors on both restraints were found to be functioning correctly. The seat belt anchorage locations for this vehicle were also determined to comply with the provisions of Canadian Motor Vehicle Safety Standard 210 - Seat Belt Assembly Anchorages.

A detailed examination of the right-rear seat belt webbing did not reveal any loading marks resulting from relative motion between the occupant and the webbing. This finding, coupled with the fact that the pathologist did not identify any bruising below the iliac crests, strongly suggests that the lap belt was improperly positioned on the abdomen prior to impact.

Case Study No. 2

The case vehicle, a 1981 Honda Accord four door sedan, was travelling southbound on a two-lane, undivided roadway. A 1975 John Deere tractor equipped with a back-hoe was parked against the west curb. The right-front corner of the case vehicle impacted the left-rear wheel of the tractor. The crush to the case vehicle was 58 cm, measured at the right-front bumper. The equivalent barrier speed for the vehicle was estimated at 24 to 32 km/h.

The driver and right-front passenger of the case vehicle were both elderly males of 69 and 68 years respectively; both were fully restrained. The driver received a contusion and strain to the right hip (MAIS 1). The right-front passenger sustained bruising as a result of seat belt loading (MAIS 1).

The left-rear passenger in the case vehicle was a 58-year-old female. She was 152 cm tall and weighed 82 kg. She received severe contusions to the abdominal wall from loading by the lap-belt webbing (MAIS 3).

The right-rear passenger was a 64-year-old female, 155 cm tall, and weighing 86 kg. She was admitted to hospital with head and abdominal injuries with massive intraperitoneal haemorrhage and expired some 17 hours later.

During an inspection of the case vehicle it was noted that the upper anchorage of the right-front restraint system had been moved vertically down the B-pillar in order to modify the seat-belt's geometry. A head contact by the right-rear occupant was evident on the upper anchorage of the right-front restraint system. This contact resulted in a laceration to the right temple, an extensive subarachnoid haemorrhage, and multiple, microscopic, cerebral contusions.

Interaction with the lap belt webbing produced extensive mesenteric tears, massive intraperitoneal and retroperitoneal haemorrhages, and extensive tears in the anterior and posterior abdominal wall (MAIS 5).

The investigating police officer found the right-rear passenger with the lap belt located across the soft abdominal area. Subsequently, a careful examination of the occupant's lap belt did not provide any indications of relative motion between the occupant and the webbing. The pathologist confirmed that there was no evidence of bruising below the iliac crests. It was concluded, therefore, that the lap belt was improperly positioned prior to impact.

Case Study No. 3

The case vehicle, a 1984 Volkswagen Jetta, was travelling eastbound along a two-lane, undivided highway. The driver of a 1977 Mercury Marquis, intending to turn left and travel westbound on the highway, lost directional control whilst making the turn. The Marquis slid into the eastbound lane and was struck in the centre-right side by the front of the Jetta.

The case vehicle received a broad frontal crush measured as 52 cm at the left-front corner and 26 cm at the right-front corner.

The barrier equivalent velocity for this vehicle was estimated as 39 to 48 km/h.

The 76-year-old male driver of the case vehicle was fully restrained. There was loading of the driver's seat back as a result of contact by the left-rear passenger. The driver struck the steering assembly and instrument panel and sustained a compression fracture of L1, and lacerations to the left arm and both knees (MAIS 2).

The right-front passenger was a 57-year-old female; she was also fully restrained. There was heavy forward loading of the right-front seat back as a result of contact by the right-rear passenger. The right-front occupant received multiple fractures to the ribs on the left side, a punctured right lung, pulmonary contusions, a fractured left wrist and bruising across the pelvic girdle (MAIS 4). Both rear-seat passengers were elderly females. Both were restrained by the available lap belts, and both were fatally injured.

The left-rear passenger was 65 years old, 168 cm in height, and weighed 64 kg. She sustained scattered abrasions across the face with associated lacerations of the mucosal surfaces of both lips. There were bilateral contusions to the cerebral hemispheres. A soft tissue injury to the lower abdominal wall was noted as being compatible with a seat belt injury. This was associated with rupture of the abdominal aorta, multiple injuries to the small bowel and mesentery of the small bowel, and extensive intraperitoneal and retroperitoneal haemorrhages (MAIS 5).

The right-rear passenger was 68 years old, 153 cm tall, with a mass of 61 kg. There was no autopsy performed on this individual; however, the attending physician indicated that there was bruising over the iliac crests with a compression fracture at C5-C6. A rupture of the abdominal aorta was suspected. The pelvis was fractured on both sides (MAIS 5).

No evidence of submarining of the rear seat occupants under their lap belt restraints was identified. It was concluded that the lap belts were improperly positioned prior to the collision; however, in the case of the right-rear occupant, the bilateral fractures to the pelvis may have allowed the belt to impinge onto the abdomen.

Case Study No. 4

The case vehicle, a 1976 Oldsmobile Cutlass four door sedan, was travelling westbound along a two lane, undivided highway. The driver of an oncoming vehicle, a 1971 Chevrolet Impala two door hardtop, lost directional control and the two vehicles collided head on. The case vehicle received a broad frontal crush measured as 89 cm at the left front end and 102 cm at the right front end. The barrier equivalent velocity for the case vehicle in this collision was estimated at 60 km/h.

All six occupants of the case vehicle were fatally injured. The occupants of interest to our current discussion were the three rear seat passengers who were all lap belt restrained. Each of these occupants sustained head and/or chest injuries; however, the cause of death in each case was severe abdominal trauma resulting from loading by the restraint system. In all three cases misuse of the available lap belt restraint was attributed to the severe injuries sustained. In two cases, a considerable amount of slack was present, allowing at least one of the occupants to submarine under the belt. In the third case the lap belt was found to be positioned too high, being located across the abdomen, above the iliac crests.

A detailed examination of the rear-seat lap belts was conducted in order to identify the manner in which the restraint systems were used. Loading marks on the seat-belt webbing from the locking bar in the tongue indicated the adjusted lengths of the centre-rear and right-rear lap belts. Reconstruction of the seat belt geometry using an exemplar vehicle revealed that a considerable amount of slack was present in the systems. Abrasion marks located on the webbing of the centre-rear lap belt were indicative of submarining by this occupant. No loading marks were identified on the left-rear lap belt; however, significant bruising was present across the abdomen and above the iliac crests of the occupant. It was concluded that this occupant's lap belt was improperly positioned prior to impact.

The left-rear passenger was a 43-year-old female. She was approximately 168 cm in height and weighed 66 kg. This occupant sustained contusions to the large intestine, liver, spleen, and right abdominal wall; transection of the jejunum; a lacerated mesentery; and a fracture with partial separation of lumbar vertebrae L2 and L3 (MAIS 4).

The centre-rear passenger was a 20-year-old female. She was approximately 163 cm tall and weighed 64 kg. This occupant received contusions to the stomach and to the small and large intestines; lacerations to the left and right lobes of the liver, right kidney, anterior abdominal muscles, psoas muscles, and wall of the aorta; a ruptured spleen; and a fracture of the lumbar spine at L3 with associated cord damage (MAIS 5).

The right-rear passenger was a 47-year-old female, weighing approximately 52 kg and 165 cm tall. She sustained lacerations to the transverse colon, small intestine and spleen; a ruptured mesentery; complete transection of the aorta in the lumbar area; and complete transection of the lumbar spine between L2 and L3 (MAIS 5).

DISCUSSION

These four cases are among some of the most severe frontal collisions investigated by the authors in which lap-belted rear occupants have sustained life-threatening injuries directly related to occupant interaction with the two-point lap belt.

We have found that the severity of the injury is roughly related to the overall crash severity. Where severe or life-threatening injury has been identified in lower speed crashes, these injuries are almost always related to markedly excessive belt slack in combination with poor belt position and/or occupant submarining under the very slack belt. MacKay (1) has suggested that submarining under the lap belt could be a very important injury mechanism for rear-seat occupants where the backs of the front seats usually provide negligible resistance to forward travel of the knees. New research techniques applied to crash tests may assist in confirming this supposition (2).

A number of investigators have identified excessive slackness in the restraint system as a major factor contributing to improper positioning of the lap belt. Such looseness also contributes to injury severity. The belt fails to engage the forward-moving human body early in the collision event, and when, eventually, this does occur, the period of vehicle crush is mostly complete. The occupant thus fails to "ride-down" the collision as a restrained part of the vehicle. This results in an increased relative velocity between the occupant and the vehicle, and higher collision forces are applied across a narrow band of vulnerable human anatomy, with disastrous results to intra-abdominal organs.

When the lap belt is properly positioned below the anterior superior iliac spines, without any significant slack in the system, the occupant is free to flex forward at the waist. While this arrangement permits contact of the head, arms, and upper torso with the front seat back, this contact is almost always much more forgiving than the upper body contact that would be experienced by the unbelted rear seat occupant. When the lap belt is properly positioned at the time of a high-energy, frontal collision, the belted occupant will markedly flex or "jack-knife" his body around the restraining two-point belt. This extreme lower trunk flexion manoeuvre demands fairly supple anatomy or disruption to the lumbar spine will occur (3). When the lap belt is in proper position on the pelvis, such lower trunk flexion will include pelvic rotation on the femoral heads, and flexion of all five lumbar vertebrae, on each other, as well as on T12 and S1. When the lap belt is riding high on the abdomen, this marked forward flexion will be restricted to the upper one or two lumbar vertebrae, which will result in disruption of the lumbar spine, and cord injury, at this level.

Campbell (4) recently reviewed the literature on the effectiveness of rear seat lap belts in crash injury reduction. He pointed out that all of the major studies reviewed agree that lap belts are of substantial overall benefit in reducing crash injury among rear seat wearers. It was clear from this review that rear seat lap belts reduce serious injury by about 40% as compared with unbelted rear occupants.

He has effectively challenged a possible misinterpretation of the recent National Transportation Safety Board study (5) in which the effectiveness of rear seat lap belts was questioned. The data analyzed has led Campbell to conclude that at high levels of crash severity the lap belt may be more likely than the lap/shoulder belt to be at its limit of protection. This leads him to conclude that lap/shoulder belts in the rear seat would provide increased protection beyond that now afforded by lap belts alone.

It is encouraging that some North-American automobile manufacturers have followed the European initiative and, in the near future, will be installing three-point belts in the rear-outboard seating positions of all new production passenger cars. This programme will leave a significant proportion of cars on the road over the next decade with two-point belts in the rear seat. Campbell notes that anchor points are available in most production cars for the installation of lap/shoulder belts in the rear seat at the owners' initiative. Volvo has recently reported on a design of a three-point restraint suitable for installation in the centre-rear seating position of their vehicles (6).

Three-point, lap and shoulder belts in the rear seat will prevent excessive forward excursion of the head and upper torso, so modifying the injury mechanisms described above. Recognizing the dangers associated with belt slack, belt malposition, and the absence of a knee bolster (1), it is incumbent on manufacturers to continue improving the geometry of the lap belt to prevent design-induced occupant errors in the lap belt placement. A recent study, and design exercise, along these lines has recently been conducted by BMW (7). As an aid to quantifying seat belt fitment, Canadian researchers have produced a belt deployment test device (8).

Our studies would concur with the analysis and conclusions by Campbell, attesting to the advisability of wearing the lap belt in the rear seat of cars, if that is the only belt system available. The injury kinematics outlined above lead us to strongly support Campbell's advice to wear the lap belt as low as possible, and as snugly as possible.

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