MISUSE OF THREE-POINT OCCUPANT RESTRAINTS IN REAL-WORLD COLLISIONS

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ABSTRACT

The use of three-point occupant restraints has been shown to be a very effective means of reducing the severity of occupant injuries over all crash modes. In a small number of cases, not involving intrusion into the occupant space, severe to fatal injuries have occurred to fully-restrained occupants, and restraint system misuse has been found to be a major causal factor. Three primary modes of seat belt misuse are identified in the present paper, these being excessive slack in the system, improper placement of the seat belt webbing, and unsuitable pre-impact posture of the occupant. The consequences of such seat belt misuse are examined through case studies of real-world collisions which have been the subjects of multi-disciplinary investigations by the authors. Such instances underscore the necessity of improving the design and performance of current restraint systems, and of providing suitable public education as to the correct manner in which seat belt systems should be utilized.

INTRODUCTION

It is generally accepted that three-point seat belt systems are an effective means of protecting motor vehicle occupants in the event of a crash. This is especially true for frontal impacts which form the most frequent collision type, and also give rise to some of the highest crash severities.

A properly-worn, three-point restraint can mitigate the effects of quite severe frontal crashes and reduce injury levels to within tolerable limits. The misuse of seat belts can produce severe, and even fatal, injuries to occupants involved in collisions of only moderate severity.

Throughout the world, governments are mandating both the installation of seat belt systems in motor vehicles, and their usage by vehicle occupants. Typically, motor vehicle safety standards address the mechanical strength of seat belt assemblies, but fail to address their comfort, convenience, and even collision performance. Widespread media campaigns stress the importance of wearing a seat belt and the benefits which are to be derived in the event of a crash. Seldom is much consideration given to the necessity for correct usage if optimal performance of the restraint system is to be realized.

If regulations governing the installation and use of seat belt systems are to be truly effective, close attention must be paid to these questions by both governments and industry.

CASE STUDIES

Case Study No. 1

The driver of a 1980 Chevrolet Chevette crossed the roadway centre line whilst attempting to negotiate a sharp curve to the right. The front end of the case vehicle struck the rear-dual wheels of the lead trailer in a tractor-double trailer combination. The car performed one complete counterclockwise rotation and struck the rear wheel of the second trailer. The barrier equivalent velocity for the initial impact was estimated as 8 km/h, whereas that for the second collision was approximately 30 km/h.

The case vehicle was occupied by two elderly persons, both of whom, after the crash, were found with the torso portion of their three-point restraint system under the axilla, both fatally injured.

Witness marks present on both the left-front and right-front restraint systems were indicative of occupant loading of the seat belts. Tongue impressions showed lap-belt lengths of 90 cm for the driver and 81 cm for the right-front passenger. Light abrasion marks were found on the D-rings of both systems; however, no transfers were made to the webbing material.

The driver, a 64-year-old female, was 155 cm tall and weighed 50 kg. This occupant sustained brain contusions at the base and anterior aspects of the frontal and temporal lobes, with bilateral subdural, periorbital, and subarachnoid haemorrhages. There were fractures to the left anterior ribs numbered 2 through 8, with a partial collapse of the left lung. There was a deep laceration to the left lower forehead with a massive haemorrhage of the anterior superior aspect of the scalp. The driver also received multiple contusions, abrasions and lacerations to the chest and the extremities. Death was due to brain damage (MAIS 5).

The right-front passenger was an 87-year-old female, 160 cm in height, and weighed 54 kg. She sustained multiple cerebral contusions over the scalp, and partial dislocation of the cervical spine from the base of the skull with extensive soft tissue haemorrhage. There was blood staining of the posterior fossal structures, and soft tissue haemorrhage in the periosteum of the left frontal skull. She also received fractures of the ribs anteriorly, numbers 2 through 9 on the left, and 1 through 9 on the right. There was perforation of the pericardial sac in the anterior wall, a superficial laceration of the left ventrical, extensive interstitial haemorrhage of the posterior mediastinum from the cervical spine to the retroperitoneum, right haemothorax, and a superficial laceration to the liver. There was a horizontal abrasion across the anterior abdomen touching both iliac crests, a full thickness laceration to the left forehead, and multiple contusions and abrasions to the chest and extremities. Death was due to brain damage and exsanguination into the chest cavity (MAIS 5).

Case Study No. 2

The case vehicle, a 1974 Buick Century two-door sedan, was travelling southbound on a two-lane county road. A 1977 International pick-up truck was northbound along the same roadway. Travelling downgrade, the truck drove onto the ice-covered deck of a bridge crossing over a river. The truck driver lost directional control and his vehicle skidded in a clockwise yaw across the roadway centre line. The front of the passenger car struck the left-front door area of the pick-up resulting in considerable crush to the structure of both vehicles.

Despite the degree of side intrusion into his occupant space, the lap-belt restrained truck driver survived the impact with multiple major fractures and serious internal injuries. The fully-restrained driver of the case vehicle loaded the upper portion of the steering wheel rim with her head, bending the rim forward and causing a 3 cm impression in the upper instrument panel. This forceful head contact resulted in a spectacular skull fracture, bilateral basal and bi-occipital (Figures 1 and 2), with transection of the basilar artery and avulsion of the brain stem. Death was instantaneous (MAIS 6).

This female driver was 158 cm tall, and weighed 57 kg. The front seat was adjusted to the fully-forward position. The damage to the front of the case vehicle was indicative of a 50 to 60 km/h barrier equivalent velocity for the collision. If the driver was wearing the available three-point lap and torso belt correctly, she would be expected to experience a forward chest excursion of 30 to 36 cm, and a forward head excursion of 56 to 60 cm. Considering the size of the driver, the dimensions of the occupant space, the position of the driver's seat in the fully-forward position, it is necessary to predict some forward or ducking motion of the head prior to collision in order to account for the force with which she made head contact with the steering wheel rim and instrument panel.

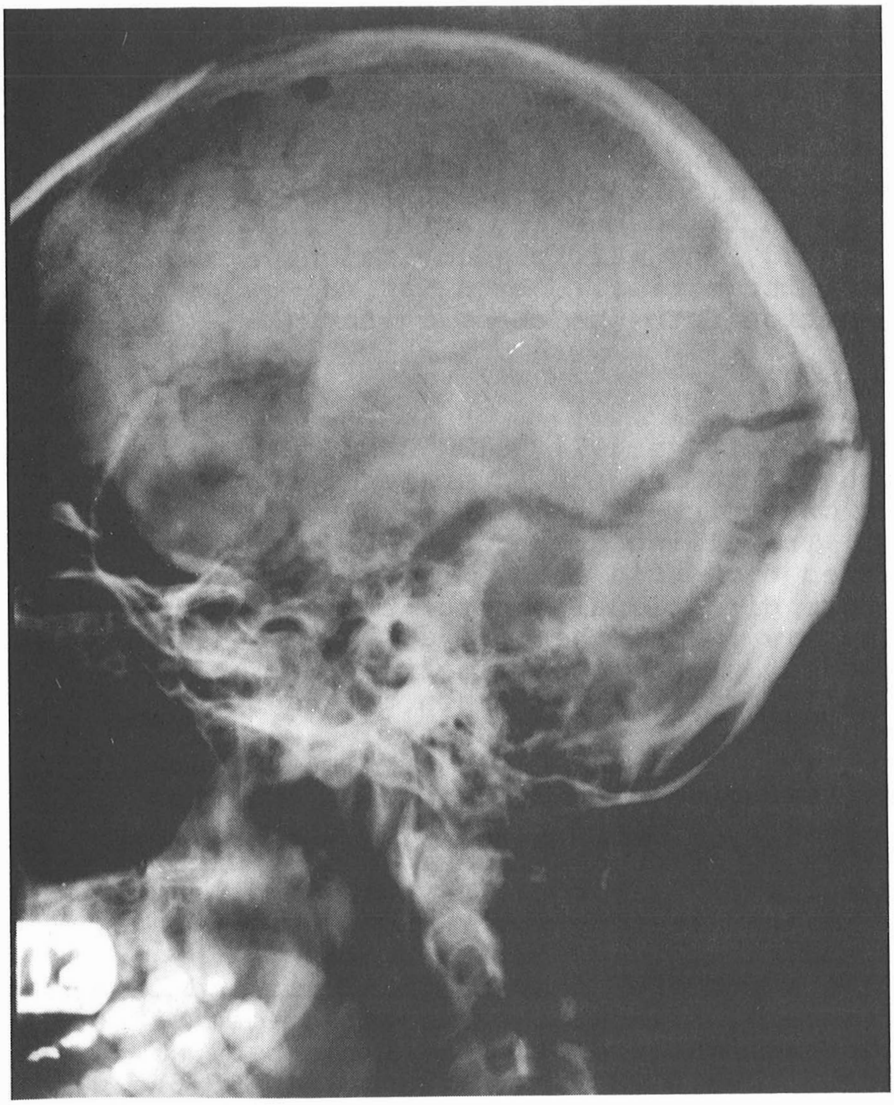

Figure 1 Radiograph showing lateral view of the bilateral basal and bi-occipital skull fracture to the driver in Case Study No. 2

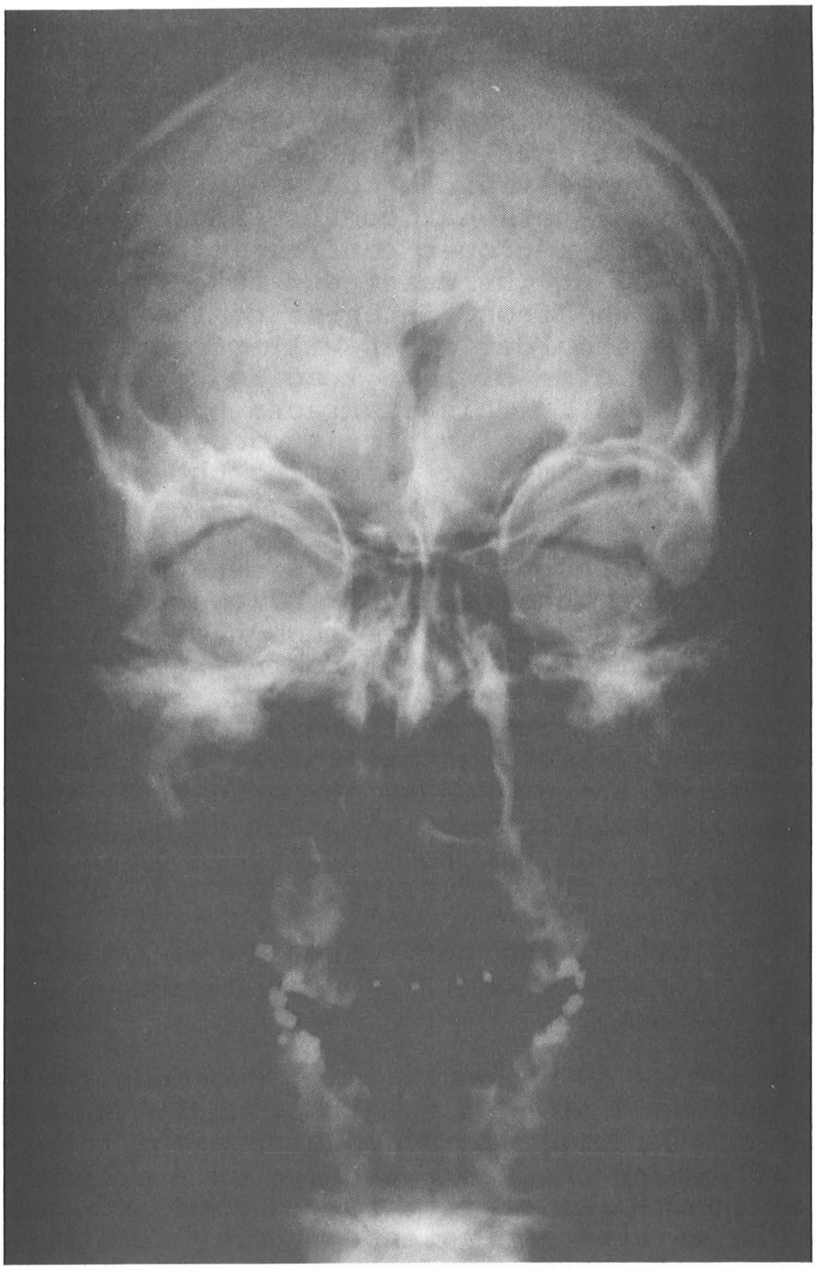

Figure 2 Radiograph showing frontal view of the bilateral basal and bi-occipital skull fracture to the driver in Case Study No. 2

Discussion

These two cases are typical of a number of cases investigated by the authors. They demonstrate the potential for severe or fatal injury when the shoulder portion of the three-point belt is defeated by advertent or inadvertent misplacement. Case Study No. 1 represents a not uncommon decision by a front seat occupant to place the shoulder portion of the belt in the axilla. The uninformed vehicle occupant usually justifies this practice as promoting personal comfort and convenience. With the seat belt in this improper configuration, the occupant is free to flex forward at the waist and make forceful head and/or chest contact with the front interior of the vehicle. The malposition of the shoulder strap will promote upward tension on the lap belt at the time of belt loading, leading to severe abdominal injuries (1). This misplacement of the shoulder portion of the three-point system is correctable through education programmes aimed at informing the motoring public of the dangers of such a manoeuvre.

Case Study No. 2 represents an inadvertent panic ducking manoeuvre that places the head forward and downward prior to any sudden vehicle motion such as braking which would have engaged the restraint system's emergency locking retractor. Pelvic contusions in the region of the anterior, superior iliac spines were evidence of the proper positioning of the lap belt prior to collision. If the driver had maintained an upright posture prior to collision she would have experienced enough forward excursion to make head contact with the steering wheel. From our reconstruction, and the known performance of this restraint system in crashes of this severity, the head injuries would have been much less severe than actually occurred. Driver education is necessary to avoid such panic manoeuvres as head ducking.

Case Study No. 3

The case vehicle, a 1984 Honda Accord two-door sedan, was travelling eastbound along a two-lane, undivided highway. The vehicle ran off the paved roadway surface and entered the southern ditch where the front end struck a culvert. Following this initial impact the vehicle rolled over and came to rest on its roof. The barrier equivalent velocity for the initial frontal impact was estimated at 30 km/h.

The right-front passenger in the case vehicle was fully restrained and had the back rest of her bucket seat in the fully-reclined position. As a result of the frontal impact the occupant slid forward and the torso portion of the restraint system caught her under the chin. She sustained a fracture of the lateral pedicles of C2 and fracture of the superior and inferior articular facets of C2-C3 on the right side (Figure 3). There was a minor sprain to the right ankle. She was unconscious briefly and subsequently complained of pain to the neck and shoulders. She lost function in both legs (MAIS 3).

This individual was immobilized and recovery took place over a period of several months.

Figure 3 Radiograph of the cervical spine of the front passenger from Case Study No. 3 showing the hangman's fracture

Discussion

This female passenger, belted in the supine position, slid under her restraint system at the time of frontal collision. The shoulder harness engaged her upper neck and chin resulting in a hangman's fracture with moderate spinal cord damage at level C2. Distraction of the upper cervical spine with the head in extension is the mechanism employed in judicial hanging, calculated to traumatize or sever the cord and cause instant death. The mechanisms of such injuries resulting from automobile collisions are discussed in detail in a companion paper (2). If vehicle manufacturers are to continue to provide fully reclining bucket seats for front seat passengers, they must caution users of the inherent dangers when the vehicle is in motion. Possibly a crotch harness component could be introduced into the seat belt system as is done in Formula 1 racing cars.

Case Study No. 4

The case vehicle, a 1981 Chevrolet Malibu Classic four door sedan, was travelling eastbound along a two-lane, urban arterial. The vehicle suddenly veered to the left, travelled across the boulevard and an intersecting roadway, and impacted a large tree. Penetration into the frontal structure of the vehicle was measured as 74 cm; the barrier equivalent velocity was estimated at 35 km/h.

The unrestrained driver made head and chest contact with the laminated windshield and energy-absorbing steering assembly respectively. He sustained moderate injuries to the head and face and moderate injuries to the chest (MAIS 3).

The right front passenger was a 30-year-old female who was 174 cm tall and weighed approximately 67 kg. She was wearing the available lap and shoulder belt; however, a detailed examination of the witness marks on the restraint system revealed that there was a considerable amount of slack present. The passenger sustained fractures to the left, anterior, lateral ribs numbered 8 through 10; a ruptured spleen; a ruptured left lobe of the liver with a laceration of the major branches into the vena cava, and haemoperitoneum resulting in exsanguination (MAIS 5). All of these injuries were attributed to loading by the restraint system webbing.

Discussion

Excessive slackness in the restraint system is a major factor contributing to the occurrence of serious injury to restrained occupants. Looseness of the belt results in magnification of the force applied to occupant tissues because of the increased time of occupant forward excursion before the restraint system engages the forward moving human body.

In a 50 km/hour frontal barrier crash, the average passenger car undergoes crushing of the frontal structures over a period of about 120 milliseconds while the occupant compartment is coming to a stop (3). Crash tests have established that a properly worn restraint system of the type available in modern vehicles will not be fully engaged until half of that time has expired. This is because of time taken for the emergency locking retractor to function and lock the inertia reel, the film-spool effect as the webbing tightens on the reel, elongation of the webbing material, and webbing penetration into surface layers of human soft tissues. The occupant thus becomes a fully restrained part of the vehicle only during the last half of the vehicle crushing phase, and then "rides down" the acceleration forces.

If the restraint system contains a significant amount of slack, it is possible for the improperly restrained occupant to continue his forward excursion for an excessive period of time. When the lax belt webbing fully engages human tissues, the period of "ride down" is completed, or almost completed. This results in an increased relative velocity between the vehicle and the occupant, and higher collision forces being applied across a narrow band of vulnerable human anatomy.

The unfortunate, female, right-front passenger in the case vehicle incurred life-threatening injury to her liver and deep veins which resulted in death. The position of the belt, and the force applied to the upper right abdominal quadrant were responsible for this disproportionately severe injury. It was challenging to explain this tragic death to her husband, the unbelted driver, who received only moderate injury.

CONCLUSIONS

There is overwhelming evidence that restraint system use provides excellent protection to vehicle occupants in the vast majority of collisions; however, very infrequently loading impressed on the occupant by the seat belt system itself is found to give rise to serious injury. In the present paper, a number of such cases have been discussed. In all of the reported cases, some form of misuse of the restraint system has been identified as being a major contributing factor to the injuries sustained.

A worldwide programme of research into promoting ideal belt geometry, improved seat design, and methods of eliminating belt slack has yielded some innovative devices and designs. Computer simulation models have been developed as an inexpensive method of studying the dynamics of fully-restrained occupants in crashes for various combinations of anchorage locations, webbing elongation, and seat cushion stiffness (4). Consideration has been paid to various aspects of seat design including seat contour and stiffness (5). Proper placement of anchor points, and the utilization of webbing clamps and pyrotechnic pretensioners and retractor devices have been studied (6,7). Such developments are being planned for or included in some late model motor vehicles (8).

Such improved designs are very timely in the light of the changes being brought about with respect to restraint system availability in automobiles, and the mandatory usage requirements in an increasing number of jurisdictions. Two of the major north-American manufacturers have stated their intentions to provide three-point occupant restraint systems in the rear-outboard seats of new passenger cars as standard equipment in the near future. Volvo has recently produced a design for a three-point belt for the centre-rear position which will be made available as an aftermarket item (9). Such developments will bring lap and shoulder belt protection to an increased number of motor vehicle occupants.

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