UPPER EXTREMITY INJURIES RELATED TO AIR BAG DEPLOYMENTS

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ABSTRACT

From our crash investigations of air bag equipped passenger cars, a subset of upper extremity injuries are presented that are related to air bag deployments. Contusions, abrasions, and sprains are not uncommonly reported. Infrequently, hand and digit fractures have been sustained and, in isolated cases, fractures of the forearm bones. The close proximity of the forearm or hand to the air bag module door is related to most of the fractures identified. Steering wheel air bag deployments can fling the hand-forearm into the instrument panel, rearview mirror or windshield, as indicated by contact scuffs, tissue debris or the star burst (spider web) pattern of windshield breakage.

THE AIR BAG should be considered as part of the preventative medicine armamentariun but it is not the ultimate polio vaccine for traffic medicine. The injury reducing potential and the lifesaving benefits of the air bag, the supplemental restraint now commonly found in the steering wheels of most new passenger cars, have been documented in the medical and engineering literature (Backaitis, 1987, Conover, 1992, Digges, 1989, Evans, 1991, Han, 1993, Huelke, 1979, Huelke, 1991, Huelke, 1992a, Huelke, 1992b, Insurance Special Report, 1991, Jagger, 1987, Kuhn, 1993, Lesher, 1993, Marsh, 1993, NHTSA, 1992, O'Neill, 1992, Resenblatt, 1993, Scott, 1993, Smally, 1992, Viano, 1991 Whitacre, 1993, and Zador, 1993). However, case reports of injuries from the air bag, particularly corneal/scleral abrasions, facial erythema, contusions, or abrasions have also been noted (Blair, 1992, Braude, 1992, Ingraham, 1991, Larkin, 1991, Lubeck, 1986, Mishler, 1991, Rimmer, 1991, Rosenblatt, 1991, Smock, 1992 and Steinmann, 1991). Cervical spine and other fractures have been related to air bag deployments as well as a heart rupture (Blacksin, 1993, Lancaster, 1993 and Traynelis, 1993).

This report documents the variety of injuries to the upper extremities related to air bag deployments, ranging from forearm and hand erythema, contusions, lacerations, or thermal burns, to fractures or dislocations of the thumb, wrist, and forearm.

These cases were investigated by the field investigation team of the University of Michigan Transportation Research Institute (UMTRI) and some from the National Highway Traffic Safety Administration (NHTSA) Special Crash Investigation Section.

MATERIALS AND METHODS

At the University of Michigan Transportation Research Institute (UMTRI) there has been an ongoing field accident research program to determine the causes of injuries and deaths in automobile crashes since 1961, with investigations primarily in Ann Arbor, Michigan and the surrounding county. In the mid-1980's investigations of air bag crashes began, with a gradual increase in frequency as more new cars were equipped with air bags. Since 1988 UMTRI's program has expanded nationwide in search of frontal crashes with air bag deployments. More than 1900 air bag notifications have been received from various sources nationwide. Car tear-down or repair, or lack of occupant injury information has precluded detailed study of many of these notifications. Over 250 air bag crashes have been investigated in detail as of December, 1993.

The National Highway Traffic Safety Administration (NHTSA) has also been conducting a special study of crashes involving automobiles equipped with air bags. To date they have investigated about 1200 air bag "crashes" with little overlap of cases between NHTSA and UMTRI. NHTSA contributed to this study by providing case information from their air bag deployment investigations.

In each case the investigators document vehicle, environmental, and occupant data including make, model, and year of the car, the amount of car crash damage, age, height, weight, and detailed injuries of the occupant(s), as well as information about the crash. From these investigations selected cases are presented here in capsule format. Injury contact data are the objective opinions of the crash investigators and rarely based on occupant statements.

RESULTS

ERYTHEMA, CONTUSIONS, ABRASIONS AND BURNS

Following an air bag deployment, the affected occupant frequently complains of various minor upper extremity injuries such as discoloration's, abrasions, or contusions. We have identified these minor injuries in about 50 air bag cases collected by UMTRI. Such injuries are caused by the deploying air bag impacting the skin. Several examples follow:

Case 1 - A 1991 Cadillac Eldorado driven by a 30-year-old unrestrained female sustained extensive right front damage when it struck a 12 cm diameter tree (Fig. 1). The driver, height-163 cm, mass-64 kg, had her seat positioned forward. She sustained contusions of both anterior forearms, had contusions of both temples, and complained of a headache, all from contact with the air bag. Contusions of the knees and cervical strain were also reported. (UM-2909-91)

Fig. 1 Frontal crash, 1991 Cadillac Eldorado.
Minor injuries sustained including contusions of forearms.
Similar injuries in Cases 2 and 3.

Case 2 - A 1992 Honda Accord LX sedan struck a guardrail and then was hit by a tractor-trailer unit. Frontal damage from the guardrail impact was severe. Damage to the left rear from the truck was minor. The 35-year-old lap-shoulder belted male driver, height-180 cm, mass-72 kg, had the seat at mid position. His right wrist and thumb were contacted by the air bag as it deployed, resulting in an abrasion on the posterior right thumb and a contusion of the anterior right wrist. The driver also had cervical strain and abrasions of the left knee and left leg. (UM-2999-92)

Case 3 - On a slippery, snow-covered road a 1992 Plymouth Sundance hit the rear of a parked car. Minor front right damage was noted. The air bag deployed. The 39-year-old lap-shoulder belted female driver, height-165 cm, weight-55 kg, sustained sore right anterior forearm muscles when her forearm was "thrown off" the steering wheel by air bag deployment. Her extremity did not impact anything within the car after bag deployment. No other injuries were reported. (UM-3118-93)

Such forearm injuries as described above have been noted to drivers in other crashes and to front right passengers who interacted with the deploying passenger side air bag. (see cases 17, 19 and 20)

Case 4 - A 1992 Dodge Grand Caravan, driven by a 52-year-old lap-shoulder belted male, height-183 cm, mass-84 kg, crossed the center line and was struck head-on by another car (Fig 2). The driver sustained minor injuries including lacerations of the knees and ankles, a contusion of the chest from the shoulder portion of the restraint system and multiple small lacerations of both the anterior right and left forearms from air bag contact. (UM-2996-92)

Fig. 2 Forearm lacerations from air bag contact in this 1992 Dodge Grand Caravan frontal crash.

There have been reports of individuals experiencing burns on their hands from the hot gases generated during air bag deployment. Two similar cases in our files are summarized below:

Case 5 - A 1990 Infiniti M30 rear-ended a stopped car. The Infiniti had moderate right front damage. The 37-year-old lap-shoulder belted female driver, height-160 cm, mass-45 kg, apparently had both of her hands on the steering wheel spokes at the time of the crash. She sustained burns on both hands from the air bag gas vented through the openings in the back of the bag. These injuries were noted as first degree burns on the dorsal left wrist and of the dorsal left hand between thumb and index finger, second degree burns in the same location on the right hand, and multiple burns of the right fingertips. (UM-NAB-022)

Case 6 - A 1990 Plymouth Sundance struck the rear of a car stopped in traffic. The Sundance had very minor front damage. The car was equipped with an early design untethered air bag (see discussion). The 65-year-old female driver, height-163 cm, mass-72 kg, was wearing her 3-point restraint. She sustained an abrasion beneath her chin and a slight contusion of her left lateral forearm from contact with the deploying air bag. The air bag vent gas melted her polyester glove at the base of her left thumb, beneath which was a minor burn. (UM-2854-90)

FLAILING EXTREMITY INJURIES

Occasionally, injuries result from the air bag flinging an upper extremity towards car interior surfaces, primarily to the windshield or instrument panel as determined from the injury, tissue debris, or skin oil transfer.

Case 7 - A 1985 Ford Tempo, attempting a left turn, struck the left side of an oncoming car. The Tempo was moderately damaged in the left front (Fig. 3). The 36-year-old male driver, height-175 cm, mass-78 kg, was wearing his 3-point restraint. His hand was thrown into the windshield by the deploying air bag, causing a contusion and slight sprain of the left wrist. The windshield was cracked from the hand impact. (Fig. 4) (UM-FMC-003)

Fig. 3 Frontal crash, 1985 Ford Tempo

Fig. 4 Windshield cracked from hand impact due to air bag deployment.

Case 8 - A 1991 Dodge Shadow went off the right side of the road and struck a tree (Fig. 5). The 25-year-old unrestrained male driver, height-180 cm, mass-98 kg, did not have any facial injuries from the air bag. Both forearm bones were fractured including an impacted fracture of the right distal radius and fractures of the adjacent ulna and of the base of the second metacarpal from striking the instrument panel when his hand was flung from the steering wheel by the deploying air bag (Fig. 6). The fractures of the right femoral neck and mid shaft, from impacting the console, would have been prevented if the available 3-point restraint had been worn. (UM-3098-93)

Fig. 5 Frontal crash into a tree, 1991 Dodge Shadow

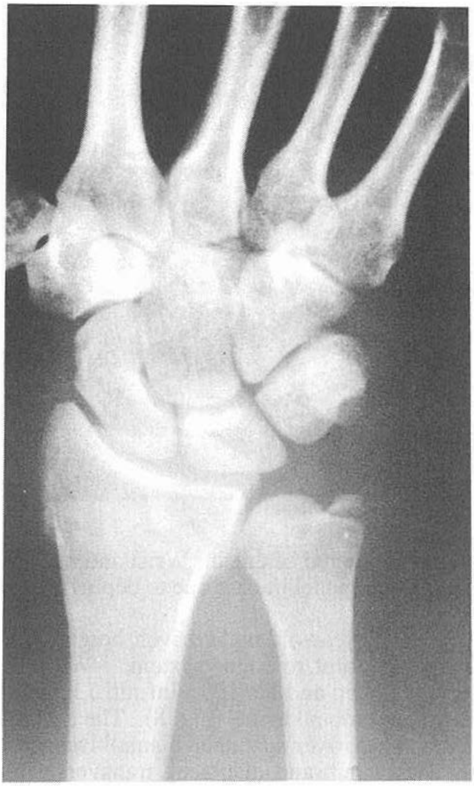

Fig. 6 Impact fracture right distal radius when the extremity was flung into the instrument panel by the deploying air bag.

Case 9 - On a wet, slippery expressway an out of control car crossed the grassy median and struck a 1990 Plymouth Acclaim in the left side (Fig. 7). In this side impact the air bag deployed. The 28-year-old female driver, height-171 cm, mass-90 kg, was wearing her 3-point restraint system. She sustained lacerations of the spleen and contusions of the lower rib cage from the interior of the driver's door, abrasions and contusions of the knee and pretibial area from the lower instrument panel and, due to air bag deployment, her right hand was flung and impacted the upper instrument panel, producing fractures of the scaphoid (wrist bone) and base of the fifth metacarpal. She also had an abrasion of the left forearm from the air bag. (UM-3078-92)

Fig. 7 Side swipe type of crash. Wrist and hand fractures from instrument panel impact due to deploying air bag.

Case 10 - A 55-year-old male driver, height-173 cm, mass-61 kg, was wearing a 3-point restraint system. While driving on an expressway he fell asleep and his 1993 Infiniti J30 went off the road and struck an earthen embankment (Fig. 8). The air bag deployed in this frontal crash. The driver sustained a small laceration of his right wrist from his wristwatch and displaced transverse fractures of the right mid radius and distal ulna and fracture of the right distal radius (from steering wheel contact due to forearm entrapment by the air bag) (Fig. 9). No other injuries were reported. (UM-NAB-039)

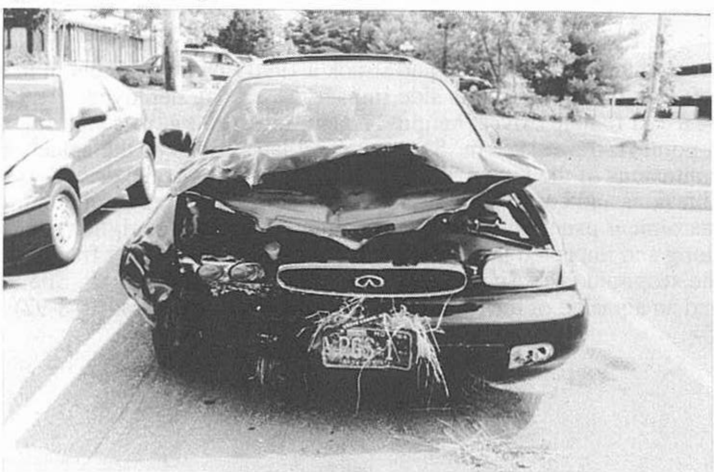

Fig. 8 1993 Infiniti J30 impacted an embankment. Forearm fractures are shown in Fig. 9

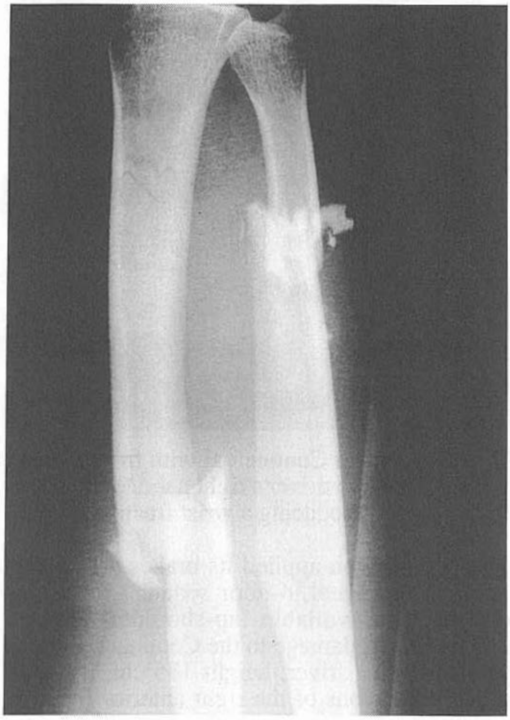

Fig. 9 Displaced fractures of right radius and ulna from steering wheel-air bag entrapment

Case 11 - While attempting to turn left, a 1990 Lincoln Continental struck a van head-on. Damage to the front of the Continental was moderate (Fig. 10). The 33-year-old lap-shoulder belted female driver, height-166 cm, mass-57 kg, sustained a fracture and abrasions of the right wrist and abrasions of the left wrist. Air bag deployment caused the wrist abrasions and propelled her right hand into the center instrument panel producing the wrist fracture. (UM-FMA- 036)

Fig. 10 1990 Lincoln Continental with frontal damage. Airbag deployment flung the driver's right hand to the instrument panel producing a wrist fracture.

Case 12: - A van applied its brakes and was rear-ended by a 1992 Lincoln Continental, 4-door sedan. Neither driver nor front passenger wore the available lap-shoulder belts. Both air bags deployed. The frontal damage to the Continental was minor (Fig. 11). The 52-year-old male driver, height-185 cm, mass-95 kg, sustained abrasions and contusions of the right anterior forearm and abdomen from the steering wheel air bag. The front right 51 year-old male, height-175 cm, mass-84 kg, had a contusion of the anterior aspect of the right forearm, a strain of the joints of the left third finger with three overlying lacerations from contact with the passenger side air bag. (UM-FMA-057)

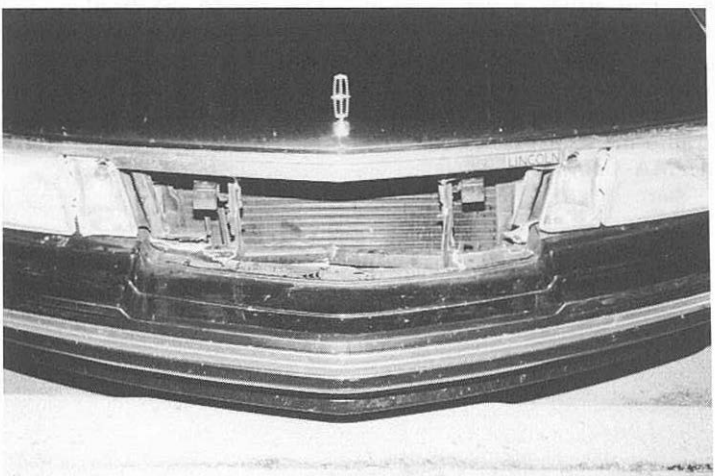

Fig. 11 1992 Lincoln Continental. Both driver and front passenger sustained forearm abrasions and hand injuries from the air bag.

Case 13 - A 1989 Dodge Daytona struck the front of an oncoming vehicle that had crossed the center line. Left front corner impact damage to the Daytona was very minor. The 29-year-old lap-shoulder belted female driver, height-170 cm, mass-65 kg, had her seat at mid position. The driver's left hand was propelled into the windshield by air bag deployment as indicated by the star burst pattern on the windshield (Fig. 12). The driver's injuries included a bruise of the left hand, from the windshield impact, a cervical spine strain, and bruises of the chest and right hip from the belt restraint webbing. (UM-CCA-006)

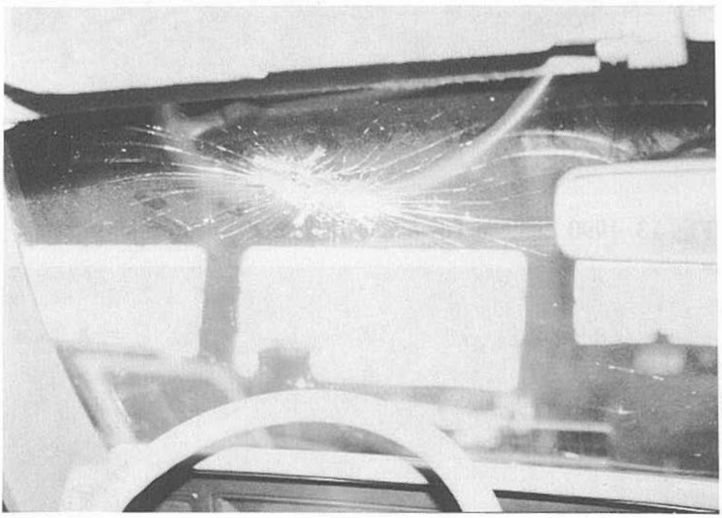

Fig. 12 Windshield star burst fracture due to driver's hand impact.

Case 14 - A 1991 Dodge Caravan SE hit the side of an oncoming car that had turned in front of it. Impact was to the Caravan's left front, producing minor damage. The 34-year-old male driver, height-178 cm, mass-86 kg, was wearing his 3-point restraint. When the air bag deployed his hand was forced upwards from the steering wheel to strike the upper left area of the windshield producing a spider web impact pattern. The driver sustained pain and muscle strain of the left hand as a result of impacting the windshield. No other injuries were reported. (UM-CCA-074)

Case 15 - A 1990 Lincoln Town Car Signature Series was traveling on a rural road when it hit the side of a farm tractor that had failed to stop (Fig. 13). The 76-year-old male driver, height-183 cm, mass-82 kg, was lap-shoulder belted. The air bag deployment flung his left hand into the windshield (Fig. 14). As a result of this impact he sustained a contusion and multiple lacerations on the dorsum of his left hand as well as a sprain of the left hand. (UM-FMA-044)

Fig. 13 1990 Lincoln Town Car driver sustained minor injuries.

Fig. 14 Hand impact producing windshield fracture. Contusions and multiple lacerations on dorsum of left hand with wrist sprain were sustained.

Case 16 - A 1991 Dodge Spirit driven by a 62-year-old 3-point restrained male, height-170 cm, mass-66 kg, failed to stop at a red light and struck the left front of another car (Fig. 15). The two cars then rotated together, striking again. The initial impact to the right front of the Spirit caused moderate damage while the second impact resulted in minor damage to the right side. The driver's hands and forearms were contacted by the deploying air bag. His right hand was forced off of the steering wheel and struck the rear view mirror.

The mirror rotated and hit and cracked the windshield. The driver sustained a contusion of his posterior right hand from this rear view mirror impact, and air bag induced abrasions of the anterior forearms and an abrasion between the right first finger and thumb. The driver also had contusions of both hips from the lap portion of the 3-point restraint. (UM-3048-92)

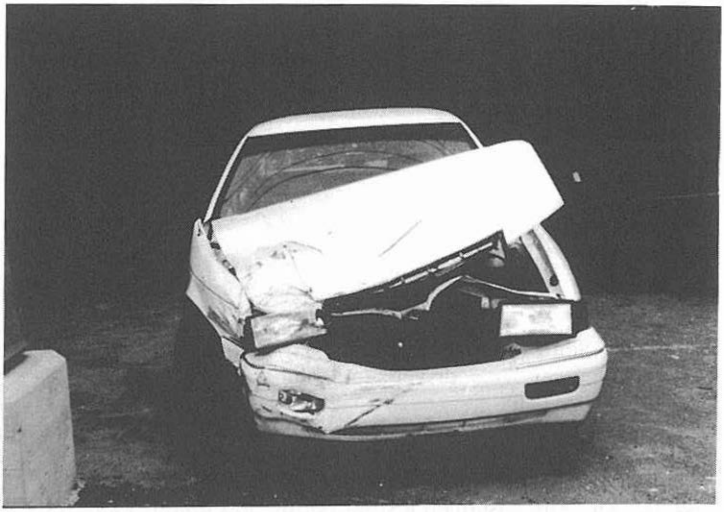

Fig. 15 1991 Dodge Spirit driver's hand injury sustained by impacting the rear view mirror.

AIR BAG MODULE COVER AND DEPLOYING AIR BAG INJURIES

During every air bag deployment the steering wheel air bag module cover is flung open with the considerable force necessary to achieve timely full deployment. We have seen several thumb injuries produced by the opening of the module covers or by the deploying air bag.

Case 17 - A 1990 Lincoln Town Car struck the right front of a car which disregarded a stop sign. The 42-year-old male driver, height-180 cm, mass 59-kg, was wearing his lap-shoulder restraint and had his seat at mid position. Air bag deployment resulted in contusions of the driver's left thumb and his anterior left upper arm. The forceful opening of the air bag module was responsible for the thumb contusion, as evidenced by the marks on the left side of the module cover (Fig. 16). The driver also sustained muscle strain across the center of his chest from the shoulder belt. The right front lap-shoulder belted passenger, a 42-year-old female, height-157 cm, mass-59 kg, with her seat in the mid position, sustained a contusion to her left anterior upper arm from the passenger air bag, as well as a contusion and muscle strain of her left hip from the seat belt buckle. (UM-FMA-045)

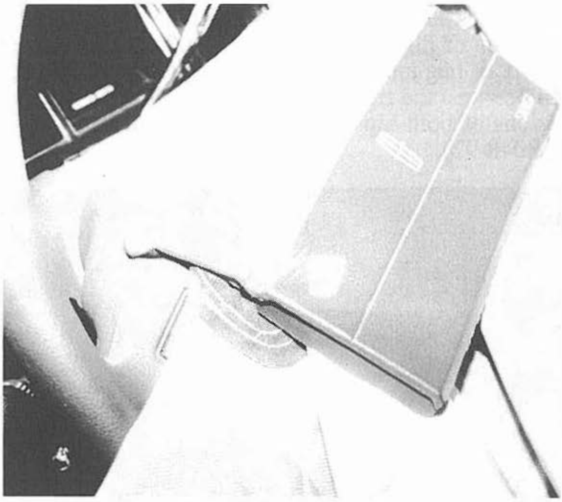

Fig. 16 Scuff on upper left of air bag module cover from the driver's left thumb.

Case 18 - A 1990 Infiniti Q45 sustained front end damage when it rear-ended a Chevrolet S-10 Blazer stopped at a traffic light. The 56-year-old lap-shoulder belted male driver, height-180 cm, mass-105 kg, only sustained a sprain of the left thumb, caused by the deploying air bag. (UM-NAB-004)

Case 19 - A 1989 Lincoln Continental, traveling at about 55 mph on a rural road, struck a large deer. The center front bumper, grille area, and hood were damaged. The 67-year-old male driver, height-170 cm, mass-82 kg, sustained an abrasion across his left chest from the shoulder belt portion of the 3-point restraint. Air bag deployment resulted in a left thumb sprain and an abrasion of his right forearm. The restrained 67-year-old female right front passenger, height-173 cm, mass-72 kg, sustained a contusion of her right wrist from air bag contact. (UM-FMA-028)

Case 20 - A 1993 Lincoln Continental rear-ended a stopped car. Damage was minor. The driver sustained minor injuries. The lap-shoulder belted front passenger, a 66-year-old female, height-157 cm, mass-61 kg, had a 5 cm tear of the skin of the web between the left thumb and hand with tearing of the underlying adductor pollicis muscle. The metacarpophalangeal joint of the thumb was dislocated with the ulnar side of the capsular ligament being torn.

In a number of cases we have noted upper extremity fractures which are related to air bag deployment. (see also cases 9 and 10).

Case 21 - A 1993 Ford Taurus was turning left when hit in the right front area. Damage to the car was minor. The male driver, 59-years old, height-170 cm, mass-54 kg, was wearing his 3-point restraint. No occupant contact marks were identified in the car. Air bag deployment produced comminuted mid-shaft fractures of the right radius and ulna (Fig. 17). His right forearm and/or hand was forced into his face producing a nasal fracture, and a fracture of the right maxillary sinus (Fig.18). Chip fractures of two lower front teeth were also sustained (UM-FMA-055). The driver's upper extremity position at the time of impact is shown in Figure 19.

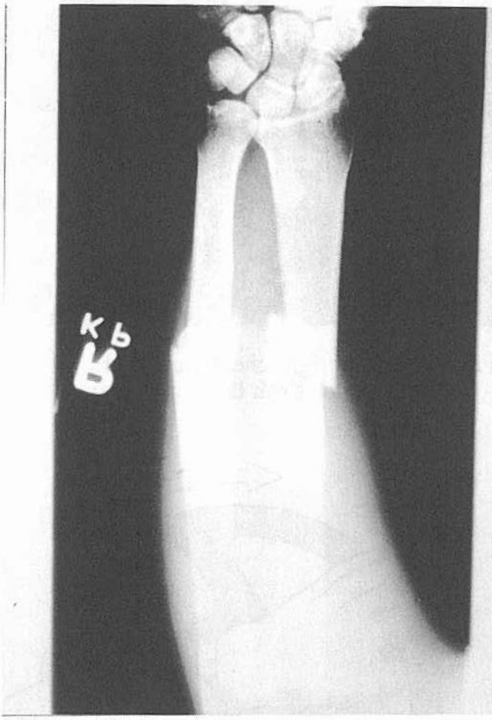

Fig. 17 Driver forearm fractures produced in a left turning maneuver. Forearm was on the air bag module cover at deployment.

Fig. 18 Fracture of the right cheek (arrow) from driver's hand impact due to air bag deployment.

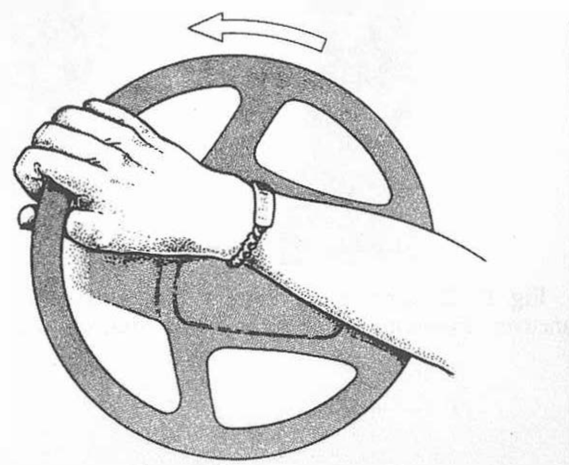

Fig. 19 Position of right forearm at time of air bag deployment producing injuries shown in Fig. 17.

Case 22 - A stopped car was struck by a 1992 Volvo 960 4-door sedan. Damage to the Volvo was negligible. The 37-year-old lap-shoulder belted female driver, height-163 cm, mass-60 kg, sustained an upper chest contusion due to shoulder belt loading. The air bag module cover tore her light weight jacket below the elbow and produced a comminuted displaced Monteggia fracture of the right proximal ulna and a dislocation of the radial head (Fig. 20). The driver subsequently developed a compartment syndrome. The driver stated that her hand struck her face during the air bag deployment. No facial injuries were reported. (CS 92-18)

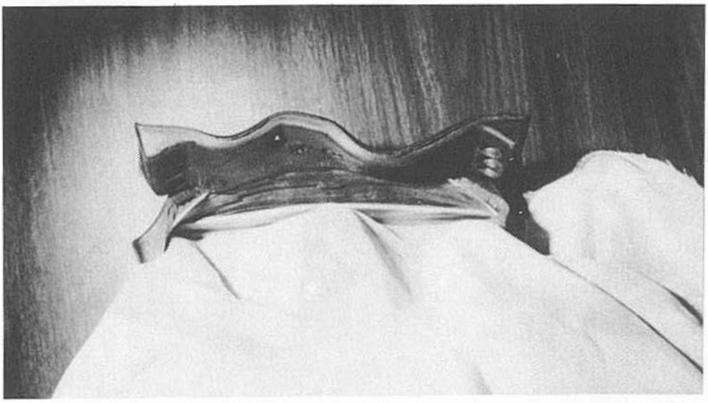

Fig. 20 Deformed air bag module cover from upper extremity impact.

Case 23 - A 1991 Mercury Grand Marquis, in a left turning maneuver, was struck along the left front side by another car (Fig. 21). On impact the upper air bag module flap contacted the mid right forearm of the 73-year-old lap-shoulder belted female driver, height-150 cm, mass-57 kg (Fig. 22). From impact by the air bag module cover and the contact of the deploying air bag she sustained multiple segmental open fractures of the right radius and ulna, with fractures of both the proximal and distal ulna as well as the olecranon. In addition, a circumferential degloving laceration (about 340 degrees) involving the skin and subcutaneous tissue was sustained. The right proximal fifth phalanx was also fractured, probably from the inflating air bag. The air bag flung her right upper extremity upward as indicated by tissue and blood spatters on the roof liner, side pillar and rear seat area. (CS 92-22)

Fig. 21 Left side front damage, 1991 Mercury Grand Marquis.

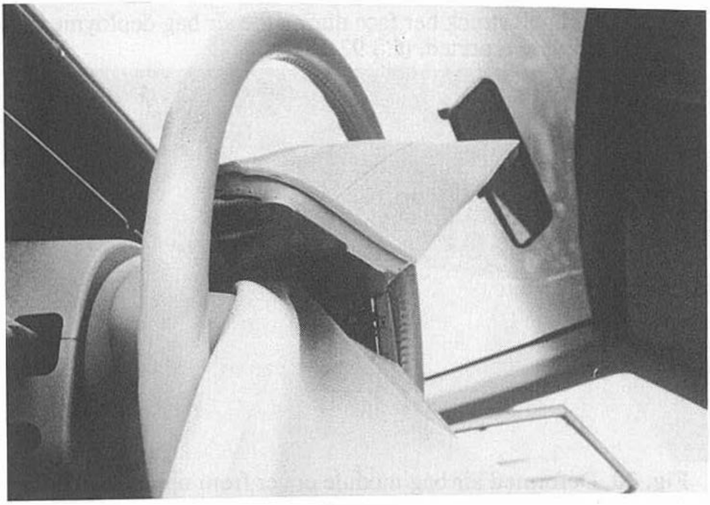

Fig. 22 Upper air bag module cover deformed by impacting the driver's right upper extremity.

Case 24 - A 75-year-old unrestrained female driver, height-163 cm, mass-41 kg, claims she passed out when driving in a left curve on a two lane road. Her car, a 1992 Mercury Grand Marquis LS, went straight and struck a 22 inch diameter tree at a change of velocity of 12 mph. The upper air bag module cover impacted her right forearm producing a nearly circumferential laceration of the mid right forearm and comminuted fractures of the distal radius and ulna. Eyeglass damage was due to face/air bag contact or by right arm/face impact. A cervical spine fracture was also diagnosed. (CS 93-01)

Case 25 - A 1991 Mercury Grand Marquis, 4 door, attempting to stop on an icy roadway slid across the oncoming lane, went off-road, and struck a tree at a relatively low speed. The 50-year-old restrained female driver, height-168 cm, mass-89 kg, sustained an open comminuted fracture of the distal right radius and ulna, and a contusion of the right abdomen. (DS 92-AB-10).

Case 26 - A 1992 Nissan NX 1600, 3 door hatchback was on an entrance ramp approaching a thruway, sustained minimal frontal damage when it struck the rear of a stopped vehicle. The 44-year-old restrained female driver, height-168 cm, mass-53 kg, sustained multiple fractures of her right radius and ulna. Her forearm was over the steering wheel at the time of air bag deployment. (NC 93-02)

Case 27 - A 1990 Ford Taurus, 4 door was attempting a left turn when it was struck by an on-coming car. The 52-year-old restrained female driver, height-155 cm, mass-59 kg, sustained fractures of the right ulnar (mid shaft), right olecranon and a dislocation of the head of the right radius from the air bag module cover. (IN 93-06)

DISCUSSION

In many automobile crashes that we and others have investigated, deployments of current generation air bags have been shown to reduce the frequency of fatalities and serious injuries to the head, face, and torso (NHTSA, 1992, O'Neill, 1992, Zador, 1993). In order to reduce the risk of serious and life threatening injuries, air bags must rapidly inflate with considerable force. Nevertheless, injuries related to air bag deployment are most often minor. There is strong evidence that, on balance, today's air bags decrease the frequency of significant injuries and are an effective supplemental restraint system. In a systematic study of accidents involving air bag deployments about 30 percent of drivers reported sustaining some sort of an air bag injury, usually erythemia or minor skin abrasions to the face, chin, or neck. Additionally, abrasions to the upper chest or hands, wrists and forearms were reported (Insurance Special Report, 1991). Other air bag related injuries include contusions, lacerations, of the forearm, neck, and face, as well as occasional eye trauma, usually corneal/scleral abrasions independent of the severity of the collision. This paper documents, for the first time, a subset of upper extremity injuries related to air bag deployments.

At initial deployment the air bag fabric can reach a velocity in the range of 160-320 kmph. Reed and Schneider have demonstrated that contact injury occurs at the point of initial air bag impact with the skin, rather than when the smooth fabric of the inflated air bag sweeps across the skin surface (Reed, 1992, Reed, 1993). New folding patterns and lower-mass-uncoated fabrics may reduce the frequency of these minor fabric impact injuries in the future, but due to the proximity of the driver's upper extremities to the steering wheel air bag module and the necessity to deploy the air bag rapidly, these more common superficial extremity injuries may not be capable of being completely eliminated.

Hand and wrist burns, produced by the venting of the air bag gas, are being noted less often with current air bag modules than with earlier models. Some air bag designs had the exhaust vents at the nine and three o'clock positions on the back of the air bag. This resulted in more frequent minor burns than are seen in some other designs, where the vents are located at eleven and one o'clock positions. Still, in crashes that result in an air bag deployment, the driver's hands can be forced off of the steering wheel towards the exhaust vents by either inertial forces or by the deploying air bag itself.

Another area of improved design is the tethering of the central portion of the air bag. The early untethered air bags bulge out in the center when fully inflated. These untethered air bags were more likely to cause the minor facial injuries because these air bags project farthest in the center, where the face contact is most often occurred. For several years tethered driver-side air bags have been installed. These bags have circles of stitching around the center of the air bag's front surface where the internal tethering strips are anchored. The tethering fabric inside the air bag restricts the excursion of the center of the air bag during deployment. The differences between tethered and untethered air bags and the various vent designs mentioned above indicate how crucial it is to include the vehicle year, make, and model when discussing occupant injuries in order to determine the type of air bag involved. Seat position is also important, for the near proximity of the front occupant to the air bag module may explain some of the air bag contact injuries.

In six of our investigations, drivers have noted that the air bag contacted their watch bands or bracelets, causing minor lacerations or contusions of the wrist or forearm. In several cases the deploying air bag caught the band of the wrist watch, ripping it off, and the broken wrist band was the cause of the wrist or forearm injury.

To benefit the front seat occupants the air bag must deploy before significant forward occupant movement has taken place. Air bag deployment occurs in less than 60 ms in which time the sensors identify the crash pulse, and the air bag is fully inflated. Therefore, the air bag(s) must be deployed with significant force in order to break through the air bag module cover and fully inflate in this short time frame. In one air bag module design, deployment flings the cover flap outward and upward at 360 kmph. If the driver has his hand or arm across the steering wheel hub as the module cover opens, it is possible that a contusion, laceration, or fracture of the forearm may be produced. Mertz (1988) identified 9 drivers with hand or arm fractures in GM 1973-76 cars where the air cushion deployed. For these the type of crash was not indicated nor the relation, if any, between air bag deployment and the fractures. Recently, a case involving the traumatic avulsion of a 23-year-old female driver's left thumb as a result of contact by the air bag module cover was reported (Smock, 1992). The injuries included a laceration at the base of the first metacarpal with deep transection of all thenar (thumb) muscles, except the tendon of the flexor pollicis longus, and an open fracture of the first metacarpal with dislocation at the metacarpalphalangeal joint. Also, an intraarticular palmar avulsion fracture of the left fifth middle phalanx, related to a passenger side air bag has been reported (Roth and Meredith).

Alternate module cover designs may reduce the potential for injury due to contact between the opening module cover and the driver's hands or forearms. Modifying designs with smaller flaps of material moving at lower velocities may reduce the potential for lacerations and fractures. Further research is needed to determine the optimal design to reduce the incidence and severity of these hand, wrist and forearm injuries within the deployment envelope while preserving the life-saving performance of air bag systems.

In certain accidents involving deceleration of the car before the major impact, as with pre crash braking or a minor collision preceding a significant impact, the occupants may move forward before the air bag sensor system has triggered, especially if the lap-shoulder restraint is not worn (Huelke, 1991, page 38). The air bag deployment is then much more likely to cause injuries. The greatest risk of injury as demonstrated in testing with crash dummies and anesthetized swine occurs when a vehicle occupant's torso is against and fully covering the air bag module at the time of deployment (Lau, 1993, Horsch, 1990).

The air bag will occasionally cause the hand/forearm to be flung towards the windshield, instrument panel, or rear view mirror resulting in injuries including minor lacerations, contusions of the posterior hand, wrist, and/or forearm, and occasionally sprains or fractures of the hand. The star burst or spider web pattern of windshield damage, previously noted to be produced by the head of an unbelted occupant, is now seen with air bag induced upper extremity flailing into the windshield. In fact, in almost all instances a lap-shoulder belted driver's head cannot reach the windshield over a deployed air bag, and rarely is there windshield contact by the head of even unbelted drivers in frontal crashes where the steering wheel air bag deployed. Thus, in frontal accidents involving air bag equipped cars, the star burst windshield damage is now most likely caused by air bag induced upper extremity impact.

In the review of the cases presented, minor head, face, or torso injuries were often noted, although facial injuries from hand/wrist impact caused by air bag deployment have also been observed. Only in very high speed crashes have more extensive torso or head injuries been observed, usually due to collapsing car structures and associated high-velocity torso loading.

The effectiveness of the passenger side air bag in frontal crashes is not known, because few cars are so equipped at this writing, and the lower occupancy rate of the front passenger seat makes data on passenger side air bag more difficult to obtain.

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