ROAD TRAFFIC ACCIDENTS, AIRBAG-RELATED INJURIES AND DEATHS

W S Smock, University of Louisville Hospital, Louisville, KY, USA

Introduction

Annually, road traffic accidents in the USA and Canada result in the loss of tens of thousands of lives, inflict hundreds of thousands of serious injuries, cost the health and insurance industries billions of dollars, and consume countless hours of investigative effort on the part of local and state law enforcement. Of all the myriad forensic and legal questions that an accident investigator and the courts need to address, two of the most significant civil and criminal issues are: how fatal or life-threatening injuries were sustained and determining who was driving. The airbag has played a role in both of these forensic issues.

Designed and promoted as a life-saving device, the airbag has made good on its promise. The National Highway Transportation Safety Administration (NHTSA) estimates that some 14 000 lives have been spared as a result of airbag deployment. Unfortunately, the same "life-saving" device has also been responsible for at least 239 deaths of men, women, and children. Thousands of other motorists have sustained severe nonfatal injuries as a result of airbag deployment including cervical spine fractures, retinal detachments, closed head injuries, and comminuted fractures and amputations of the hand and upper extremity. Ironically, many of the injuries and deaths are not occurring at high speeds but in low- and moderate-speed collisions.

The History of Airbag Research and Development

The airbag was first patented in 1952 and Ford and General Motors began experimenting with these early prototypes in the late 1950s. Research and testing by the automotive industry revealed in the early 1960s that the forces of airbag deployment had the potential to induce serious and fatal injuries, particularly to children. Testing demonstrated that there was sufficient force associated with airbag deployment to amputate the steel-hinged arm from a test dummy and traumatically eject a child from a vehicle. Live-animal testing by the automotive industry produced catastrophic injuries including cardiac rupture, hepatic rupture, splenic rupture, aortic and vena cava transection, atlantooccipital dislocation, cervical spine fractures, and severe closed head injury. A General Motors study indicated "many of the exposures were at loading severities beyond the level representing an estimate of nearly 100% risk of severe injury." Well before airbags were placed in standard production, the testing and data were clear: airbag deployment could inflict serious and fatal injuries.

Unfortunately, soon after airbag-equipped vehicles were marketed in the USA and Canada in 1989 and 1990, the serious and life-threatening injuries that were originally observed in the industry's laboratories using animal models began to be observed on the nation's highways in the human population. The first six driver airbag-related deaths were women of short stature. It was also noted that their fatal injuries could be sustained even if they were lap and chest belt restrained. The injuries initially seen in these six women included massive head injuries with diffuse axonal injury, subdural and epidural hematomas, and skull fractures. Subsequently, additional airbag-induced fatal injuries in restrained and unrestrained occupants have included atlantooccipital dislocations, cervical spine fractures, brainstem lacerations, cardiac perforations and valvular injuries, aortic transection, pulmonary contusions, and multiple rib fractures.

Mechanisms of Injury

Sodium azide is the explosive propellant used to initiate the deployment cycle in most airbag designs in use today (Figure 1). When sodium azide is ignited, the deploying airbag explodes, filling with nitrogen gas and carbon dioxide, and moves rapidly rearward toward the occupant at speeds of up to 210 mph (336 kph). Reconstruction of the injuries incurred during deployment can be traced to the system component inflicting them: the canvas-covered airbag, the airbag module cover, or both (Figure 2).

Obviously, the types of injuries that result from impact with the canvas airbag are different from those that result from impact with its module cover. There are three phases to describe airbag deployment: "punch out," "catapult," and "bag slap." Injuries can be inflicted at any point during the deployment process.

Figure 1 Sodium azide is an explosive propellant that is the source of nitrogen gas for airbag inflation. Toxic byproducts of sodium azide combustion may cause damage to pulmonary tissue.

Figure 2 The canvas airbag and the module cover are both capable of inflicting serious and fatal injuries. Reproduced with permission Smock WS. Accident Investigation: Airbag-related Injuries and Deaths. In: *Encyclopedia of Forensic Sciences*. Edited by Jan A Siegel, Pekka J Saukko, Geoffery C Knupfer. Academic Press: London. © 2000 with permission from Elsevier.

Phases of Airbag Deployment

Punch Out

This is the initial stage of deployment. If the bag makes contact at this stage, the following injuries can result: atlantooccipital dislocation, cervical spine fracture with brainstem transection, cardiac, liver, and splenic lacerations, diffuse axonal injuries, subdural and epidural hematomas, and decapitation. Impact with the upper extremity during this phase will result in massive fractures, degloving, and amputations.

Catapult

This is the mid-stage of deployment when the rapidly inflating bag "catapults" or drives the head and neck rearward. This occurs with sufficient energy to rupture blood vessels, tear ligaments, rupture globes, and fracture cervical vertebrae. The neck and facial injuries occur as the result of cervical spine hyperextension and direct trauma.

Bag Slap

This is the final stage of deployment, which occurs at the bag's peak excursion. Appropriately named, this happens when the canvas bag's fabric may "slap" the occupant's face or arms, resulting in injuries to the eye and epithelium.

Airbag Tethers and Covers

Early airbag designs in some vehicles did not include the use of an internal tethering system to limit the rearward excursion of the bag. Untethered airbags can extend beyond 21 in (53 cm) (Figure 3) compared to 12–14 in (30–35 cm) of excursion in tethered models. This excessive rearward movement has been responsible for severe injuries to the face and in particular to the eyes. Even the properly restrained, non-near positioned occupant can sustain severe injuries from untethered airbags.

The airbag module covers are located in the steering wheel on the driver's side and in the dashboard panel on the passenger side. As the bag deploys, the module cover is also propelled outward at speeds of up to 210 mph (336 kph). Most steering wheel designs house the horn within the airbag module compartment, which is an invitation for devastating upper extremity injuries (Figure 4). Hand and arm injuries observed in individuals whose extremities were in contact with the module at the moment of its rupture include: degloving, fracture, dislocation, fracture dislocation, and amputations (partial and complete of digits and forearms) (Figure 5). If the module cover makes contact with an occupant's face, head, or neck, skull fractures and severe or fatal head injuries, and decapitations have also been observed. The driver's side cover is generally made

Figure 3 Untethered airbags can extend well into the restrained occupant's space. This airbag from a Nissan Maxima extended 21 in (53 cm) rearward and was responsible for this patient's total loss of vision from a ruptured globe.

Figure 4 Air bag module covers with built-in horn activation buttons are an invitation for serious injuries to the upper extremity (**Figures 5, 21–28**).

Figure 5 An open fracture with degloving of the forearm from impact with an airbag module cover.

with a rubberized plastic type of material, while the passenger side may have a metal housing (Figure 6). Contact with either type can prove fatal.

Mechanism of Injury

Ocular Injuries

The eyes are extremely vulnerable to direct and indirect airbag-induced trauma in both the restrained and unrestrained occupant. These injuries range from corneal abrasions secondary to direct contact with the airbag to alkali chemical burns from contact with unburned sodium azide and sodium hydroxide to retinal detachment and globe rupture from the blunt force trauma of the expanding bag (Figures 7, 8, and 9).

Direct trauma Impact to the globe and facial structure from the bag during the punch out or catapult stage may be catastrophic. Globe rupture, lens dislocation, blowout fractures, and retinal detachment are among the most serious ocular injuries reported. External signs of ocular trauma include periorbital

Figure 6 Air bag module covers constructed with a metal frame are exceedingly dangerous and can easily amputate the hand or forearm. Reproduced with permission Smock WS. Accident Investigation: Airbag-related Injuries and Deaths. In: *Encyclopedia of Forensic Sciences*. Edited by Jan A Siegel, Pekka J Saukko and Geoffrey Ckuupter Academic Press London © 2000 with permission from Elsevier.

Figure 7 Massive ocular trauma from a passenger-side airbag. The patient sustained globe rupture and orbital fractures from impact with a cane that was propelled into his face (**Figure 11**).

Figure 8 Chemosis and hyphema from a passenger-side airbag.

Figure 9 Periorbital contusions and abrasions from a passenger-side airbag.

Figure 10 Air bag impacts to glass lenses have resulted in incised wounds to the globe.

lacerations and contusions, hyphemas, and corneal abrasions. The wearing of eyeglasses with plastic lenses has proven to be of benefit in the prevention of corneal abrasions, as it offers a degree of barrier protection between the eyes and the deploying bag, whereas eyeglasses with glass lenses have been responsible for lacerations of the globe when glass fragments are driven into the eye (Figure 10). In severe corneal abrasions, the airbag's weave pattern can be visualized imprinted on the cornea.

Indirect trauma The eyes are also vulnerable to trauma from intermediate objects. The most common indirect object is the hand, accidentally caught in the path of the module cover or bag, which is propelled rapidly upward into the globe. Other examples include pipes, canes, cell phones, and pets (Figure 11).

The transfer of blood, facial tissue, eyebrow hair, and eye or facial makeup to the bag will assist the investigator in determining that the airbag component was responsible for the injuries observed

Figure 11 Any objects, like this walking cane, caught in the path of the deploying airbag, can be propelled into the face and eyes of the passenger (Figure 7).

(Figure 12). The intermediate objects may also display damage and evidence of trace material (Figure 11). Examination of eyeglass frames and lens will also be of benefit to the forensic investigator (Figure 13).

Cranial and Intracranial Injuries

When acceleration forces are applied to the cranial vault, a variety of traumatic injuries to the brain and surrounding structures will result. These injuries are caused by direct blunt trauma (module cover) and rapid accelerations (airbag) of the brain tissue and vessels. These include subdural and epidural hematomas, cortical contusions, diffuse axonal injury, atlantooccipital dislocations, skull fractures, and brainstem transections (Figure 14). The most common cranial injury associated with airbag deployment is that of facial abrasion (Figure 15). The abrasions result from a sliding contact between the bag and the face and tend to be deep.

A forensic examination of both the bag and the module cover is warranted to look for evidence of transferred material or physical damage from contact. Hair, blood, epithelial tissue, and makeup are the materials most commonly transferred to the bag. The module cover is also an important source of transferred material. Module cover design dictates

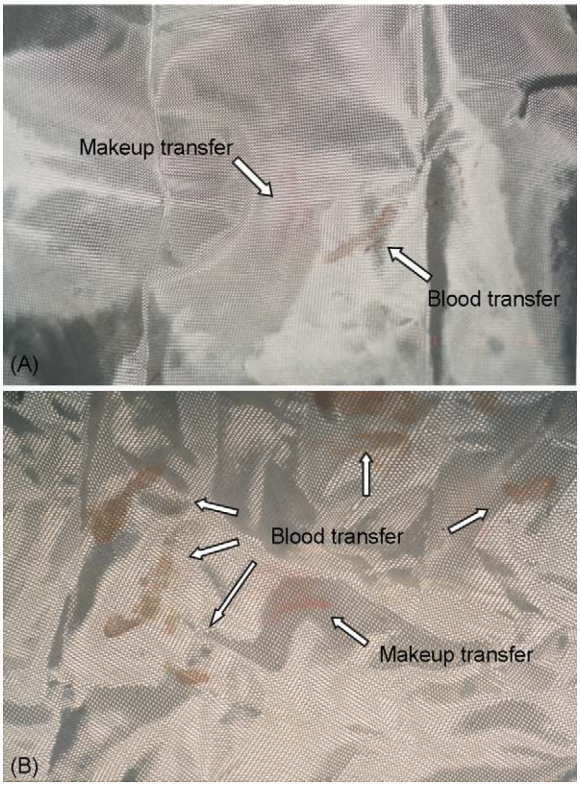

Figure 12 Blood, tissue, and makeup are easily transferred to the airbag. This trace evidence will facilitate the determination of the etiology of an occupant's injuries and in the determination of an occupant's role, driver or passenger.

Figure 13 Examination of eyeglass frames will assist the investigator in the reconstruction of ocular injuries.

how far the arc of the module flap will extend on deployment. Asymmetrical covers, those that do not split in the middle, will have a longer arc and will therefore have a higher risk of impacting an occupant's face or upper extremity (Figure 16). Cranial impact from the module cover occurs more frequently with unrestrained occupants but also occurs with short-statured restrained drivers. Tearing

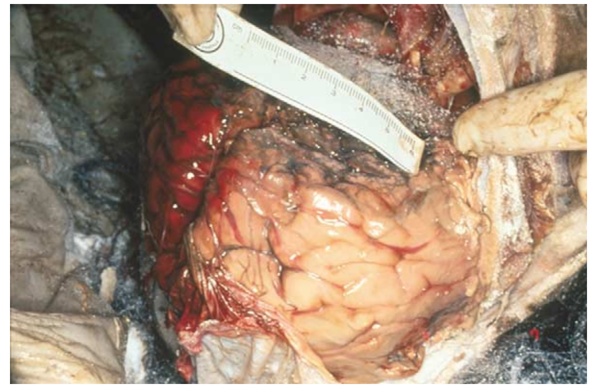

Figure 14 Subdural and subarachnoid hemorrhage from cranial impact in a restrained, short-statured, female driver of a 1990 Ford Taurus.

Figure 15 Facial abrasions are the most common airbag-induced facial injury.

of the module cover or transfer of facial tissue or hair is evidence of traumatic impact during deployment (Figure 17).

Cervical Spine Injuries

When a driver or passenger sustains a blow from an airbag or module cover the cervical spine is at risk. The rapid and violent hyperextension of the cervical spine can disrupt the anatomical structures and easily exceed human tolerances. Injuries commonly seen as a result of this rapid hyperextension include atlantooccipital dislocation, comminuted fractures of one or more upper cervical vertebrae, rupture of the anterior and posterior longitudinal spinal ligaments, vertebral artery injury, and cervical spine disarticulation with transection of the cervical cord (Figure 18). The majority of these injuries are associated with

Figure 16 Module covers that split in an asymmetrical manner are more likely to impact facial structures because of a longer arc on opening. This Ford module cover extends 5 1/2 in (14 cm) from the steering wheel hub.

Figure 17 The tearing of this thick module cover occurred when the cover impacted the left side of the face of the women in Figure 14. Reproduced with permission Smock WS. Accident Investigation: Airbag-related Injuries and Deaths. In: *Encyclopedia of Forensic Sciences*. Edited by Jan A Siegel, Pekka J Saukko, Geoffery C Knupfer. Academic Press: London. © 2000 with permission from Elsevier.

the upper cervical vertebrae, although lower cervical vertebrae injuries have been observed.

Deep abrasions overlying the victim's chin and neck area are evidence of airbag-induced hyperextension

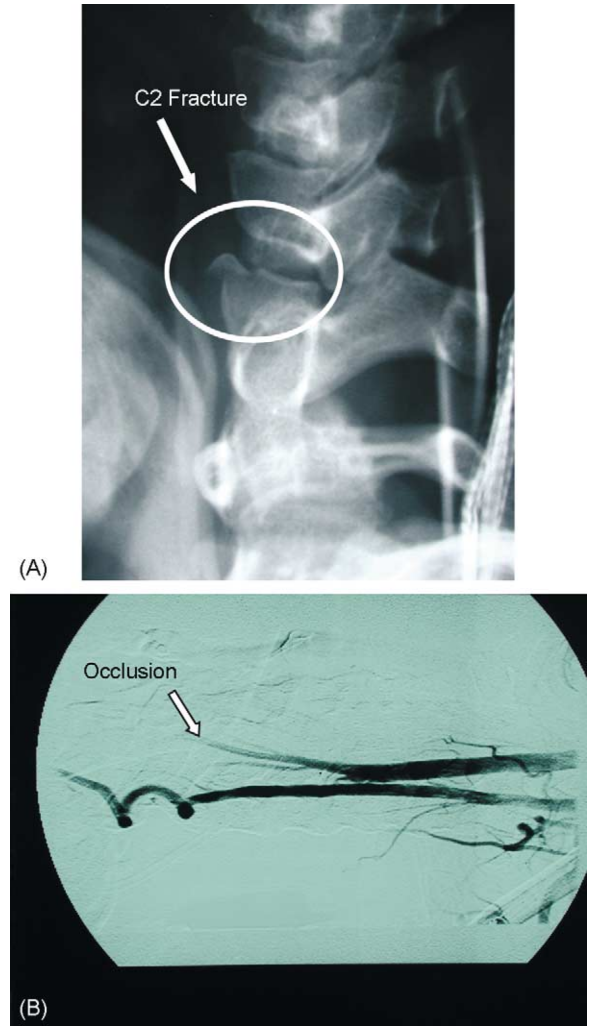

Figure 18 The rapid and forceful hyperextension of the neck and cervical spine from the airbag resulted in a C2 fracture with a vertebral artery injury.

(Figure 19). These injuries should correspond to the transference of epithelial tissue to the airbag or module cover.

Thoracic Injuries

Substantial blunt thoracic trauma, from the airbag or module cover, can occur to the restrained or unrestrained occupant. Severe and fatal thoracic injuries, historically only associated with high-velocity motor vehicle collisions, are occurring from impacts with airbags. Aortic transactions, cardiac and valvular lacerations, pulmonary contusions and lacerations, and sternal and rib fractures are common, even in very low-speed collisions.

The forward positioned occupant, restrained or unrestrained, is most at risk. Many victims who sustain thoracic injuries have translated forward, toward the module cover, due to preimpact braking.

Figure 19 Deep abrasions under the chin from a hyperextension injury to the neck (**Figure 18**).

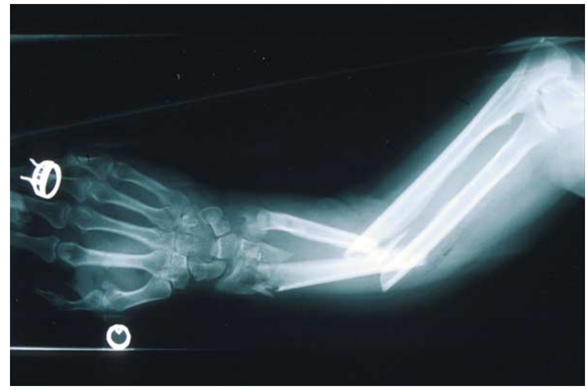

Figure 21 Radiograph of the forearm of a driver who was attempting to blow the horn at the time of airbag deployment. The driver was restrained.

Figure 20 An airbag cutoff switch should be considered for occupants who cannot sit at least 12 in (30 cm) from the airbag module (www.airbagonoff.com).

Figure 22 Partial thumb amputation from a passenger airbag.

Examination of the module cover for fabric imprints or tears will provide evidence of impact.

Abdominal Injuries

The abdominal organs are also at significant risk for direct blunt trauma. Severe and fatal abdominal injuries associated with airbags include liver laceration, splenic laceration, pancreatic laceration, diaphragmatic rupture, and vena cava transection. Placental abruption and fetal demise can also occur from blunt airbag trauma. Pregnant occupants, both driver and passenger, should move their seats back as far as possible from the airbag module. If the abdomen of a pregnant woman is not at least 12 in (30 cm) from the steering wheel the driver should consider installing an airbag cutoff switch (Figure 20).

Upper Extremity Injuries

The upper extremities are especially vulnerable to traumatic injury from the deploying bag and its module cover. Upper extremity injuries in motor vehicle collisions have increased more than 400% since the introduction of airbags. When an individual's hand or forearm is on or near the module cover at the moment of deployment, the occupant can expect to sustain multiple fractures, and/or tissue degloving or amputation of fingers, hand, or forearm (Figures 21, 22, 23, and 24).

Vehicles with the horn activation button located within the module cover pose a significantly increased risk of injury to the occupant's upper extremities at the moment of deployment. Many of these upper extremity injuries are associated with an occupant's attempt to blow the horn just prior to a collision. Despite the propensity for a driver's to sound a warning prior to a collision, neither the NHTSA nor the automobile manufacturers has taken the necessary steps to warn drivers of this hazard.

Forces from airbag deployment may be transmitted to the hand, wrist or forearm and may even involve the humerus (Figure 25). It is not unusual to see significantly comminuted fractures involving the wrist,

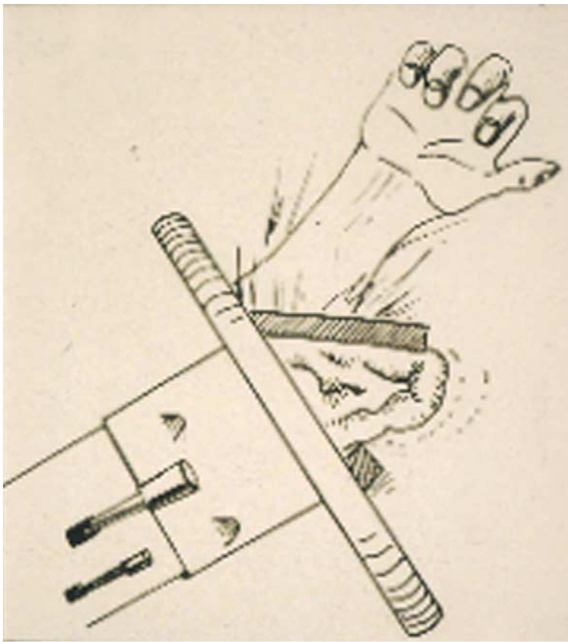

Figure 23 Placement of the forearm over the module cover at the moment of deployment will result in severe fractures.

Figure 24 Comminuted fractures of a wrist from the placement of the passenger's hand on the deploying module cover.

forearm, elbow, and distal humerus (Figures 26 and 27). The vehicles whose module covers are of a higher mass have the capacity to inflict more severe injuries. Some of the worst offenders are module covers located on the passenger side, which may have a soft coating of plastic on the exterior but have an underlying piece of rigid metal (Figure 6). The placement of hands on the passenger-side dashboard, in a bracing maneuver, has resulted in the traumatic amputation of hands and forearms (Figure 28).

Examination of the module cover is extremely beneficial to the reconstruction of upper extremity injuries. Deformation of the module cover is evidence of arm placement on or near the cover

Figure 25 Radiograph of proximal humeral fracture and comminuted elbow fracture from a passenger side airbag.

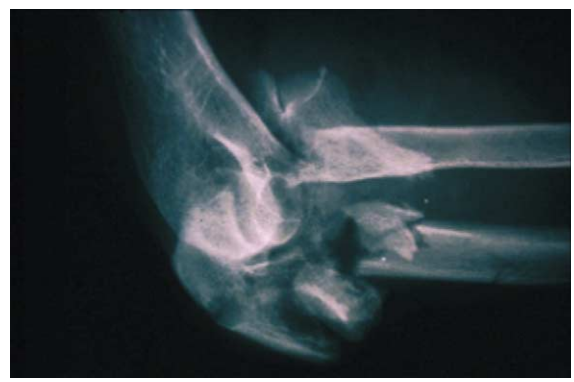

Figure 26 Radiograph of a comminuted elbow fracture caused by a blow from the module cover.

Figure 27 Radiograph of a comminuted elbow fracture with dislocation from module cover impact.

during deployment (Figure 29). Fabric imprints may also be transferred to the cover (Figure 30). Nonpatterned scuffmarks may be present (Figure 31). Blood from open fractures may be deposited on both the bag and module cover (Figure 32).

Figure 28 Partial hand amputation from placement on the passenger module cover in a bracing maneuver (Figure 29).

Figure 29 Deformation of the passenger module cover from arm placement (Figure 30).

Lower Extremity Injuries

The resting of an occupant's foot or feet on the passenger module cover during deployment will result in comminuted fractures and soft tissue injury to the feet, ankles, and lower legs. The term "airbag ankle" was coined in 2000 when a 13-year-old girl sustained a comminuted fracture above the ankle from impact with the module cover (Figure 33).

Inspection of the module cover may reveal pattern or material transfer. Imprints of the sole of a shoe have been found on passenger module covers (Figures 33 and 34). Nonpatterned scuffing may also be present on the cover as evidence of contact.

Respiratory Injuries

Airbag deployment is initiated by the ignition of sodium azide. The byproducts of combustion as well as other inert materials within the airbag produce a large volume of gas and a white cloud of residue within the

Figure 30 Fabric imprint on module cover is evidence of module cover impact with the patient's forearm.

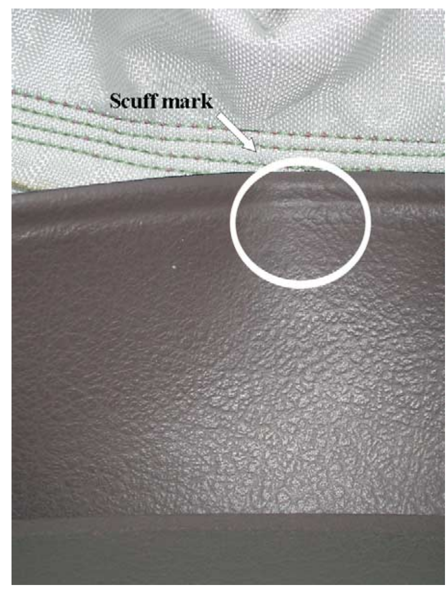

Figure 31 Nonpatterned scuffmark on module cover from hand placement. Injuries of each occupant can be matched to module cover damage.

Figure 32 Blood on the airbag can be matched to an occupant, driver, or passenger.

Figure 33 Comminuted distal tibia and fibula fractures from placement of the foot on the module cover at the time of deployment, a.k.a. ''airbag ankle.''

Figure 34 Pattern of the imprint on the module cover matched the sole of the passenger's shoe.

vehicle. Many occupants have thought that this indicated a vehicle fire. The principal components of this gas and white cloud are nitrogen and carbon dioxide with cornstarch, talc, sodium bicarbonate, and metallic oxides. There may be a small percentage of unburned sodium azide present within this powder as well. Inhalation of these materials can result in a chemical pneumonitis or induce of asthma-type symptoms, and they have been reported to be toxic to the pulmonary tissue.

Determination of Occupant Role

The second principal forensic issue related to airbag deployment is the ability of evidence from the state of the airbag to assist in the determination of an occupant's role, driver or passenger. Locard's principle regarding the transfer of physical evidence between two impacting objects is dramatically observed in the case of airbags and injuries induced by airbag module covers. The transfer of evidence to the airbag itself may take various forms: blood, epithelial tissue, and hair. The transfer of makeup is also commonly observed, including the deposition of lipstick, rouge and mascara to the airbag (Figure 12). The analysis of the blood spatter pattern on the bag could assist the investigator in determining the position of the occupant and the configuration of the steering wheel at the moment of air bag deployment.

Examination of the airbag module cover may reveal the presence of trace evidence. Depending upon the design of the module cover, there may actually be tearing or bending of the module cover, indicative of contact with an occupant's more rigid (bony) surface: face or forearm. Scuff-type marks on the module cover indicate contact with an object, frequently the forearm (Figure 31). Fabric imprints may also be seen on close inspection (Figure 30).

Forensic investigators, in cases where the role of the occupants is unclear or denied by involved parties, should perform forensic evaluations on all of the vehicle's occupants to document the presence or absence of airbag-induced injuries. Processing of the vehicles in a timely fashion by forensic evidence technicians will help insure that valuable evidence on the bag, module cover, or other interior components does not degrade with time and will be photographically documented. Vehicles should be covered with a tarp at the scene to prevent hair or fibers from being blown away during towing to an indoor garage.

Side Airbags

Beginning in 1995, automobile manufacturers began installing several different types of "side airbags" including seat-mounted, door-mounted, window-curtain, and inflatable-tubular types. The first reported injury from a side airbag occurred in December 1996 and involved a 3-year-old child. The side airbag was a door-mounted type. It was not until October 1999, that NHTSA issued a consumer advisory regarding the potential dangers of side airbags. The advisory stated "children who are seated in close proximity to a side airbag may be at risk of serious or fatal injury, especially if the child's head, neck or chest is in close proximity to the airbag at the time of deployment." To date, NHTSA has not reported any fatalities and fewer than 15 injuries from side airbags. As in frontal airbags, the injuries are similarly attributed to the force of deployment from the airbag itself and/or the module cover. The risks for injuries to the head, neck, and thorax of both adult and child occupants that lean against the side-mounted module are real. The forensic investigator should employ the same techniques for investigating side airbag incidents as are utilized in the investigation of frontal airbag injuries.

Conclusion

The airbag, despite claims of being a life-saving device, has clearly demonstrated that it can induce serious and fatal injuries to restrained and unrestrained adults and children. Fortunately with the reduction of airbag deployment aggressivity beginning in 1997, the numbers of severe and fatal injures have declined. Forensic investigators must understand the mechanisms of airbag-induced injuries in order to reconstruct how, why, and in whom these injuries occur. The transfer of material between airbag, module cover, and occupant, and the presence of airbag-specific injuries, will be a tremendous asset to the forensic investigator and the courts in determining, beyond a reasonable doubt, the role, driver or passenger, of a vehicle's occupants.

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