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Airbag Protected Crash Victims - The Challenge of Identifying Occult Injuries

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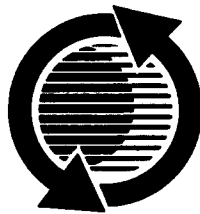
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ABSTRACT

A multidisciplinary, automobile crash investigation team at the Jackson Memorial Hospital/Ryder Trauma Center in Miami, Florida, is conducting a detailed medical and engineering study. The focus is restrained (seatbelts and/or air bag) occupants involved in frontal crashes, who have also been severely injured. More than 60 crashes have been included in the study to date.

Analysis of the initial data indicates that restraint systems are working to reduce many of the head and chest injuries which unrestrained occupants suffer.

However, internal injuries among air bag-protected occupants may be unrecognized in the field providing new challenges in triage and injury diagnosis. In other cases, survival in extremely high severity crashes presents trauma management challenges due to the extent and complexity of the multiple injuries which result. The paper provides case examples to illustrate types of chest and abdominal injuries associated with air bag cases. Three types of cases are presented: (1) Jackson Study Involving Occult Chest /Abdominal Injury, (2) National Accident Sampling System (NASS) Special Crash Investigation (SCI) and (3) Jackson Study Involving Crash Severities Greater than 45 MPH.

To assist in recognizing the extent of injuries to occupants protected by air bags, it is suggested that additional evidence from the crash scene be used in the triage criteria. For the occult chest/abdominal cases observed in the Jackson study, deformation of the steering system was the vehicle characteristic most frequently observed.

The challenges of recognizing injuries to air bag-protected occupants are discussed. The presence of steering wheel deformation may be a sufficient signal of caution to justify transporting the injured victim to a Level 1 or 2 trauma center so that a close examination for occult injuries can be made.

INTRODUCTION

Air bags first became available in passenger automobiles about twenty years ago. During the present decade, the penetration of these devices in the new car fleet will approach one hundred percent. It is estimated that by the year 2000 more than five hundred thousand air bag deployments will occur each year. Yet, there is little medical literature detailing the injury patterns of air bag-protected occupants involved in crashes [1]. Anecdotal reports exist particularly on minor injuries associated with air bag deployments such as abrasions of the cornea of the eye and lacerations of the face [2].

Because air bags are less than 100% effective, injuries will still occurr. The medical community will be challenged by occupants who avoid head, chest or abdominal trauma but experience injuries of their un(air bag)-protected extremities. Of similar concern, occupants may sustain trauma to the chest or abdominal organs through impacts with the air bag or through collisions with internal contents like the steering wheel. The mechanisms of injury may include overwhelming the air bag's energy management capabilities due to very high crash forces or multiple collisions wherein the air bag is deflated during some of the collisions. In any event, the injury patterns in air bag-protected occupants must be discerned so that treatment strategies can be optimized and hopefully injury countermeasures can be developed.

This paper summarizes the detailed investigation of a number of air bag-protected individuals involved in crashes whose injuries warranted admission to a trauma center.

METHODS AND PROCEDURES

A research protocol for addressing seriously injured, restrained occupants of frontal automobile collisions was implemented at the University of Miami/Jackson Memorial Medical Center

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in Miami, Florida beginning July, 1991. In August, 1992, all trauma services were moved into a newly constructed, dedicated trauma care facility named the Ryder Trauma Center. The Center includes unique capabilities to perform injury research. In particular, a computer system has been developed and implemented throughout the Ryder Trauma Center to address the challenge of acquiring and analyzing the enormous amount of information associated with injuries. The **CARE** system is designed to be integrated with the clinical, administrative, research and educational components of the center. Innovative technologies such as radio-linked terminals, computer-compatible cameras and multimedia electronic displays are incorporated into the system [3]. The research data elements include reconstructions of the automobile crash scene and the vehicular damage, description of the patient's clinical course and outcome status and definition of the economic implications. The database encompasses electronic images such as x-rays, digitized voice and video segments in addition to conventional elements.

Every automobile crash-related admission to the trauma center was considered for possible inclusion in the study. Once a patient was determined, on a preliminary basis, to meet the study criteria, a number of parallel activities began:

· A crash study researcher attempted to interview the patient (and perhaps other occupants of the crash vehicle), scene-responding Emergency Medical Services (EMS) personnel and the investigating police. If it were concluded that the study requirements had been met, the patient was then asked (after being briefed on the nature of the study and his/her rights) to sign a form consenting to participate in the study.

· If the patient consented, the crash investigator sought to evaluate the vehicle and the scene. This individual is an experienced National Accident Sampling System (NASS) investigator. Vehicle location was typically contained in the police report. Every effort was made to have access to such data sources within 24 hours of the crash since the evidence at the accident scene, as well as that in and on the vehicle, deteriorated within a short time after the crash.

· Once the accident vehicle became available, the second phase of data collection began. That is, the NASS investigator confirmed whether or not the collision was frontal and whether or not the subject had been restrained. The physical evidence of air bag deployment and/or seat belt/child-restraint engagement in the position of the subject was crucial for establishing that study restraint criteria had been met.

It should be noted that an extremely useful source of information was photographs or videos taken at the scene. In several cases, representatives of the police, the EMS, local television stations and even amateur videographers provided useful documentation. In a few cases, it established restraint status.

· Once a patient consented to participate in the study and the crash investigator determined that the direction of force and the restraint status was appropriate, the remaining vehicle and scene data as well as pertinent clinical and economic data were collected. The crash investigator attempted to establish occupant/vehicle contact points as well as the energy characteristics of the crash following NASS reference standards [4].

· The extent of the injuries, the therapeutic interventions used to correct them, the post-therapeutic course (both within the hospital and after discharge) as well as the economic, social and psychological implications of the subject's injuries were then assessed through medical record review and interviews. A major analytical approach of the study was the multidisciplinary review, during which injury mechanisms were defined. The goal of these meetings was to incorporate the judgments of general and specialty surgeons, forensic pathologists, trauma nurses, the crash investigator, automotive safety engineers, police accident investigation specialists and EMS personnel. The various data elements and evidence from all phases of the investigation were presented to them for discussion and review in their role as an expert panel.

DESCRIPTION OF DATA COLLECTED TO DATE

The study to date includes 62 injured occupants. All occupants were protected by some type of restraint system. Table 1 shows the distribution of restraint systems

TABLE 1
Restraint Distribution

TYPE OF RESTRAINT	NUMBER
LAP & SHOULDER BELT	39
SHOULDER BELT ONLY	6
AIR BAG ONLY	10
LAP & SHOULDER BELT, AIR BAG	7

One of the criteria for admission to this study is that the vehicle occupant was admitted to the Ryder Trauma Center. In most cases, the victim was suspected on admission of having one or more severe injuries. The cases collected are suitable for developing hypotheses regarding the cause and mechanisms of the

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injuries and possible injury reduction countermeasures. However, population-based crash studies are required to assess the overall effectiveness of the safety belt and air bag systems. Many such studies have been reported in the literature. The National Highway Traffic Safety Administration (NHTSA) recently reported that safety belts were about 45% effective in reducing moderate to critical injuries. In 1992, a total of 5,226 lives were saved by safety belts. Air bags in conjunction with safety belts are reported to be between 55%-68% effective in reducing moderate to critical injuries. Through 1992, air bags and/or safety belts have saved an estimated 558 lives in air bag equipped cars, and reduced nearly 40,000 moderate to critical injuries.[5].

A general observation of the injured occupants in the study to date confirms other findings that air bags and seat belt systems are doing a good job of reducing the severity of injuries. The severity and extent of the head and chest trauma are generally much less than has been observed for the unrestrained population which made up most of the motor vehicle trauma admissions in years past.

This reduced extent of trauma still carries with it the need for careful examination and diagnosis of the residual trauma. Especially for air bag cases, the physiological response of the victim at the crash site does not consistently predict the gravity of their trauma.

The analysis to follow will address the residual injuries observed in air bag cases and will focus on the occult (not immediately obvious) chest and abdominal injuries observed to date.

The 17 occupants protected by air bags who were entered into the study to date had a total of 101 injuries. The distribution of injuries by body region is shown in Table 2. This table also shows the Harm distribution. In the Harm accounting procedure, weighing factors are applied to the injury data, with each injury described according to its threat to life and weighted in proportion to its monetary cost. The procedure was pioneered by Malliaris [6,7]. The monetary weighing factors are based on cost data developed by Miller [8].

TABLE 2
Injury Distribution in Air Bag Equipped Cars
17 Cases

Region	# of Injuries	Harm %
Head/Neck	28	22%
Chest/Abdomen	22	38%
Lower Extremity	35	36%
Upper Extremity	16	4%
TOTAL	**101**	**100%**

Table 2 shows that head/neck injuries constitute 28% of the injuries, but only 22% of the Harm. In contrast, chest/abdominal injuries comprise 22% of the injuries, but 38% of the Harm. This result suggests that the chest/abdominal injuries are generally more serious than the other injuries for the cases collected to date.

The most common vehicle feature which was associated with chest/abdominal injuries was a bent steering wheel or a compressed steering column. Ninety-five percent of the Harm to the chest/abdomen region was associated with a steering wheel/column deformation.

CASE STUDIES-In the sections to follow, nine selected air bag cases will be summarized.

Four of the 17 air bag cases in the Jackson study involved occult chest/abdominal injuries. Among these cases, three involved multiple impacts, at a relatively moderate delta V. The fourth was a high severity (37 MPH delta V) impact. All occupants survived.

In addition to the Jackson cases, three cases from the NASS-SCI on-site air bag deployment investigation fleet are presented. These three cases are all moderate delta V (less than 25 MPH) frontal impacts into trees or poles. In all three cases, the occupant died of chest/abdominal injuries.

JACKSON OCCULT INJURY CASES
Case # 92-004

FIGURE 1

A 1992 Lincoln Town Car (Fig. 1) was traveling on a two lane road through a swampy region at a speed of 60 MPH when the left front tire blew out. The posted speed was 45 MPH. The time was 8:42 PM, the weather was rainy and the road was wet. The Lincoln swerved left of center, across the path of a 1982 Mercury Marquis. The two vehicles impacted left-headlight to left-headlight, with a contact width of 8". The Lincoln, directed to the left by this impact, continued along the left shoulder until it sustained a centerline impact with a concrete utility pole, approximately 350' from the first impact. The displacement measurements were as follows: Maximum vehicle crush - 30", Left "A" pillar intrusion - 3.25", Left instrument panel intrusion - 3", Steering wheel deformation - 2". The estimated delta

V for the car-to-car impact was 19 MPH and for the pole the impact was 22 MPH.

The driver was a healthy 83-year-old retired male who weighed 200 lbs. and was 5' 10" tall. He was married to a young woman and was the father of a then 4-year-old child. Protection was provided by an air bag and manual lap and shoulder belts. He sustained the following injuries:

- AIS-5   Hematoma, subdural bilateral
- AIS-1   Laceration, ear left
- AIS-2   Fracture, ribs left (3)
- AIS-4   Rupture, spleen with hemorrhage
- AIS-2   Laceration, descending colon mesentery
- AIS-1   Laceration, elbow left
- AIS-2   Fracture, navicular left
- AIS-2   Fracture, acetabulum with dislocation femur left
- AIS-2   Fracture, ankle left

The EMS personnel at the scene of the crash found that the driver did not meet any of the objective criteria which would have mandated transport to a trauma center (trauma center admission criteria) [9]. Because of suspicion of severe injury, EMS transported the patient by helicopter to a Level 1 trauma center. The patient had a multi-week stormy hospital course wherein he underwent multiple surgical procedures. He was discharged to a nursing home, where he remains today.
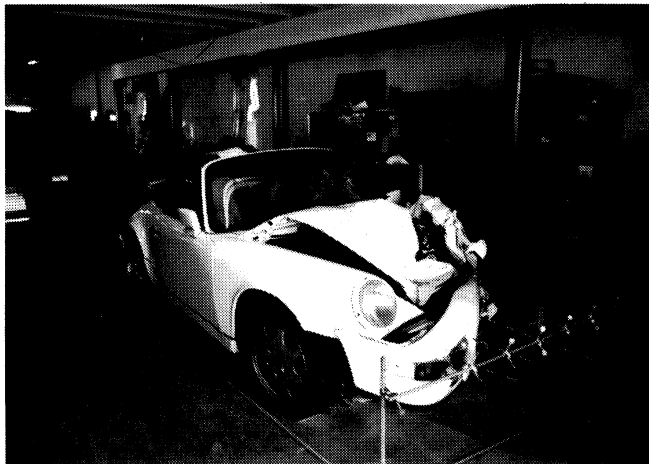
Case #92-023

FIGURE 2

A 1990 Porsche Carrera (Fig. 2) impacted the rear of a 1985 Pontiac Fiero which was parked for a tire change in the fast lane of a busy three lane divided highway. The travel speed prior to impact was at the speed limit, about 55 MPH and the delta V is estimated at 22 MPH. The time was 3:30 PM, the weather was clear and the surface was dry. A van traveling ahead of the Porsche blocked the view of the parked Pontiac until the last instant, preventing timely evasive action. The Porsche sustained two impacts. The major impact was with the rear of the parked Pontiac. A second impact occurred with the left front fender of the Porsche impacting the concrete median barrier at a low delta V. The Porsche sustained a maximum frontal crush of 28.5" and a left toe pan intrusion of 4.5". The steering wheel was deformed 1". The driver was a 50-year-old male businessman. He was 5' 11" tall and weighed 220 lbs. He was protected by an air bag and manual belt. His injuries were:

- AIS-2   Fracture, ribs left (3-5)
- AIS-2   Laceration, liver
- AIS-1   Contusion, antecubital fossae (bilateral)
- AIS-2   Fracture, acetabulum left

At the scene, the patient did not meet trauma center admission criteria and was transported to an emergency room, not a trauma center. After a number of hours in that facility, the patient's condition deteriorated and he was transferred to a trauma center. He had a complex hospital course during which he underwent numerous surgical procedures. During his hospital care he developed a number of complications. A year after the crash the patient was unable to resume his pre-injury activities largely due to psychological problems.

Case #92-006

FIGURE 3

At 5:00 AM, a 1992 Honda Civic DX (Fig. 3) approached a right angle intersection in a residential area. The vehicle was traveling at 40 MPH, 10 MPH above the posted speed limit. Unable to negotiate the 90 degree turn to the left, the driver locked the brakes and proceeded straight ahead, leaving 45 feet of skid marks. The vehicle crossed a 5.0" high curb and a sidewalk, crashed through a wood fence and continued another 20' before impacting a cement block stucco house. The left side of the car went through the sliding glass door but the right side impacted the cement block

exterior wall and the inside bedroom wall which was parallel to the direction of travel (Fig. 4).

FIGURE 4

The vehicle continued into the house striking an occupied bed in the master bedroom and coming to rest inside the house. The maximum vehicle crush was 23.0", the right toe pan intrusion was 8.0" and the steering wheel deformation was 4.0". The estimated delta V was 23 MPH. The driver was a 34-year-old male bartender who weighed 134 lbs. and was 5' 6" tall. His BAC was .079, measured 12 hours after the crash. He was wearing the manual belt system and the air bag deployed. He sustained a single injury:

AIS-2   Laceration, liver with hematoma

The patient did not meet trauma center admission criteria and was transported to the nearest hospital, not a trauma center. He developed severe abdominal pain, suggestive of intra-abdominal injury, a number of hours later. He was then transferred to a Level 1 trauma center. The liver injury was treated non-surgically. The patient was discharged home a few days after admission and has done well.

Case #92-017

FIGURE 5

A 1991 Mercury Grand Marquis (Fig. 5) was traveling northbound on a two lane road. The posted speed for this area is 50 MPH. At 8:24 PM, the weather was cloudy and the road surface was dry when a 1989 Chevrolet pick-up truck had to brake suddenly to avoid striking a slower moving vehicle in the same lane. The pick-up truck swerved to the left into the northbound lanes. The Mercury struck the pick-up truck in the front end with the front bumper. After the initial contact, both vehicles rotated and sideslapped. The Mercury came to rest facing in a northeasterly direction. There was 65.0" of direct contact across the front bumper of the Mercury and the maximum extent of crush for this impact was 37.75". The vehicle sustained a left toe pan intrusion of 8.0" and a left instrument panel intrusion of 4.0". The steering wheel deformation was 3.0". The delta V was calculated to be 37 MPH.

The driver was a 63-year-old male engineer who weighed 175 lbs. and was 5' 10" tall. Protection was provided by an air bag as well as lap and shoulder belts. He sustained the following injuries:

- AIS-3   Fracture, ribs left (6-8) right (1)
- AIS-3   Contusion, lungs bilateral
- AIS-4   Contusion, cardiac
- AIS-2   Fracture, calcaneus right

This crash occurred in an area not served by a trauma center. The patient was transported from the scene to a local hospital. His injuries led to cardiac and respiratory insufficiency. These problems were not adequately treated. A number of days after the crash he was transferred to a Level 1 trauma center in a critically-ill state. The patient had a multi-week critical course which included a number of operations. He was discharged home and within two months had resumed all his pre-injury activities.

NASS SPECIAL CRASH INVESTIGATION OF FATALITIES INVOLVING CHEST/ABDOMINAL INJURIES IN LOW SEVERITY CRASHES

Case #91-12

A 1990 Dodge Shadow impacted a 10" diameter utility pole on the left side of a rural two lane state route where the speed limit was 35 MPH. The impact was at 12 o'clock and at the centerline of the Dodge's bumper. It produced a maximum of 14.5" of bumper crush. The resulting delta V of 14.4 MPH deployed the air bag. The steering wheel was bent .25" and the shear capsule was compressed 1.6".

The driver was a 36-year-old female, 5' 3" tall, weighing 112 lbs. She had a history of epilepsy. She was wearing her 3-point belt system. Her injuries were:

- AIS-3   Fractures, ribs bilateral
- AIS-3   Rupture, spleen
- AIS-5   Rupture, abdominal aorta

The patient was reportedly unconscious at the scene and she was transported to a local hospital.

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Shortly after admission, the patient's condition deteriorated. She was taken to the operating room wherein she died presumably of the aortic rupture.

Case # 92-4

The driver of a 1986 Ford Tempo lost control of the car during a coughing attack. The Tempo traversed a 5" curb and impacted a wooden utility pole located on the right side of an urban street. The driver air bag deployed. The maximum depth of bumper crush was 14.8" which produced a delta V of 17 MPH. The steering wheel was deformed 3.3" forward.

The driver was a 57-year-old female, 5' 6" tall, weighing 150 lbs. Her seat adjustment was 3" from the full forward position. Her injuries were:

- AIS-3   Rupture, spleen
- AIS-1   Contusion, abdominal wall
- AIS-1   Contusion, breast bilateral
- AIS-1   Abrasion, chin
- AIS-1   Laceration, lower lip

The crash victim was conscious at the scene and reported no pain. She was transported to a local hospital where on admission she was reportedly stable. Four hours following the crash she expired. There was concern by the case reviewers that the injuries to the spleen were not initially recognized.

Case #91-10

A 1991 Pontiac Firebird ran through a T-intersection in a residential area and impacted an 18" diameter tree with its center front. The estimated impact speed was 21 MPH with a delta V of 19 MPH. The vehicle sustained a maximum depth of crush of 22" from the 12 o'clock direction of force impact. The steering wheel was deformed 2" forward and the steering column shear capsule was separated 3".

The driver was a 46-year-old male, 5' 11" tall and weighed 230 lbs. He was wearing manual lap and shoulder belts. He temporarily lost consciousness as he approached the T-intersection. The impact with the tree caused the air bag to deploy. The driver sustained the following injuries:

- AIS-4   Fractures, ribs bilateral (2-9)
- AIS-4   Contusion, heart
- AIS-1   Ecchymosis, legs, distal to the knees
- AIS-1   Abrasion, chin
- AIS-1   Abrasion, forehead with ecchymosis

The driver remained conscious post-crash and was transported to a local hospital where he expired several hours following the crash. The apparent cause of death was the contusion of the heart. However, the apparent loss of consciousness prior to the crash opens the question of a heart attack at that time. Acute and/or chronic heart disease could have exacerbated the problem of the contusion, according to the case reviewers.

JACKSON HIGH CRASH SEVERITY CASES

Case #93-001

A 1992 Honda Civic DX (Fig. 6) was traveling northbound at 12:43 AM. The road surface was dry, the weather conditions were clear and the estimated speed was 40 MPH, the same as the posted speed. As the Honda entered a right hand curve, the vehicle crossed the centerline into the path of a 1993 Mitsubishi Starion. The vehicles struck head-on in the southbound lane. After the impact with the Mitsubishi, the Honda struck and mounted the west barrier curb. The Honda continued traveling west and struck a bridge rail with the left front bumper. After this impact, the Honda rotated clockwise and came to rest on the west sidewalk. There was 54" of direct contact on the front bumper of the Honda. The maximum extent of crush was 42.25". In addition, there was a brake pedal intrusion of 14.5" and a left toe panel intrusion of 12.5". The delta V for the Honda was 55 MPH.

FIGURE 6

The Honda driver was a 40-year-old male factory worker who weighed 155 lbs. and was 5' 8" tall. He was protected by an air bag and lap and shoulder belts. His BAC was .200. He sustained the following injuries:

- AIS-1   Laceration, forehead (minor)
- AIS-1   Abrasion, neck left
- AIS-1   Contusion, chest upper bilateral
- AIS-3   **Fracture, ribs right (2-4) with** pneumothorax
- AIS-1   Abrasion, forearm left
- AIS-1   Abrasion, upper thigh right
- AIS-1   Abrasion, knee left
- AIS-2   Fracture, calcaneus right
- AIS-2   Fx/Dislocation, tarsal/metatarsal joint right
- AIS-2   Fracture, metatarsals right (2-4)
- AIS-2   Fracture, metatarsals left (2-4)
- AIS-2   Fracture, medial malleolus left

The patient met trauma center admission criteria and was transported directly to a Level 1 trauma center

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from the scene. The hospital course was less than two weeks during which he underwent multiple orthopedic surgeries. He was discharged home with outpatient rehabilitation. Follow-up revealed that the patient was walking with support but was still unable to wear his right shoe. He returned to work approximately three months post-crash.
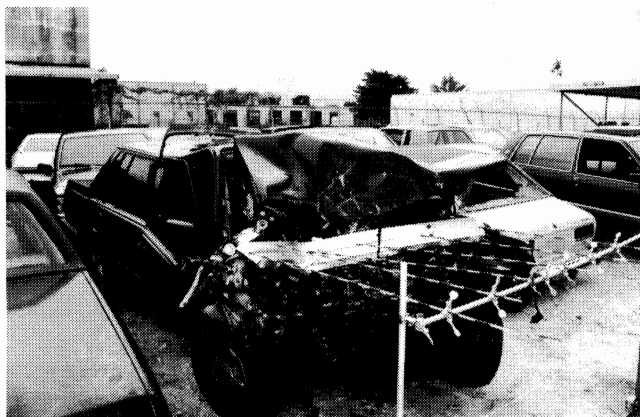
Case #91-002

FIGURE 7

A 1991 Volvo 740 Turbo (Fig. 7) was traveling westbound in the second lane at an estimated speed of 60 MPH, exceeding the posted speed by 15 MPH. At 11:55 AM, the weather was clear and the road was dry when the driver reportedly "blacked out". The vehicle continued forward crossing the eastbound lanes and struck a 5.5" barrier curb with the left front wheel. It then mounted the curb and continued in a westerly direction across a 7' concrete sidewalk and grass lawn. It continued approximately 75' striking an aluminum traffic signal control box which measured 2'x3'x7'. The control box was uprooted from the impact and came to rest 95' west and 57' north of its point of origin. The Volvo continued forward another 10' and struck an 18" square concrete utility pole. The direct contact of the front bumper was 36" and the maximum extent of crush was 47.7". The vehicle sustained a right "A" pillar intrusion of 5.5" and a right dash intrusion of 4.0". The delta V was calculated to be 55 MPH.

The driver was a 39-year-old male businessman who weighed 323 lbs. and was 5' 11" tall. Protection was provided by an air bag only. He sustained the following injuries:

AIS-3   Hemorrhage, subarachnoid
AIS-2   Laceration, scalp major
AIS-2   Fracture, C7 vertebra
AIS-1   Contusion, chest
AIS-2   Laceration, mesentery small bowel
AIS-4   Avulsion, small bowel
AIS-2   Contusion, colon
AIS-1   Abrasion, forearm right
AIS-3   Fracture, femur right open

The patient did not meet trauma center admission criteria at the crash scene. He was transported to the Level 1 trauma center because it was the nearest facility. Although initially stable, within an hour of admission the patient's condition began to deteriorate significantly. He was taken to the operating room for treatment of seemingly correctable problems. During the abdominal operations, he developed severe problems including cardiac and respiratory failure. The cause of these problems is unclear. He died less than 24 hours later of multiple organ system failure.

Table 3 summarizes the Jackson air bag occult injury cases. Note steering column deformation ("DEF") occurred in all these cases.

TABLE 3
AIR BAG CASES-OCCULT INTERNAL INJURIES

CASE #	CAR	DEF	INJURY	TRIAGED
92-004	92-Lincoln	2.0"	4-Spleen	Trauma Ctr EMS Susp.
92-023	90-Porsche	1.0"	2-Liver	Hospital
92-006	92-Honda	4.0"	2-Liver	Hospital
92-017	91-Mercury	3.0"	3-Lung	Hospital

Table 4 summaries the NASS data for air bag cases. Note that steering wheel deformation was reported in 23 cases. Of those 15 admitted to the hospital, nine had AIS-3 or greater injuries.

TABLE 4
NASS DATA 1989-1991- AIR BAG DEPLOYMENT
FRONTAL CRASHES

135	Cases of air bag deployment
626	Injuries to occupants
23	Cases with reported steering wheel deformation
9	Occupants suffered AIS-3+ injuries

DISCUSSION

OCCULT INJURIES-The air bag may have ushered in a new era in injury management. Strategies for dealing with severely injured people emanate from military approaches. The methods of assessing injuries on the field, stabilizing life threatening derangements in physiology and anatomy, rapidly transporting patients to hospitals wherein definitive diagnostic and therapeutic interventions can be provided have continued to improve throughout the history of American military conflicts. The concept of "triage" is fundamental to these processes. It involves the allocation of resources to injured individuals based on the severity of the injuries and the likelihood of survival.

Injuries which occur in military situations are typically related to the penetration of one or more body parts by bullets and shrapnel. The presence of a life- or limb-threatening injury is obvious by the degree of

physiological compromise, such as shock, and/or the entry location of the projectile and its presumed path in the body. In automobile related injuries the damaging forces are typically blunt. At the scene of a crash the presence of an internal injury, such as a laceration of the liver, is suggested if there is external evidence of contact (over the area of the liver) such as bruising or pain, and/or if there is physiological abnormality such as shock.

The clinician dealing with blunt trauma must always maintain a high level of suspicion of injury; the failure to recognize injuries can lead to loss of life or limb. Decisions on whether a trauma victim needs to be taken to a hospital and the level of trauma care expertise of the receiving hospital is based on triage criteria mandated typically by state governments. The most capable trauma centers are designated Level 1 or 2 according to the American College of Surgeons Committee on Trauma (ACSCOT) standards [9].

ACSCOT and other organizations have developed criteria that largely are the basis for local trauma system's criteria. These are typically based on physiological abnormalities such as systolic blood pressure below 90 millimeters of mercury or Glasgow Coma Score below 13. Location of injury is also included in some systems' criteria, such as bullet wound to the abdomen. Another group of criteria is mechanism of injury such as a fall of more than two building stories or ejection from a vehicle in a crash. The last group of criteria is called "index of suspicion". These are based on the opinion of EMS personnel at the scene. Even though other objective criteria are not present, the patient does not "look right" and therefore should be evaluated in a trauma center. The criteria which are utilized in Dade County, Florida, wherein the Ryder Trauma Center is located, are listed below.

ADULT TRAUMA CRITERIA
USED IN DADE COUNTY, FLORIDA
- Systolic BP≤ 90
- Respiratory rate <10 or >29 BPM
- Glasgow Coma Scale ≤ 13
- Penetrating injury to head, neck, chest, abdomen or groin
- Paralysis
- Second or third degree burns ≥ 15% TBSA
- Amputation proximal to wrist or ankle
- Ejection from motor vehicle

Most studies have shown that the combination of criteria that are utilized by individual trauma systems work well [10]. Quality of care analyses, which are mandated for trauma systems, typically show very few cases where injured individuals did not receive adequate treatment. One way of evaluating the quality of care in a system is to evaluate deaths and determine if any were preventable. Most well organized trauma systems have low preventable death rates [11].

The air bag may affect the ability to successfully evaluate crash-involved occupants utilizing existing criteria. The air bag-protected occupant typically will not have physiologically compromising head, chest or abdominal injuries nor the facial lacerations, bruises and fractures that often make crash victims "look" seriously injured. Personnel at the scene may not send occupants, who later turn out to have serious injuries, to trauma centers.

In most cases, the injuries to occupants protected by air bags are less severe than to occupants without airbags, but the problem is that the residual injuries may not be recognized by EMS or emergency room personnel. It is not that the air bag contributes to injury, but that it changes a very serious, obvious injury into a less serious, but less obvious injury. If this less obvious injury is not treated, it may become a serious problem.

What kinds of injuries may not be initially obvious but become life threatening? Any chest or abdominal injury wherein the immediate physiological implications are minimal fall into this category, such as contusions and lacerations of the lungs, aorta and heart. In the abdomen tears of the solid organs, in particular of the liver and spleen, can initially cause limited bleeding with little blood pressure loss and minimal abdominal pain. The mesenteries which connect the bowel components to their central blood supplies can be torn with limited initial bleeding. The bowel can also be torn. Bleeding is less problematic with bowel injuries; contamination of the abdominal cavity with irritating and often infection producing components is the problem. Continued loss of blood and/or contamination of the abdomen typically leads to very serious problems.

Even minutes of uncorrected shock and contamination can lead to death or failure of other organ systems such as the lungs or the immune system.

How can the air bag contribute to serious abdominal and chest injuries which are not initially noticeable? There appears to be three mechanisms:

- The air bag may contact the chest or abdomen directly during deployment with enough force to injure internal organs. This appears to be a rare event. It occurs mainly when the occupant is in close proximity to the bag as it deploys.

- The occupant's position and size, and/or the velocity of the crash may exceed the air bag's protective capability allowing the occupant to contact an internal component of the automobile, particularly the steering wheel. The examples to date of this include large occupants and crash velocities in excess of 35 miles per hour.

- There may be multiple collisions wherein the air bag has partially or completely deflated after the initial

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external collision. Thus, the occupant can contact internal objects such as the steering wheel.

The problem is that the occupant may not meet existing trauma center admission criteria after one of these types of events. However, the individual may have sustained some chest or abdominal internal injury as previously described. It appears that suspicion of injury must occur if these potentially injured occupants are to receive a full evaluation in the hospital. In present trauma centers the determination that an individual has an internal abdominal or chest injury is based on a combination of available historical information, physical examination and diagnostic tests. The latter include: x-rays (which are particularly useful in evaluating lung injuries), ultrasound (to examine the heart for internal injury and/or bleeding into its surrounding sac), CAT scanning (which is useful mainly for abdominal injuries and in a limited fashion chest injuries), angiography (which is particularly useful for evaluating the most potentially life-threatening occult injury--partial tear of the thoracic aorta) and diagnostic peritoneal lavage (which is extremely useful for discovering bleeding in the abdominal cavity).

Not all injuries require surgery. Today many lacerations of the liver and spleen are treated without surgery. The diagnosis of these non-operated injuries is typically made via CAT scan. The stable patient can be observed in an intensive care unit. The immediate capability of performing surgery if the patient deteriorates is a necessary requirement of this strategy. Non-operative therapy works in part because the patients are kept at bed rest. At rest the injured organs, especially the liver, typically heal rapidly. When patients with these injuries are sent home from the crash scene, because they appear uninjured, their normal activities can further stress the injured organs causing life-threatening bleeding.

Dealing with injury in the era of the air bag is dramatically different than in the setting of the battlefield. The injuries in the air bag setting will often not be obvious and the receiving hospital may evaluate many patients who turn out to be injury-free. In the military scenario the injuries are obvious and hospitals are for the clearly life-threatened patient.

The challenge is to find reliable indicators of potential injury that are available at the crash scene. Deformation of the steering wheel in frontal collisions appears, in the small number of cases studied to date by the Jackson investigation team, to be a useful indicator of possible abdominal or thoracic injury. As Table 4 indicates, all four of the cases wherein occult abdominal injury occurred to air bag-protected drivers, there was steering wheel deformation. Based on these observations a Research Note was developed by NHTSA suggesting that EMS evaluate the steering wheel in these cases [12]. The Note recommends that deformation of the steering wheel be considered as a criterion for further evaluation, in a hospital setting, of the stable, air bag-protected driver involved in a frontal crash.

Other potential sources of information about possible internal abdominal or chest injuries in air bag-protected crash occupants are the amount of deformation to the exterior of the automobile and/or intrusion of internal components. Occupant stature and position at the crash moment may turn out to be very predictive, particularly if the occupant is out of position or on top of the air bag as it deploys. Crashes which include multiple collisions may correlate highly with injuries.

Continued, detailed study of air bag-involved crashes wherein occult injuries occur is necessary. Traditional analyses of real-life crashes, such as NASS, do not provide precise definition of the clinical course. For example, the timeline from the crash to injury discovery and treatment is of real importance. Hospital-based studies involving multidisciplinary teams such as the ones ongoing at the Ryder Trauma Center and the Maryland Institute for Emergency Medical Services are necessary to provide these data [13].

SUMMARY

The number of air bag-involved crashes wherein difficult triage decisions need to be made is unknown at this time. As previously stated, it is estimated by NHTSA that by the year 2000 more than five hundred thousand air bag deployments will occur yearly. To avoid missing injuries, triage strategies err on the side of transporting patients, who may have serious injuries, to trauma centers for evaluation. Applying this to air bag-protected occupants, there may be many admissions to trauma centers for work-up of occult injuries. On the other side of the equation, admissions of severely injured occupants may decrease as a function of air bag protection.

Determinations need to be made as to whether evaluations of initially stable crash victims, with suspicion of major injury, can be performed in the most sophisticated trauma care arenas (Level 1 or 2 trauma centers). They have the expertise and equipment to work-up these patients and treat their spectrum of injuries. At this time, however, these centers concentrate on treating individuals with obvious threat to life or limb and are often functioning at or above capacity [14]. In the air bag era, the role of the trauma center may need to be broadly expanded to include the evaluation of stable patients who may have incurred occult injuries.

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