The Effect of Frontal Air Bags on Eye Injury Patterns in Automobile Crashes

Stefan M. Duma, PhD; M. Virginia Jernigan, BS; Joel D. Stitzel, MS; Ian P. Herring, DVM; John S. Crowley, MD; Fred T. Brozoski, MS; Cameron R. Bass, PhD

Objective: To investigate eye injuries resulting from frontal automobile crashes and to determine the effects of frontal air bags.

Methods: The National Automotive Sampling System database files from January 1, 1993, through December 31, 1999, were examined in a 3-part study that included an investigation of 22,236 individual crashes that occurred in the United States. A new 4-level eye injury severity scale that quantifies injuries based on recovery time, need for surgery, and possible loss of sight was developed.

Results: Of all occupants who were exposed to an air bag deployment, 3% sustained an eye injury. In contrast, 2% of occupants not exposed to an air bag deployment sustained an eye injury. A closer examination of the type of eye injuries showed that there was a statistically significant increase in the risk of corneal abrasions for occupants who were exposed to an air bag compared with those who were not (P = .03). Of occupants exposed to an air bag deployment, 0.5% sustained a corneal abrasion compared with 0.04% of occupants who were not exposed to an air bag.

Conclusions: Using the new injury levels, it was shown that although occupants exposed to an air bag deployment had a higher risk of sustaining minor eye injuries, the air bag appears to have provided a beneficial exchange by reducing the number of severe eye injuries.

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ALTHOUGH AIR BAGS have reduced the incidence of fatal and severe injuries in automobile collisions, they have been shown to increase the risk of less severe injuries. These associated minor injuries include upper extremity fractures, skin abrasions, and eye injuries. In particular, the medical literature is replete with case studies of air bag–induced eye injuries. In addition to air bag–induced eye injuries, Müller-Jensen and Hove found that broken windshield glass was a serious eye injury mechanism, with 40% of these cases resulting in blindness in at least 1 eye.

Most case studies focus on only a few occupants. However, 4 articles in particular include numerous cases of air bag–induced eye injuries. Duma et al present an analysis of 25 air bag–induced eye injury cases; they found that the most serious injuries were a result of the occupant being struck by the air bag during deployment. Ghafouri et al found bilateral injuries in 27% of 43 air bag–induced eye injury cases. Vichnev et al report 14 cases and note that the most severe injuries were to occupants wearing eyeglasses, all of whom sustained permanent ocular damage. Stein et al provide a detailed summary of the 97 published case studies that included a wide range of ocular injuries, from corneal abrasions to ruptured globes.

There are a paucity of experimental data on air bag–induced eye injuries compared with the number of individual case study publications. Fukagawa et al found that increased inflator aggressivity contributed to increased endothelial cell damage. The most recent air bag–related study examined the injury potential of high-speed foam particles released during air bag deployment. This study illustrates the compounding risk of eye injuries from not only air bag contact, but also from particles released from the module during deployment.

Although previous studies have provided insight into the interaction between an air bag and the eye, the national incidence and relative risk of air bag–induced eye injuries are unknown. The purpose of this article is to determine the

From the Impact Biomechanics Laboratory, Virginia Polytechnic Institute and State University, Blacksburg (Drs Duma and Herring, Ms Jernigan, and Mr Stitzel); the US Army Aeromedical Research Laboratory, Fort Rucker, Ala (Dr Crowley and Mr Brozoski); and the Automobile Safety Laboratory, University of Virginia, Charlottesville (Dr Bass).
To eliminate the inaccuracies associated with small case study projections, this study used the National Automotive Sampling System (NASS) database. The 2 primary advantages of using the NASS database are that it includes an analysis of approximately 5000 cases per year and the injuries are coded by trained nurses using the Abbreviated Injury Scale (AIS). The AIS classifies injuries by body region on a 6-point scale ranging from low severity (AIS1) to fatal (AIS6). The AIS values are assigned for injuries that may require surgery and present a guarded long-term prognosis; and level 4, the most serious eye injuries that would result in blindness.

PART 3: OCCUPANT AND CRASH CHARACTERISTICS

Occupants exposed to an air bag deployment were divided into 2 groups: group 1 included all occupants who received an air bag-induced eye injury and group 2 included all the remaining occupants. The occupants in group 2 could have sustained an eye injury in the crash, but the source would be something other than the air bag. The groups were divided in this way to identify occupant characteristics related to incidence of air bag-induced injury.

PART 1: CRASHES WITH AND WITHOUT AIR BAG DEPLOYMENT

A total of 10770828 occupants from 22236 cases were included in this study for the 7-year period from 1993 through 1999 (Figure 1). Each year, there were more weighted value, which scales the incidence of the particular crash investigated to a number that represents actual occurrence of similar noninvestigated crashes that occur in the United States each year. The weighting factor for each case is included in the NASS database. This procedure has been used in national injury projection studies to analyze injury severity and crash characteristics for topics such as lower-extremity injury patterns, upper-extremity injury patterns, and restraint effectiveness in motor vehicle crashes. The occupant and injury numbers reported represented the weighted numbers based on the raw cases. Statistical analyses were performed using the SUDAAN statistical software, version 7.0, for weighted survey data (Research Triangle Institute, Research Triangle Park, NC).

For this study, NASS cases from January 1, 1993, through December 31, 1999, were selected if they included drivers and front seat occupants only, while excluding ejected occupants and rollovers. In addition, only frontal-impact crashes, defined as having a primary direction of force of 11, 12, or 1 o’clock, were considered. Eye injuries were defined as damage to the periorbital skin, globe, or orbital bones. Occupants with injuries and total injuries to occupants were analyzed for trends in injury incidence, type, and severity. Eye injuries in the NASS database were identified using the current AIS injury codes. The study was divided into 3 parts.

METHODS

First, crashes with an air bag deployment were considered. For all occupants who were exposed to an air bag deployment, the number of occupants sustaining an eye injury was compared with the total number who did not sustain an eye injury. Next, an analogous search was performed for crashes in which the air bag did not deploy.

RESULTS

A new eye injury grouping method was developed to assess the severity of eye injuries based on both the need for ocular surgery and the potential for loss of sight. The AIS system does not address both these criteria because it only considers the overall threat to life. Eye injuries were divided into 4 new injury groups (Table 1): level 1 includes minor injuries to the skin; level 2, minor injuries to the eye; level 3, more serious eye injuries that may require surgery and present a guarded long-term prognosis; and level 4, the most serious eye injuries that would result in blindness.

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The NASS cases are collected from 24 separate field research teams across the United States. Crashes are considered for NASS investigation if they occur on a traffic way, are reported to police, involve a harmful event, and involve at least 1 towed passenger car, light truck, or van. Because it is not practical to investigate every crash in the United States every year, each case investigated for the NASS database is assigned a weighted value, which scales the incidence of the particular crash investigated to a number that represents actual occurrence of similar noninvestigated crashes that occur in the United States each year. The weighting factor for each case is included in the NASS database. This procedure has been used in national injury projection studies to analyze injury severity and crash characteristics for topics such as lower-extremity injury patterns, upper-extremity injury patterns, and restraint effectiveness in motor vehicle crashes. The occupant and injury numbers reported represent the weighted numbers based on the raw cases. Statistical analyses were performed using the SUDAAN statistical software, version 7.0, for weighted survey data (Research Triangle Institute, Research Triangle Park, NC).

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Table 1. New AIS Severity Levels for Eye Injuries, Classified by Need for Surgery, Expected Recovery Time, and Possible Loss of Sight*

<table>
<thead>
<tr>
<th>AIS Severity Level</th>
<th>AIS No.</th>
<th>Injury Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1: Skin, eyelid, or orbit area soft tissue</td>
<td>297099.1</td>
<td>Skin NFS</td>
</tr>
<tr>
<td>Level 2: Eye, less severe</td>
<td>240499.1</td>
<td>Eye NFS</td>
</tr>
<tr>
<td></td>
<td>240416.1</td>
<td>Conjunctiva injury</td>
</tr>
<tr>
<td></td>
<td>240602.1</td>
<td>Corneal abrasion</td>
</tr>
<tr>
<td></td>
<td>240699.1</td>
<td>Corneal injury NFS</td>
</tr>
<tr>
<td></td>
<td>241499.1</td>
<td>Uvea injury</td>
</tr>
<tr>
<td></td>
<td>241699.1</td>
<td>Posterior vitreous detachment</td>
</tr>
<tr>
<td>Level 3: Eye, more severe</td>
<td>240408.1</td>
<td>Tear duct laceration</td>
</tr>
<tr>
<td></td>
<td>240412.1</td>
<td>Choroid rupture</td>
</tr>
<tr>
<td></td>
<td>240604.1</td>
<td>Corneal contusion</td>
</tr>
<tr>
<td></td>
<td>240604.1</td>
<td>Corneal hyphema</td>
</tr>
<tr>
<td></td>
<td>240606.1</td>
<td>Corneal laceration</td>
</tr>
<tr>
<td></td>
<td>240800.1</td>
<td>Iris laceration</td>
</tr>
<tr>
<td></td>
<td>241000.1</td>
<td>Retinal laceration</td>
</tr>
<tr>
<td></td>
<td>241200.1</td>
<td>Scleral laceration</td>
</tr>
<tr>
<td></td>
<td>251200.2</td>
<td>Orbital fracture NFS</td>
</tr>
<tr>
<td></td>
<td>251202.2</td>
<td>Orbital fracture closed</td>
</tr>
<tr>
<td></td>
<td>251204.3</td>
<td>Orbital fracture open/displaced</td>
</tr>
<tr>
<td></td>
<td>230202.2</td>
<td>Optic nerve contusion</td>
</tr>
<tr>
<td></td>
<td>230204.2</td>
<td>Optic nerve laceration</td>
</tr>
<tr>
<td></td>
<td>230206.2</td>
<td>Optic nerve avulsion</td>
</tr>
<tr>
<td></td>
<td>230299.1</td>
<td>Optic nerve injury NFS</td>
</tr>
<tr>
<td></td>
<td>240402.2</td>
<td>Eye avulsion/enucleation</td>
</tr>
<tr>
<td></td>
<td>241002.2</td>
<td>Retinal detachment</td>
</tr>
<tr>
<td></td>
<td>241202.2</td>
<td>Scleral globe rupture</td>
</tr>
</tbody>
</table>

*AIS indicates Abbreviated Injury Scale; NFS, not further specified.
occupants who sustained an eye injury in a crash without an air bag deployment than in a crash with an air bag deployment. As the proportion of air bag–equipped vehicles in the fleet increases, the number of occupants who sustain an eye injury in a crash with air bag deployment has also increased.

For crashes in which the occupant was exposed to an air bag deployment, 60,112 (3%) of 1,946,924 occupants in similar crashes sustained an eye injury (Figure 2). In contrast, for crashes without an air bag deployment, 178,151 (2%) of 8,823,904 occupants sustained an eye injury. This difference was not statistically significant ($P = .15$).

Given that each occupant may have had multiple eye injuries, it is shown that 26% of all eye injuries occurred to occupants exposed to an air bag deployment (Figure 3). If the occupants with an eye injury were exposed to an air bag deployment, the air bag was the source of the eye injury for 88% of the injuries. If an air bag did not deploy, the top 3 sources for eye injury were the windshield (34%), steering wheel (27%), and instrument panel (14%). Regardless of injury source, 76% of occupants who incurred an eye injury were drivers, and 24% were right front seat passengers.

PART 2: INJURY SEVERITY

Although air bag exposure was shown to increase the incidence of eye injuries, the severity of the resulting eye injuries is more important. Sorting the eye injuries into the 4 newly defined levels, it was shown that eye injuries from crashes without an air bag deployment were distributed as follows: level 1, 85.0%; level 2, 4.4%; level 3, 10.1%; and level 4, 0.4% (Figure 4). A total of 10.5% of the injuries were more serious, representing the categories of levels 3 and 4 combined. In crashes with air bag deployments, only 7.2% of injuries were more serious level 3 and 4 injuries. There was a shift in the severity of eye injuries depending on whether the occupants were exposed to an air bag deployment, with the lower-severity injuries occurring to occupants exposed to an air bag deployment.
When examining the specific injury types, there was a statistically significant increase in risk of corneal abrasions for occupants exposed to an air bag deployment (P = .03). Of the occupants exposed to an air bag deployment, 0.9% sustained a corneal abrasion, compared with 0.04% of occupants not exposed to an air bag deployment.

PART 3: OCCUPANT AND CRASH CHARACTERISTICS

Occupant Sex

Women represented 65% of occupants who sustained an air bag–induced eye injury; however, this proportion was not statistically significant (P = .19).

Eyeglasses Use

Of occupants who sustained an air bag–induced eye injury, 29% were wearing glasses, whereas 25% of occupants who did not receive an air bag–induced eye injury were wearing glasses. However, this variable was not found to be statistically significant in predicting risk of air bag–induced eye injury (P = .81).

Contact Lens Use

Of occupants who sustained an air bag–induced eye injury, 46% were wearing contact lenses, whereas 11% of occupants who did not receive an air bag–induced eye injury were wearing contact lenses. Contact lens wear was not found to be a statistically significant variable in predicting risk of air bag–induced eye injury (P = .31).

Seat Belt Use

Of occupants who sustained an air bag–induced eye injury, 75% were wearing a seat belt, compared with 85.6% of occupants who did not receive an air bag–induced eye injury. This study indicated that the occupants who did not sustain an air bag–induced eye injury had a slightly higher rate of seat belt use; however, the difference was not statistically significant (P = .45).

Group 1 vs Group 2

The 1946924 occupants exposed to an air bag deployment were split into 2 groups: group 1 was made up of occupants who sustained an eye injury with an air bag as the source, and group 2 was the remaining set of occupants who were exposed to an air bag deployment but who did not have an air bag–induced eye injury (Table 2). Within a 95% confidence interval, occupant height, age, and crash Δ velocity were not significantly correlated with the risk of incidence of air bag–induced eye injury. However, it was found that lighter occupants were more likely to sustain an air bag–induced eye injury.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Air Bag–Induced Injury, Mean (SD)</th>
<th>No Air Bag–Induced Injury, Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupant height, cm</td>
<td>171.3 (1.2)</td>
<td>171.1 (0.4)</td>
</tr>
<tr>
<td>Occupant weight, kg</td>
<td>64.8 (2.3)</td>
<td>72.3 (1.3)</td>
</tr>
<tr>
<td>Occupant age, y</td>
<td>36.3 (7.1)</td>
<td>34.1 (0.7)</td>
</tr>
<tr>
<td>Δ Velocity, km/h</td>
<td>18.7 (2.7)</td>
<td>21.9 (0.5)</td>
</tr>
</tbody>
</table>

Although more occupants were injured when exposed to an air bag deployment, the air bag did provide a beneficial exchange by decreasing the severity of the associated eye injuries. A closer examination factoring in the type of eye injury showed that there was a statistically significant increase in the risk of corneal abrasions for occupants who were exposed to an air bag deployment (P = .03). Of particular interest to this study is the realization that an increasing proportion of the population will have had corrective vision procedures performed in the years to come. This, combined with the rising proportion of air bag–equipped vehicles in the fleet, warrants further investigation.

In conclusion, this article presents the most comprehensive eye injury study to date; it investigates the years 1993 through 1999. An analysis of the cases indicates that 3% of occupants exposed to an air bag deployment sustained an eye injury, compared with 2% of occupants not exposed to an air bag deployment. Moreover, there was a significant increase in the risk of corneal abra- sion for occupants exposed to an air bag deployment (P = .03).

Establishment of the new eye injury severity levels allowed for a more accurate estimation of eye trauma, thereby introducing a new tool to evaluate the patterns of automobile-related eye injuries. Using the 4 new levels to group eye injury severity, it was found that the overall severity of eye injuries decreased with air bag deployment. This was presumably accomplished because the air bag minimizes occupant contact with the windshield and steering wheel, which were the 2 leading sources of serious eye injuries. The current trend of increasing the number of air bags in the fleet as well as the increasing percentage of the population electing for corrective vision surgery is potentially alarming. This vulnerability allows for the current trend of reduction of more severe injuries due to air bag exposure to be re-
versed, a concern that warrants the continued investigation of air bag design, vision correction procedures, and eye wear protection.

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