Injury Risk to Restrained Children Exposed to Deployed First- and Second-Generation Air Bags in Frontal Crashes

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Objective: To estimate the risk of serious nonfatal injuries in frontal crashes among belted children seated in the right front seat of vehicles in which second-generation passenger air bags deployed compared with that of belted children seated in the right front seat of vehicles in which first-generation passenger air bags deployed.

Design and Setting: We enrolled a probability sample of 1781 seat belt-restrained occupants aged 3 through 15 years seated in the right front seat, exposed to deployed passenger air bags in frontal crashes involving insured vehicles in 3 large US regions, between December 1, 1998, and November 30, 2002. A telephone interview was conducted with the driver of the vehicle using a previously validated instrument. The study sample was weighted according to each subject’s probability of selection, with analyses conducted on the weighted sample.

Main Outcome Measure: Risk of serious injury (Abbreviated Injury Scale score of ≥2 injuries and facial lacerations).

Results: The risk of serious injury for restrained children in the right front seat exposed to deployed second-generation passenger air bags was 9.9%, compared with 14.9% for similar children exposed to deployed first-generation passenger air bags (adjusted odds ratio, 0.59; 95% confidence interval, 0.36-0.97).

Conclusion: This study provides evidence based on field data that the risk of injury to children exposed to deploying second-generation passenger air bags is reduced compared with earlier designs.

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BEGINNING IN THE 1990S, A portion of the deaths and injuries to children in motor vehicle crashes were attributed to exposure to deploying passenger air bags. During this time several reports of children killed by deploying passenger air bags in minor crashes focused attention on the unique needs of children in automotive safety.\(^1\)\(^2\) Braver et al\(^1\) estimated that passenger air bags reduced adult occupant fatalities by 18% in frontal crashes and by 11% in all crashes while increasing the risk of death for children younger than 10 years by 34%. Others supported this finding.\(^3\)\(^4\)\(^5\) Passenger air bags have also been shown to increase the risk of nonfatal injury to children by 87%.\(^6\)

Faced with the challenge of balancing benefits to adult passengers while minimizing risk to child occupants, the National Highway Traffic Safety Administration (NHTSA) initiated a 2-pronged response of education and regulation. First, the NHTSA, joined by national organizations such as the National Safety Council, the Air Bag and Seat Belt Safety Campaign, the American Academy of Pediatrics, the American College of Emergency Physicians, and the American Medical Association, recommended that all child passengers younger than 13 years sit in the rear seats of vehicles. Second, in 1997, the NHTSA enacted a substantial regulatory change to Federal Motor Vehicle Safety Standard 208, which provided automakers a choice between certifying frontal crash performance for unbelted adults by either rigid barrier tests or sled tests.\(^7\) This change in the standard, in many cases, resulted in the redesign of frontal air bags to reduce the force with which they deploy.\(^8\) These new air bags are generally referred to as “second-generation air bags.”

Child exposure to passenger air bags remains a persistent public health problem. Despite the rear seat recommendation, many children—one of every 8 children in crashes\(^9\) continue to sit in the right front seat of passenger air bag-equipped vehicles. As the number of passenger air bag-equipped vehicles on the roadways continues to rise, the actual number of children exposed to a deploying passenger air bag concurrently increases. In early 1999, 73 of every 10000 children in crashes were
exposed to an air bag deployment. By the end of 2002, this figure rose to 148 per 10,000 children in crashes.\textsuperscript{11}

To date several studies have examined the influence of the new air bag technology on adult drivers and passengers. Studies using the National Automotive Sampling System, a probability sample of police-reported crashes in the United States,\textsuperscript{12,13} and a trauma center–based surveillance system\textsuperscript{14} suggested protection to adults in high-speed crashes. As of July 2004, the NHTSA reported that second-generation air bags had resulted in substantially fewer child fatalities than earlier designs,\textsuperscript{15} but, to our knowledge, no studies have measured the effect of air bag redesign on a large sample of child passengers, nor have any studies examined the effect of second-generation air bags on the risk of nonfatal injuries. Therefore, the objective of this study was to estimate the risk of serious nonfatal injuries in frontal crashes among belted children in the front seat of vehicles in which second-generation passenger air bags deployed, compared with that of belted children in the front seat of vehicles in which first-generation passenger air bags deployed.

### METHODS

**STUDY POPULATION AND DATA COLLECTION**

Data were collected from December 1, 1998, through November 30, 2002. A description of the study methods has been published previously.\textsuperscript{16} The project consists of a large-scale, child-specific crash surveillance system: insurance claims from State Farm Insurance Co, Bloomington, Ill, function as the source of subjects, with telephone interview and on-site crash investigations serving as the primary sources of data.

Vehicles qualifying for inclusion were State Farm–insured, model year 1990 or newer, and involved in a crash with at least 1 child occupant being 15 years or younger. Qualifying crashes were limited to those that occurred in 13 states and the District of Columbia, representing 3 large regions of the United States (East: New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, West Virginia, North Carolina, and the District of Columbia; Midwest: Ohio, Michigan, Indiana, and Illinois; and West: California, Nevada, and Arizona). After policyholders consented to participate in the study, limited data were transferred electronically to researchers at The Children's Hospital of Philadelphia and University of Pennsylvania. Data in this initial transfer included contact information for the insured, the age and gender of each child occupant, and a coded variable describing the level of medical treatment received by each child occupant as reported by the policyholder (no treatment, physician's office or emergency department only, admitted to the hospital, or death).

A stratified cluster sample was designed to select vehicles (the unit of sampling) to conduct a telephone interview with the driver. Vehicles containing children who received medical treatment following the crash were oversampled so that most injured children would be selected while maintaining the representativeness of the overall population. If a vehicle was sampled, all child occupants in that vehicle were included in the survey. Drivers of sampled vehicles were contacted by telephone and, if a passenger had received medical treatment, screened via an abbreviated survey telephone interview to verify the presence of at least 1 child occupant in the vehicle with an injury. All vehicles with at least 1 child who screened positive for injury and a 10% random sample of vehicles in which all child occupants who were reported to receive medical treatment but screened negative for injury were selected for a full interview; a 2.5% sample of crashes where no medical treatment was received was also selected. The full interview with the driver of the vehicle and parent(s) of the involved children lasted approximately 30 minutes. The median length of time between the date of the crash and the completion of the interview was 6 days, with 93% of the interviews completed within 47 days of the crash.

The eligible study population consisted of all 430,508 children riding in 288,187 State Farm–insured vehicles newer than 1990 reporting a crash claim between December 1, 1998, and November 30, 2002. Claim representatives correctly identified 95% of the eligible vehicles identified by the electronic claims system, and 73% of the policyholders consented for participation in this study. Of these, 18% were sampled for interview and an estimated 81% of these were successfully interviewed (Figure). Comparing the sample with population values from all eligible State Farm claims, we see little difference in geographic region, vehicle model year, vehicle type, tow status of the vehicle, and child age.

For crashes in which child occupants were seriously injured or killed, in-depth crash investigations were performed. Parents and caregivers were contacted via telephone to confirm the details of the crash. Contact information from selected crashes was then forwarded to a crash investigation firm (Dynamic Science, Inc, Annapolis, Md), and a full-scale on-site crash investigation was conducted using custom child-specific data collection forms. Among crashes selected for investigation, 97% were completed. For this analysis, these crashes were used to examine the validity of information obtained from the telephone interview.
Table 1. Child, Driver, Vehicle, and Crash Characteristics Among Restrained Children Exposed to Deploying First- and Second-Generation Passenger Air Bags in Frontal Crashes

<table>
<thead>
<tr>
<th>Variable</th>
<th>First (n = 1031)</th>
<th>Second (n = 750)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child’s age, y</td>
<td></td>
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<tr>
<td>3-8</td>
<td>149 (170) [16.5]</td>
<td>91 (178) [23.7]</td>
</tr>
<tr>
<td>9-12</td>
<td>245 (319) [31.0]</td>
<td>162 (261) [34.8]</td>
</tr>
<tr>
<td>13-15</td>
<td>308 (542) [52.5]</td>
<td>193 (311) [41.5]</td>
</tr>
<tr>
<td>Driver’s age &lt; 25 y</td>
<td>151 (199) [19.3]</td>
<td>80 (158) [21.1]</td>
</tr>
<tr>
<td>Intrusion</td>
<td>152 (218) [21.1]</td>
<td>80 (120) [16.0]</td>
</tr>
<tr>
<td>Type of vehicle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger car</td>
<td>524 (796) [77.2]</td>
<td>297 (495) [66.0]</td>
</tr>
<tr>
<td>Sport utility vehicle</td>
<td>39 (39) [3.8]</td>
<td>62 (63) [8.4]</td>
</tr>
<tr>
<td>Minivan</td>
<td>125 (182) [17.7]</td>
<td>61 (157) [20.9]</td>
</tr>
<tr>
<td>Pickup truck</td>
<td>10 (10) [1.0]</td>
<td>22 (31) [4.1]</td>
</tr>
<tr>
<td>Cargo van</td>
<td>4 (4) [0.4]</td>
<td>4 (4) [0.5]</td>
</tr>
<tr>
<td>Vehicle model year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990-1993</td>
<td>21 (24) [2.3]</td>
<td>0</td>
</tr>
<tr>
<td>1994-1997</td>
<td>652 (989) [94.0]</td>
<td>0</td>
</tr>
<tr>
<td>1998-2000</td>
<td>29 (38) [3.7]</td>
<td>378 (641) [85.5]</td>
</tr>
<tr>
<td>2001+</td>
<td>0</td>
<td>70 (109) [14.5]</td>
</tr>
</tbody>
</table>

Variable Definitions

Restraint status of children was determined from the telephone survey. For this analysis, only those children who were restrained by a seat belt were included. Among the 161 children for whom paired information on restraint use was available from both the telephone survey and crash investigations, agreement was 88% between the driver report and the crash investigator (κ statistic = 0.74). Crash severity was categorized by driver report of intrusion into the occupant compartment of the vehicle via the telephone survey. Seating location of each child was determined from the telephone survey. Among the 170 children for whom paired information on seating position (front vs rear) was available from both the telephone survey and crash investigations, agreement was 99% between the driver report and the crash investigator (κ statistic = 0.99).

Survey questions regarding injuries to children were designed to provide responses that were classified by body region and severity based on the Abbreviated Injury Scale (AIS) score,17 and have been previously validated for their ability to distinguish AIS 2 or greater from less severe injuries.18 For this study, children were classified as “seriously injured” if a parent or driver reported a clinically significant injury: any injury with an AIS score of 2 or greater (concussions and more serious brain injuries, all internal organ injuries, spinal cord injuries, and extremity fractures) or facial lacerations. Injuries included all those injuries sustained by the child occupant, not just those injuries that could be attributed to the air bag deployment. Direction of the first impact was determined from the driver report of the plane of the vehicle where the initial impact occurred (front, side, rear, other). Only frontal crashes were included in this analysis.

Deployment of the air bag was determined from survey responses. Air bags were categorized as first-generation (all premodel year 1998 vehicles and 1998 vehicles without redesigned air bags) and second-generation air bag systems (all 1998 vehicles with redesigned systems and all 1999 and newer vehicles). Information on the date a particular vehicle was certified to the new standards was determined from data obtained from NHTSA’s Special Crash Investigation Division, which obtained the information directly from the manufacturers as part of their evaluation of the air bag regulation. The study protocol was reviewed and approved by the Institutional review boards of both The Children’s Hospital of Philadelphia and The University of Pennsylvania School of Medicine.

Data Analysis

Analyses assessing risk of injury were limited to frontal impact crashes with a child occupant in the right front seat who was exposed to a deployed passenger air bag. Because very few children in child restraints or booster seats or younger than 3 years were exposed to a passenger air bag, we restricted the study sample to seat belt–restrained children between 3 and 15 years. The risk of serious nonfatal injuries in frontal crashes among belted children seated in the right front seat of vehicles in which second-generation passenger air bags deployed was compared with that of belted children seated in the right front seat of vehicles in which first-generation passenger air bags deployed.

Logistic regression modeling was used to compute the odds ratio (OR) of injury for those exposed to deployed first-generation air bags vs second-generation air bags, both unadjusted and adjusted for several potential confounders including child age modeled as a 3-level covariate (3-8 years, 9-12 years, 13-15 years linear term), crash severity (intrusion or no intrusion), and vehicle type (passenger car, sport utility vehicle [SUV], minivan, pickup truck, or cargo van).

Because sampling was based on the likelihood of an injury, subjects least likely to be injured were underrepresented in the study sample in a manner potentially associated with the predictors of interest.19 To account for this potential bias, sampling weights were used equal to the inverse of the probability of selection. To adjust inference to account for these sampling weights, as well as the stratification of subjects by medical treatment and clustering of subjects by vehicle, robust χ² tests of association and Taylor series linearization estimates of the logistic regression parameter variances were calculated using SASSCSharp: Software for the Statistical Analysis of Correlated Data, Version 8.0 (Research Triangle Institute, Research Triangle Park, NC). Results of logistic regression modeling were expressed as unadjusted and adjusted ORs with corresponding 95% confidence intervals (CIs).

Results

Complete interview data were obtained on 1148 (unweighted n) seat belt–restrained, right front-seat-children ages 3 through 15 years exposed to a deploying passenger air bag in a frontal impact crash, representing 1781 (weighted n) child passengers in the study population. One thousand thirty-one children were exposed to a first-generation passenger air bag, and 750 were exposed to a second-generation passenger air bag. Characteristics of the study sample are listed in Table 1. Serious injuries (AIS score ≥ 2 plus facial lacerations) were reported in 210 sampled children representing an estimated 228 children or 12.8% of the population (14.9% in the first-generation group vs 9.9% in the second-generation group). After adjusting for child age, vehicle type, and crash severity, children exposed to second-generation systems sustained fewer serious injuries than those exposed to first-generation passenger air bags (adjusted OR, 0.59; 95% CI, 0.36-0.97) (Table 2). There were fewer injuries to all body regions except the abdomen in the second-
generation group, although none of the body region–specific results achieved statistical significance. There were no fatalities in either group.

## COMMENT

This study provides the first field assessment of the effect of the regulatory changes to air bags implemented in the late 1990s on restrained child passengers. Data suggest that the objective of this change in policy, the reduction of injuries to child occupants, is being met by these new systems in frontal crashes with air bag deployment.

Our previous work reported that children exposed to a deploying passenger air bag were at an 87% increased risk of serious injury compared with children in similar crashes who were not exposed to a passenger air bag.8 That study, however, combined vehicles of model year 1990 to 2002, irrespective of the changes in regulation that occurred with model year 1998. The current analyses extend our prior findings and, to our knowledge, provide the first field assessment of the recent substantial air bag regulatory changes.

We found that restrained children ages 3 through 15 seated in the right front seat exposed to a deployed second-generation air bag experience a 41% reduction in the odds of serious injury, after adjusting for differences in child age, vehicle type, and crash severity between the 2 air bag types. These data also highlighted nonsignificant trends of reduction in injuries to the head, face, and lower extremities. This is consistent with previous laboratory data on second-generation air bag designs, which predicted a reduction compared with older designs in head injury risk for occupants closest to the air bag during deployment.20 Poor seat belt and vehicle seat fit in young children often lead to close occupant proximity to the air bag during deployment.

Despite the risk reduction to restrained children exposed to a deployed second-generation air bag in this study, clinicians, educators, and policymakers should maintain the current recommendation to place children younger than 13 years in the rear rows in an age-appropriate restraint. First-generation air bags will remain in the vehicle fleet for many years and the development of educational messages for consumers that distinguish between the 2 designs is complex. Clinicians can continue to play an important role through anticipatory guidance regarding appropriate seating position for children in second-generation air bag–equipped vehicles. Future research should be conducted that explicitly compares the risk of injury to children seated in the right front seat in vehicles equipped with newer passenger air bags to those seated in the rear seat before changes to current seating recommendations are considered.

Air bag designs continue to undergo significant redesigns in an effort to optimize their effectiveness in serious crashes while minimizing their risk of adverse injuries in more minor crashes. In 2001, additional revisions were made to the federal regulation covering air bag performance now requiring the testing of air bag systems for all sized occupants, including children. The field data presented in this article provide a suitable baseline to which future air bag designs can be compared.

Our study sample represents the entire spectrum of crashes reported to an insurance company including property damage only, as well as bodily injury crashes. While our sample included a significant number of vehicles with intrusion into the occupant compartment, we likely do not have a representative sample of the most severe crashes. The NHTSA’s Special Crash Investigation Division monitors fatal child injuries associated with air bag deployments and have documented a reduction in fatalities with second-generation air bags.15 This result is likely attributed to a combination of technology change and increased rear seating. Future work should monitor the safety provided to child occupants by newer-generation air bags in the most severe crashes.

Data for this study were obtained via telephone interview primarily with the driver and/or parent of the child and were, therefore, subject to potential misclassification. Ongoing comparison of driver-reported child restraint use and seating position to evidence from crash investigations has demonstrated a high degree of agreement. In addition, our results on age-specific restraint use and seating position are similar to those of other recently reported population-based studies of child occupants.4,21 It is possible that some of those reported to be restrained by a seat belt were actually unrestrained, thus resulting in a

<table>
<thead>
<tr>
<th>Variable</th>
<th>First (n = 1031)</th>
<th>Second (n = 750)</th>
<th>Crude OR (95% CI)</th>
<th>Adjusted OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>136 (154) [14.9]</td>
<td>74 (74) [9.9]</td>
<td>0.62 (0.37-1.04)</td>
<td>0.59 (0.36-0.97)</td>
</tr>
<tr>
<td>Head</td>
<td>64 (79) [7.7]</td>
<td>35 (35) [4.7]</td>
<td>0.59 (0.32-1.09)</td>
<td>0.61 (0.34-1.08)</td>
</tr>
<tr>
<td>Face</td>
<td>30 (30) [2.9]</td>
<td>14 (14) [1.9]</td>
<td>0.63 (0.30-1.32)</td>
<td>0.60 (0.28-1.28)</td>
</tr>
<tr>
<td>Chest</td>
<td>6 (6) [0.6]</td>
<td>1 (1) [0.1]</td>
<td>0.23 (0.03-1.36)</td>
<td>0.23 (0.03-1.73)</td>
</tr>
<tr>
<td>Abdomen</td>
<td>3 (3) [0.3]</td>
<td>6 (6) [0.8]</td>
<td>2.76 (0.66-11.60)</td>
<td>2.50 (0.66-9.48)</td>
</tr>
<tr>
<td>Neck</td>
<td>4 (4) [0.4]</td>
<td>2 (2) [0.3]</td>
<td>0.69 (0.12-3.90)</td>
<td>0.68 (0.09-4.89)</td>
</tr>
<tr>
<td>Upper extremity</td>
<td>38 (41) [4.0]</td>
<td>25 (25) [3.3]</td>
<td>0.83 (0.44-1.59)</td>
<td>0.75 (0.39-1.44)</td>
</tr>
<tr>
<td>Lower extremity</td>
<td>13 (13) [1.3]</td>
<td>4 (4) [0.5]</td>
<td>0.42 (0.13-1.37)</td>
<td>0.42 (0.12-1.42)</td>
</tr>
</tbody>
</table>

*Adjusted for vehicle type (sports utility vehicle, passenger car, minivan, pickup truck, cargo van), child age, and crash severity (intrusion or no intrusion).
form of selection bias in that unrestrained children would have been incorrectly included in the study sample. There is no evidence that this misreporting would vary by generation of air bag; therefore, it is difficult to estimate the potential effect of this misclassification on our results. Further, our estimate of crash severity, driver report of intrusion, is a gross proxy of that measure. More direct measures such as change in velocity were unable to be determined via telephone survey and, therefore, are unable to be used in these analyses. The effect of this potential source of measurement error, a common limitation of many crash studies, may affect our results in an unpredictable manner. It is unlikely that errors in reporting would vary between drivers of vehicles with second-generation air bags and those with first-generation air bags, thus the effect of any errors on the results of this study of seat belt restrained children only would be limited.

Lastly, these analyses were conducted on a belted population in crashes where the air bag deployed and cannot define the net hazard to children in vehicles equipped with second-generation air bags. Studies incorporating unrestrained child occupants, nondeployment crashes and nonfrontal crashes would be necessary to conclusively assess the performance on the new designs. Future work using the Partners for Child Passenger Safety database will be used to address this question.

Surveillance data of the nature presented in this study are crucial for identifying the magnitude of the risk of injury to children from seated in front of deploying passenger air bags. While the pattern of injuries noted in this study among children exposed to passenger air bags is consistent with injuries caused by interaction with air bags sustained by children who contact an air bag during a crash, this study, based on survey data, cannot not establish conclusively this causation for the subjects’ injuries. Improvements seen in the vehicles with the newer air bag designs may possibly be due to other crash-worthiness improvements in the vehicle rather than the design changes in the air bag alone. Future work will use crash investigation methods to ascertain how often the air bag in the source of the injury and to elucidate the specific mechanisms by which children are injured in these crashes.

To our knowledge, this study provides the first evidence that second-generation air bag designs provide reduced injury risk over the first-generation systems for restrained child passengers in the front seat exposed to a deployed air bag. These results offer assurance to policymakers and restraint designers regarding the effect of their changes in the late 1990s. Owing to a diversity of crash conditions and air bag designs in the current fleet, physicians offering anticipatory guidance should continue with current recommendations for children to sit age-appropriately restrained in the rear seat. Consistent maintenance of this important message is critical as consumers may misinterpret the improvements in air bag design as permission to place children in the front seat.

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REFERENCES


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