



Original Contribution

Association of First- and Second-Generation Air Bags with Front Occupant Death in Car Crashes: A Matched Cohort Study

Carin M. Olson^{1,2}, Peter Cummings^{2,3}, and Frederick P. Rivara^{2,3,4}

¹ Department of Medicine, School of Medicine, University of Washington, Seattle, WA.

² Department of Epidemiology, School of Public Health and Community Medicine, University of Washington, Seattle, WA.

³ Harborview Injury Prevention and Research Center, University of Washington, Seattle, WA.

⁴ Department of Pediatrics, School of Medicine, University of Washington, Seattle, WA.

Received for publication October 4, 2005; accepted for publication January 23, 2006.

First-generation air bags entail a decreased risk of death for most front seat occupants in car crashes but an increased risk for children. Second-generation air bags were developed to reduce the risks for children, despite the possibility of decreasing protection for others. Using a matched cohort design, the authors estimated risk ratios for death for use of each generation of air bag versus no air bag, adjusted for seat position, restraint use, sex, age, and all vehicle and crash characteristics, among 128,208 automobile occupants involved in fatal crashes on US roadways during 1990–2002. The authors then compared adjusted risk ratios (aRRs) between the two generations of air bags. Among front seat occupants, the aRR for death with a first-generation air bag was 0.90 (95% confidence interval (CI): 0.86, 0.94); the aRR with a second-generation air bag was 0.89 (95% CI: 0.79, 1.00) ($p = 0.83$ for comparison of aRRs). Among children under age 6 years, the aRR with a first-generation air bag was 1.66 (95% CI: 1.20, 2.30), while the aRR with a second-generation air bag was 1.10 (95% CI: 0.63, 1.93) ($p = 0.20$ for comparison of aRRs). The differences in aRRs between first- and second-generation air bags among other subgroups were small and not statistically significant.

accidents; traffic; air bags; automobiles; motor vehicles; protective devices

Abbreviations: CI, confidence interval; FARS, Fatality Analysis Reporting System.

Front air bags reduce injury and death for most drivers and right front seat passengers in vehicle crashes (1). First-generation air bags were designed to protect an unbelted adult male at the 50th percentile of body height and weight in a severe frontal crash (2). To meet this requirement, first-generation air bags were designed to deploy within 0.05 seconds at 140–200 miles per hour (224–320 km/hour) (3). These first-generation air bags have been lethal for children and small adults in some crashes (4, 5).

Second-generation air bags were developed to mitigate this problem; most passenger vehicles of model year 1998 and virtually all passenger vehicles of later model years have second-generation air bags (5, 6). Second-generation air bags

include advanced air bags and depowered air bags. Advanced air bags may have any of several features, including different deployment thresholds or forces depending on crash severity or on the occupant's weight, position, or use of restraints (2, 7–9). A few manufacturers introduced advanced air bags in model year 2000 vehicles. Depowered air bags inflate 20–35 percent less aggressively than first-generation air bags and were permitted in passenger vehicles by model year 1998 (6). Concern has been expressed that large unrestrained occupants propelled at high force might overwhelm such air bags (6, 10, 11). Thus, depowered air bags may represent a tradeoff between decreasing the risk of death for some occupants and increasing the risk for others, such as unrestrained adults.

Correspondence to Dr. Carin M. Olson, Box 356123, Division of Emergency Medicine, University of Washington Medical Center, Seattle, WA 98195 (e-mail: colson@u.washington.edu).

In this study, we estimated risk ratios for death associated with the presence of a first-generation air bag versus no air bag and the presence of a second-generation air bag versus no air bag for front seat occupants in a car crash. We investigated how these associations varied according to occupant's seat position (driver's seat or right front passenger seat), restraint use, sex, and age and the direction of impact. We then compared estimated risk ratios between the two generations of air bags. We used a matched cohort design, which compares occupants in the same vehicle, thereby controlling for all measured and unmeasured characteristics of the vehicle and crash (12–15).

MATERIALS AND METHODS

Study sample

We used data from the Fatality Analysis Reporting System (FARS), a publicly available data set maintained by the National Highway Traffic Safety Administration (16). This data set includes information about all motor vehicle crashes occurring on public roadways in the United States in which at least one person dies within 30 days. Information for FARS is obtained from many sources, including police accident reports, state vehicle registration files, state driver licensing files, state highway department data, vital statistics, death certificates, coroner/medical examiner reports, hospital medical records, and emergency medical service reports (16). We obtained additional data from the Vindicator software program (Highway Loss Data Institute, Arlington, Virginia), which contains information provided by manufacturers on vehicle characteristics according to vehicle identification number. The data sets were linked through the partial vehicle identification number provided by FARS. This study was certified as being exempt from review by the University of Washington's human subjects review board.

Subjects were occupants of passenger cars (including convertibles) of model years 1987–2003 that crashed during the period 1990–2002. Subjects in cars that crashed during a year and in a state missing more than 25 percent of data on restraint use were excluded. Occupants of pickup trucks, large trucks, sport utility vehicles, minivans, vans, and buses were excluded. Cars had to have two, three, or four occupants (including a driver) in the left front (driver's), right front, left rear, or right rear seats, at least one of whom died; cars with occupants in middle seats or with two occupants in the same seat were excluded. Subjects who died from events other than crashes (e.g., fires, explosions, immersions, gas inhalations, or falls from the car) were excluded. A total of 151,297 occupants of 62,333 cars met these criteria (figure 1).

Outcome and exposure variables

The study outcome was occupant death within 30 days of the crash. The exposure of interest was having a functional front air bag present, whether or not it deployed. Air bag presence was based primarily on Vindicator data. However, Vindicator data on air bag presence were missing for 1,012 (0.7 percent) of 151,297 occupants. For them, we assumed

that front seat occupants in cars of model year 1998 or newer had an air bag present (3, 17); for those in older-model cars, we used FARS data on air bag presence. We further classified air bags as second-generation on the basis of the vehicle's model year being 1998 or newer (5, 6). Model year was based on Vindicator data unless it was missing. In that case, FARS data were substituted for 2,396 (1.6 percent) of the 151,297 occupants in 978 (1.6 percent) of the 62,333 cars. Finally, if the FARS database listed air bags as being "off," "not replaced," or "disabled," we assumed this information to be correct. Thus, we excluded the 76 (0.05 percent) occupants in the 30 (0.05 percent) cars with such air bag information (figure 1).

Missing data

Among the remaining 151,221 occupants of 62,303 cars, 219 (0.1 percent) had missing data on death; 1,183 (0.8 percent) had missing data on air bags; 12,382 (8.2 percent) had missing data on restraints; 309 (0.2 percent) had missing data on sex; and 1,135 (0.8 percent) had missing data on age. Some occupants had missing data on more than one characteristic; 136,751 (90.4 percent) had no missing data on any characteristic. However, if any occupant had missing data on any of these characteristics, we excluded all of the occupants in the car. The final study sample included 128,208 occupants of 53,249 cars (figure 1). We compared the known characteristics of occupants who were excluded with the characteristics of occupants who were included and found them to be similar: The proportions of excluded and included occupants with an air bag were 28.6 percent and 29.6 percent, respectively; the proportions of those who died were 49.1 percent and 51.4 percent; the proportions of those who were restrained were 56.8 percent and 55.0 percent; the proportions of those who were male were 57.8 percent and 54.5 percent; and the median ages were 25 years and 27 years.

Statistical methods

We used a matched cohort design. Matching on a characteristic (and accounting for the matching in the analysis) removes any association between that characteristic and the exposure, eliminating potential confounding (14, 15). By matching occupants within a vehicle in a crash, any association between vehicle or crash characteristics and the exposure is eliminated. In this way, the design controls for all characteristics of the vehicle as well as the crash, including vehicle age, speed, size, intrusion due to the crash, and direction of impact (12, 13). We assigned a unique vehicle number, derived from the data year, state code, crash number, and vehicle number within the crash, to each occupant of a car. We then used a conditional fixed-effects Poisson regression model, matching on the sets defined by the unique vehicle number. Matching allows estimates of interaction between the exposure and the characteristics on which subjects are matched. Thus, we were able to explore whether the effect of air bags varied according to characteristics of the vehicle or the crash, such as the direction of impact. In matched analyses, matched groups that are discordant for an exposure contribute to the estimate of the

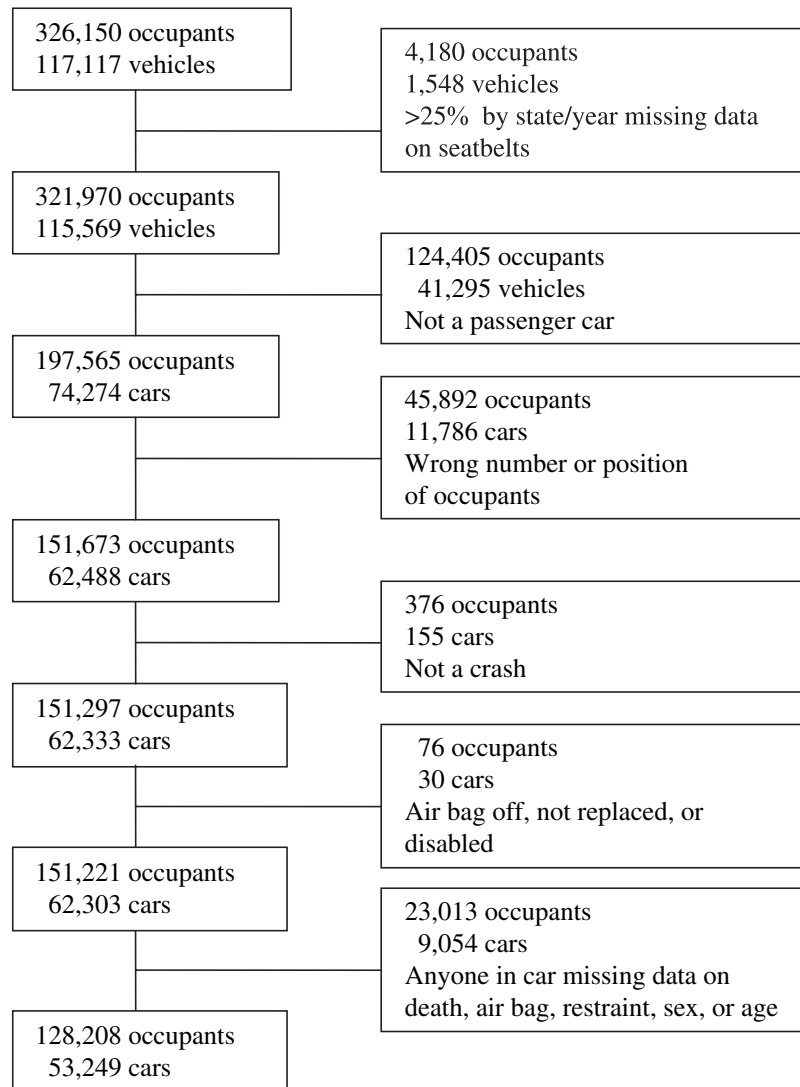


FIGURE 1. Derivation of a data set on occupants of passenger cars in which at least one person died within 30 days of a crash occurring on US roadways during 1990–2002.

effect of that exposure. In our study, occupants within each car who were discordant on air bag status contributed to the estimate of the effect of air bags; occupant discordance on other characteristics allowed adjustment for occupant characteristics and contributed to the estimates of how air bag effects varied by occupant characteristics. For estimation of associations, the matched cohort design requires information only from cars in which at least one occupant died. Nevertheless, the estimated associations apply to occupants of all cars with two, three, or four occupants that crashed, even if no one died (13).

We estimated risk ratios and 95 percent confidence intervals for an occupant with an air bag of each generation versus a similar occupant without an air bag by comparing occupants within the same vehicle (12, 13). All risk ratios were adjusted for seat position (driver's, right front passen-

ger's, or rear), use of restraints (yes or no), sex, and age (using quadratic splines with knots at 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, and 90 years) (18). Occupants were classified as restrained if FARS listed them as using a lap, shoulder, or three-point seat belt (manual or automatic) or a child safety seat. For crashes in which at least one front occupant dies, restraint use reported by police agrees substantially (19) ($\kappa = 0.79$) with restraint use reported by trained investigators (20). By using an analysis matched on vehicle, we also adjusted our risk ratio estimates for all vehicle and crash characteristics (12–15).

We estimated adjusted risk ratios for death for each air bag generation among subgroups defined by occupant characteristics (seat position, sex, restraint use, and age) and crash characteristics (frontal or nonfrontal direction of impact). To generate unbiased estimates for the association of

air bags with death for children in the right front passenger's seat, we needed children in other seat positions for comparison; then we could adjust for children's ages and include interactions between children's ages and air bags. Therefore, we included rear seat occupants, since few drivers were children. However, this introduced other sources of potential confounding (12). Estimates for the effect of restraints vary between front seats and rear seats (17, 21), so we included an interaction term for the interaction between restraints and sitting in the rear seat. Estimates for the effect of seat position on the risk of death vary with age (17, 21), so we included interaction terms for the interaction between seat position and age. For this adjustment term, we modeled age as linear splines with knots at 6, 13, and 50 years. Although we adjusted for seat position, using a single term for the rear seat would have confounded the effects of air bags with the effects of sitting in the rear seat, because there were no air bags in rear seats. Therefore, we included three terms for the rear seat: one for cars with no air bag, one for cars with only a driver's air bag, and one for cars with dual air bags.

We defined frontal crashes as those in which the principal impact on the car was between 11:00 and 1:00 (with 12:00 being the center front). For estimates of effect by frontal or nonfrontal impact, we also included interaction terms for the interaction between seat position and direction of impact. However, we did not include those terms in other models, since they had little effect on other estimates. Because crashes of this severity may not be purely frontal or non-frontal and because air bags are present regardless of the direction of impact, most of our adjusted risk ratio estimates were for crashes with any direction of impact.

We compared adjusted risk ratio estimates for first-generation air bags with adjusted estimates for second-generation air bags. To test whether adjusted risk ratio estimates by air bag generation varied between subgroups, we used the likelihood ratio test for heterogeneity (22). To compare second-generation air bags with first-generation air bags within subgroups, we used the ratio of their risk ratios (23). Comparisons were considered statistically significant at a two-sided α of 0.05. All analyses used Stata 8.2 (Stata Corporation, College Station, Texas).

RESULTS

Restraint use was greatest among occupants with a second-generation air bag and least among those with no air bag. The smallest proportions of right front passengers in the youngest age groups were among those with a second-generation air bag; the greatest proportions were among those with no air bag. Right front passengers (median age, 29 years) were older than rear passengers (median age, 18 years). Occupants with a first- or second-generation air bag were less likely to be involved in a fatal crash with frontal impact than were occupants with no air bag (table 1).

Among all front seat occupants, the adjusted risk ratio for death in any crash with a first-generation air bag compared with a similar occupant with no air bag was 0.90 (95 percent confidence interval (CI): 0.86, 0.94); the adjusted risk ratio for a front seat occupant with a second-generation air bag

TABLE 1. Characteristics of 128,208 occupants in 53,249 cars in which at least one person died within 30 days of a crash occurring on US roadways during 1990–2002*

	No air bag (n = 29,561)		First-generation air bag (n = 19,103)		Second-generation air bag (n = 4,585)		No air bag (n = 37,462)		First-generation air bag (n = 9,856)		Second-generation air bag (n = 4,433)		Rear passengers (n = 23,208)		All occupants (n = 128,208)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Died	15,313	51.8	9,640	50.5	2,413	52.6	21,936	58.6	5,389	54.7	2,429	54.8	8,717	37.6	65,837	51.4
Restrained	16,891	57.1	11,561	60.5	2,954	64.4	21,016	56.1	5,942	60.3	2,824	63.7	9,303	40.1	70,491	55.0
Male sex	18,318	62.0	12,335	64.6	2,922	63.7	17,298	46.2	4,728	48.0	2,072	46.7	12,247	52.8	69,920	54.5
Age (years)																
0–5	0	0	0	0	0	0	1,012	2.7	164	1.7	46	1.0	3,122	13.5	4,344	3.4
6–12	12	0	3	0	0	0	1,429	3.8	346	3.5	125	2.8	2,655	11.4	4,570	3.4
13–49	20,949	70.9	12,573	65.8	3,054	66.6	23,115	61.7	6,262	63.5	2,782	62.8	13,858	59.7	82,593	64.4
≥50	8,600	29.1	6,527	34.2	1,531	33.4	11,906	31.8	3,084	31.3	1,480	33.4	3,573	15.4	36,701	28.6
Frontal impact†	14,508	49.8	8,154	43.5	1,846	41.0	18,508	49.0	3,982	41.2	1,789	41.1	10,431	45.7	58,768	45.8

* Percentages may not add up to 100 because of rounding.
 † Defined as a principal impact location from 11:00 through 1:00 on the car. Data were available for 126,131 occupants.

TABLE 2. Adjusted* risk ratio for death among front seat occupants with an air bag compared with similar occupants without an air bag, according to air bag generation, among 128,208 occupants in fatal car crashes occurring on US roadways during 1990–2002

	First-generation air bag		Second-generation air bag		<i>p</i> value‡
	aRR†	95% CI†	aRR	95% CI	
All front seat occupants	0.90	0.86, 0.94	0.89	0.79, 1.00	0.83
Seat position					0.92
Driver's	0.91	0.87, 0.96	0.91	0.80, 1.03	
Front passenger's	0.87	0.82, 0.92	0.86	0.76, 0.97	
Sex					0.69
Male	0.93	0.88, 0.98	0.93	0.82, 1.06	
Female	0.86	0.81, 0.91	0.83	0.74, 0.95	
Restraint use					0.71
Restrained	0.87	0.82, 0.91	0.84	0.74, 0.95	
Unrestrained	0.94	0.89, 1.00	0.97	0.84, 1.11	
Age (years)					0.37
0–5	1.66	1.20, 2.30	1.10	0.63, 1.93	
6–12	0.93	0.74, 1.17	0.71	0.48, 1.05	
13–49	0.92	0.87, 0.97	0.93	0.82, 1.05	
≥50	0.86	0.81, 0.92	0.80	0.68, 0.96	
Direction of impact					0.60
Frontal	0.79	0.75, 0.85	0.74	0.62, 0.87	
Nonfrontal	1.00	0.94, 1.06	1.03	0.89, 1.19	

* Adjusted for seat position (driver's, right front passenger's, or rear), restraint use, sex, age (as quadratic splines), and all vehicle and crash characteristics. Includes terms for interaction between restraints and rear seat; seat position and age (as linear splines); rear seat and cars with no air bags; rear seat and cars with only a driver's air bag; and rear seat and cars with dual air bags. Models for frontal and nonfrontal impact also include interaction terms for the interaction between seat position and direction of impact.

† aRR, adjusted risk ratio; CI, confidence interval.

‡ *p* value for likelihood ratio test for heterogeneity of second-generation aRRs compared with first-generation aRRs between subgroups.

compared with a similar occupant with no air bag was 0.89 (95 percent CI: 0.79, 1.00) ($p = 0.83$ for comparison of adjusted risk ratios) (table 2). The adjusted risk ratio for death in any crash with a first-generation air bag compared with the adjusted risk ratio for death with a second-generation air bag did not differ significantly between subgroups by seat position, sex, restraint use, age, or direction of impact (table 2). Among children under age 6 years, the adjusted risk ratio for death in any crash with a first-generation air bag compared with no air bag was 1.66 (95 percent CI: 1.20, 2.30); the adjusted risk ratio with a second-generation air bag was 1.10 (95 percent CI: 0.63, 1.93) ($p = 0.20$ for the comparison of these adjusted risk ratios). There was no large or statistically significant increase in the adjusted risk ratio for death with a second-generation air bag as compared with the adjusted risk ratio for death with a first-generation air bag for any subgroup characterized by combinations of seat position, sex, restraint use, age, and direction of impact (table 3). The adjusted risk ratio for death with an air bag of either generation was decreased only in frontal crashes; it was not

significantly different from 1 in nonfrontal crashes (tables 2 and 3).

DISCUSSION

First-generation air bags were associated with a 10 percent decrease in the risk of death for an average front seat occupant; second-generation air bags were associated with an 11 percent decrease. For most front seat occupants, there was no large or statistically significant difference in the adjusted risk ratio for death with first-generation air bags and the adjusted risk ratio for death with second-generation air bags. However, while first-generation air bags were associated with a statistically significant increase in the risk of death for children under age 6 years (adjusted risk ratio = 1.66, 95 percent CI: 1.20, 2.30), second-generation air bags were not (adjusted risk ratio = 1.10, 95 percent CI: 0.63, 1.93) ($p = 0.20$ for comparison of adjusted risk ratios). There was no large or statistically significant increase between the

TABLE 3. Adjusted* risk ratio (aRR) for death among front seat occupants with an air bag compared with similar occupants without an air bag, according to combinations of characteristics, and ratio of second-generation aRR to first-generation aRR among 128,208 occupants in fatal car crashes occurring on US roadways during 1990–2002

	First-generation air bag		Second-generation air bag		Ratio of aRRs	95% CI†
	aRR	95% CI	aRR	95% CI		
<i>Restrained drivers</i>						
Sex						
Male	0.90	0.85, 0.96	0.89	0.78, 1.02	0.99	0.87, 1.13
Female	0.85	0.80, 0.90	0.81	0.70, 0.94	0.96	0.83, 1.10
Age (years)						
13–49	0.89	0.84, 0.95	0.89	0.77, 1.02	0.99	0.87, 1.14
≥50	0.86	0.80, 0.92	0.79	0.66, 0.94	0.92	0.77, 1.10
Direction of impact						
Frontal	0.77	0.72, 0.83	0.71	0.59, 0.85	0.92	0.77, 1.10
Nonfrontal	0.98	0.91, 1.04	1.00	0.85, 1.18	1.02	0.88, 1.19
<i>Unrestrained drivers</i>						
Sex						
Male	0.97	0.92, 1.04	1.02	0.88, 1.18	1.04	0.90, 1.20
Female	0.92	0.85, 0.98	0.92	0.79, 1.08	1.01	0.86, 1.18
Age (years)						
13–49	0.97	0.91, 1.03	1.01	0.87, 1.18	1.04	0.90, 1.21
≥50	0.93	0.86, 1.01	0.90	0.74, 1.09	0.96	0.79, 1.18
Direction of impact						
Frontal	0.85	0.79, 0.91	0.82	0.68, 0.99	0.97	0.81, 1.17
Nonfrontal	1.07	1.00, 1.15	1.16	0.98, 1.38	1.18	0.91, 1.28
<i>Restrained right front passengers</i>						
Sex						
Male	0.87	0.81, 0.94	0.86	0.74, .99	0.98	0.85, 1.13
Female	0.82	0.77, 0.88	0.78	0.68, 0.90	0.95	0.83, 1.09
Age (years)						
0–5	1.63	1.18, 2.26	1.07	0.61, 1.89	0.66	0.35, 1.24
6–12	0.91	0.72, 1.14	0.68	0.46, 1.01	0.75	0.49, 1.16
13–49	0.84	0.78, 0.91	0.84	0.73, 0.97	1.00	0.87, 1.15
≥50	0.81	0.75, 0.88	0.74	0.62, 0.89	0.92	0.77, 1.10
Direction of impact						
Frontal	0.74	0.68, 0.80	0.66	0.55, 0.80	0.90	0.75, 1.08
Nonfrontal	0.93	0.87, 1.00	0.94	0.80, 1.10	1.01	0.86, 1.17
<i>Unrestrained right front passengers</i>						
Sex						
Male	0.94	0.88, 1.01	0.98	0.84, 1.14	1.04	0.89, 1.20
Female	0.89	0.82, 0.96	0.89	0.76, 1.04	1.00	0.86, 1.17
Age (years)						
0–5	1.77	1.28, 2.46	1.22	0.69, 2.17	0.69	0.36, 1.31
6–12	0.98	0.78, 1.24	0.78	0.52, 1.16	0.79	0.51, 1.23
13–49	0.92	0.85, 0.98	0.96	0.82, 1.11	1.05	0.90, 1.21
≥50	0.88	0.81, 0.96	0.85	0.70, 1.03	0.96	0.79, 1.18
Direction of impact						
Frontal	0.81	0.75, 0.88	0.77	0.64, 0.93	0.95	0.79, 1.15
Nonfrontal	1.02	0.95, 1.11	1.09	0.92, 1.29	1.06	0.90, 1.26

* Adjusted for seat position (driver's, right front passenger's, or rear), restraint use, sex, age (as quadratic splines), and all vehicle and crash characteristics. Includes terms for interaction between restraints and rear seat; seat position and age (as linear splines); rear seat and cars with no air bags; rear seat and cars with only a driver's air bag; and rear seat and cars with dual air bags. Models for frontal and nonfrontal impact also include interaction terms for the interaction between seat position and direction of impact.

† CI, confidence interval.

adjusted risk ratio for death with a second-generation air bag and the adjusted risk ratio for death with a first-generation air bag for any subgroup, including unrestrained adult males, a group some researchers have suggested might receive less protection with a depowered air bag (6, 10, 11). The number of occupants in some subgroups became small as subgroups were finely categorized. Although most estimates showed that air bags were associated with a decreased adjusted risk ratio for death, some confidence intervals included the possibility that air bags were associated with an increased adjusted risk ratio.

Previous studies

To our knowledge, no previous study has estimated the association between risk of death and use of a second-generation air bag versus no air bag. However, some studies have compared the risk of death with a second-generation air bag with the risk with a first-generation air bag. Segui-Gomez and Baker (24) used data from the National Automotive Sampling System–Crashworthiness Data System for drivers involved in frontal crashes, using the car's model year as a surrogate for the type of air bag (as we did in our study). They reported that significantly fewer drivers of model year 1998 and newer vehicles died (2.2 percent) than drivers of model year 1993–1997 vehicles (2.5 percent) (24). However, that study could not distinguish the effects of air bags from other safety improvements in newer cars. In another study, Braver et al. (25) selected FARS data on vehicles that did not change design in any way other than the air bag during 1997–1999. They compared the number of driver deaths in vehicles of model year 1998–1999 with the number expected on the basis of death rates per registered vehicle of model year 1997. For cars in frontal crashes, the unadjusted rate ratio for death in newer vehicles compared with the number expected was 0.89 (95 percent CI: 0.82, 0.97) (25). In yet another study, Arbogast et al. (26) used a sample comprising information about crashes from insurance claims, telephone interviews, and on-site investigations. Among restrained children aged 3–15 years who had been sitting in the front right passenger seat, those in vehicles with second-generation air bags had an adjusted odds ratio for serious injury of 0.59 (95 percent CI: 0.30, 0.97) compared with those with first-generation air bags (26).

Mechanisms

Occupants in the path of a deploying air bag may receive its full force and be injured by it. Women, generally being smaller than men, may sit relatively close to the dashboard or steering column and so be at increased risk of death from deploying air bags (5, 6, 27). Children, too, may often be sitting close to the dashboard, leaning forward, or riding in a rear-facing child seat. These positions may put them in the path of a deploying air bag, causing them to receive its full force (3, 5, 6, 27). Second-generation air bags were designed to hit occupants in their path with less force than first-generation air bags. This may explain the lower adjusted risk ratio for death we found among children under age 6 years with a second-generation air bag compared with a first-generation air bag.

Large occupants, such as adult males, may overpower a deploying air bag (6, 10) and not receive adequate protection during a crash. Similarly, unrestrained occupants may be thrown forward with great force during a crash, not only overpowering the air bag but coming into its path (11, 27, 28). This was the basis for concern that unrestrained occupants, particularly unrestrained adults, might have a higher risk of death with a depowered air bag than with a first-generation air bag (6, 10, 11, 28). We found no large or statistically significant elevated risk of death for males or unrestrained occupants with a second-generation air bag as compared with a first-generation air bag.

Limitations

Generalizability. Our analysis was restricted to passenger cars, and our estimates of association may not apply to other passenger vehicles. Other studies have reported that the effect of air bags varies by vehicle size (27, 29, 30) and body type (24, 25). Since our study design required cars to have at least two occupants, our estimates of association may not apply to cars in which the driver is the only occupant. While the presence of unrestrained rear occupants is associated with increased risk of death for front occupants, that association is not confounded by the presence of an air bag (31); in turn, any association between air bag presence and death would not be confounded by unrestrained rear occupants.

Missing data. We excluded 15.2 percent of potential study occupants and 14.5 percent of potential study cars because someone in the vehicle was missing data on important characteristics. Our estimates may be biased if data were not missing at random.

Possible misclassification. Estimates may also be biased by data misclassification, to which restraint use is particularly susceptible. However, in crashes so severe that someone dies (such as those we analyzed), misclassification of restraint use is not great (20, 32). Second-generation air bags included both depowered air bags and advanced air bags. While FARS data and Vindicator software allowed us to identify a car's make, model, and year and the presence or absence of an air bag, we found no comprehensive way to determine which vehicles had advanced air bags. We used a model year of 1998 or newer as a proxy for having second-generation air bags, and some misclassification was possible. Since few vehicles had advanced air bags during the years of our study (33), our estimates for second-generation air bags were influenced more by depowered air bags than by advanced air bags. If advanced air bags were more protective than depowered air bags, our estimates of the effect of second-generation air bags on death would be closer to zero than the effects of depowered air bags alone.

Other factors. We used the FARS database for information on child restraints. FARS does not distinguish between rear-facing infant seats, forward-facing child seats, and booster seats. Thus, we could not identify the effects of different child restraint devices. For crashes occurring during 1994 and more recently, the presence of a child safety seat and improper use of a child safety seat were coded separately in FARS. We included the 438 occupants associated

with improper use of a child safety seat as being restrained, since the effect of improper use could not be determined.

We could estimate the effects of air bags according to characteristics for which FARS contained data on two or more occupants. To estimate the effect of air bags for children in the right front seat, we needed children in the rear for comparison. We addressed inherent differences in risk of death for these different positions by adjusting for seat position and by including terms for interaction between restraint use and the rear seat, seat position and age, the rear seat and cars with no air bag, the rear seat and cars with only a driver's air bag, and the rear seat and cars with dual air bags. However, our estimates may have been biased if other factors varied systematically with both air bag presence and seat position within vehicles.

FARS began including data on the driver's height and weight in 1998. However, similar data on other occupants were not available for comparison. Therefore, we could not examine potentially relevant occupant characteristics, such as body size.

Strengths

By matching occupants within each vehicle, the matched cohort design controlled for all characteristics of the vehicle and crash (12–15). This addressed the possibility that our estimates were biased by vehicle or crash characteristics that might be associated with the presence of an air bag. For example, cars in which air bags were first introduced often had other safety features, and the people who first bought such cars may have been cautious drivers. Regression analysis allowed us to adjust for characteristics of the occupants within vehicles and to estimate whether the effect of air bags depended on certain characteristics of the occupants, the vehicle, or the crash (12, 13).

We used the FARS data set, which includes crashes in which at least one person died. Such crashes are typically investigated thoroughly (16). This may have increased the accuracy of the data we used. A matched cohort study requires information only on persons who had the study outcome. However, the estimated associations apply to all crashes of cars with two, three, or four occupants, even if no one died (13).

Conclusion

In this analysis, first- and second-generation air bags were associated with similar decreases in the adjusted risk ratio for death for most front seat occupants. However, for children under age 6 years, first-generation air bags were associated with a significantly increased adjusted risk ratio for death, while second-generation air bags were not. Second-generation air bags were not associated with a significantly increased adjusted risk ratio for death for any type of occupant as compared with the adjusted risk ratio for death with first-generation air bags. Consumers, policy-makers, and manufacturers can be assured that the increased safety of second-generation air bags for children was not offset by less protection for older occupants.

ACKNOWLEDGMENTS

This work was supported in part by grant R49 CE000197 from the Centers for Disease Control and Prevention (Atlanta, Georgia).

The authors thank Christopher D. Mack of the Harborview Injury Prevention and Research Center (Seattle, Washington) for preparing the data files for analysis.

The Centers for Disease Control and Prevention had no role in the design or conduct of this study; in the collection, management, analysis, or interpretation of the data; or in the preparation, review, or approval of the manuscript. Dr. Carin M. Olson had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Conflict of interest: none declared.

REFERENCES

1. Air-bag-associated fatal injuries to infants and children riding in front passenger seats—United States. *MMWR Morb Mortal Wkly Rep* 1995;44:845–7.
2. Pacelli L. Asleep at the wheel of auto safety? Recent air bag regulations by the National Highway Traffic Safety Administration. *J Contemp Health Law Policy* 1999;15:739–77.
3. Update: fatal air bag-related injuries to children—United States, 1993–1996. *MMWR Morb Mortal Wkly Rep* 1996; 45:1073–6.
4. National Highway Traffic Safety Administration. Air bag-related injuries. *Ann Emerg Med* 2003;42:285–6.
5. Chidester AB, Roston TA. Air bag crash investigations. (Paper no. 246). In: *Proceedings of the 17th International Technical Conference on Enhanced Safety of Vehicles, Amsterdam 2001, June 4–7, 2001*. Washington, DC: National Highway Traffic Safety Administration, US Department of Transportation, 2001. (DOT publication no. HS 809 220).
6. National Highway Traffic Safety Administration, US Department of Transportation. Federal motor vehicle safety standards; occupant crash protection. 49 CFR Part 571. *Federal Register* 2005;70:28878–88.
7. Graham JD, Goldie SJ, Segui-Gomez M, et al. Reducing risks to children in vehicles with passenger airbags. *Pediatrics* 1998;102:e3. (Electronic article).
8. Insurance Institute for Highway Safety. Q&A: airbags. Arlington, VA: Insurance Institute for Highway Safety, 2004. (<http://www.iihs.org/research/qanda/airbags.html>). (Accessed June 28, 2004).
9. Stewart TC, Girotti MJ, Nikore V, et al. Effect of airbag deployment on head injuries in severe passenger motor vehicle crashes in Ontario, Canada. *J Trauma* 2003;54:266–72.
10. Ferguson SA, Schneider L, Segui-Gomez M, et al. The blue ribbon panel on depowered and advanced airbags—status report on airbag performance. *Annu Proc Assoc Adv Automot Med* 2003;47:79–81.
11. O'Neill B. Airbag test requirements under proposed new rule. Transportation Subcommittee, US House of Representatives Appropriations Committee. Arlington, VA: Insurance Institute for Highway Safety, 2000.
12. Cummings P, McKnight B, Weiss NS. Matched-pair cohort methods in traffic crash research. *Accid Anal Prev* 2003;35: 131–41.
13. Cummings P, McKnight B, Greenland S. Matched cohort methods for injury research. *Epidemiol Rev* 2003;25:43–50.

14. Rothman KJ, Greenland S. *Modern epidemiology*. Philadelphia, PA: Lippincott-Raven, 1998:160–1.
15. Greenland S. Modelling risk ratios from matched cohort data: an estimating equation approach. *Appl Stat* 1994;43:223–32.
16. National Center for Statistics and Analysis, National Highway Traffic Safety Administration. *Fatality Analysis Reporting System (FARS)*. Washington, DC: National Highway Traffic Safety Administration, 2005. (<http://www-nrd.nhtsa.dot.gov/departments/nrd-30/ncsa/FARS.html>). (Accessed May 6, 2005).
17. Braver ER, Whitfield R, Ferguson SA. Seating positions and children's risk of dying in motor vehicle crashes. *Inj Prev* 1998;4:181–7.
18. Greenland S. Dose-response and trend analysis in epidemiology: alternatives to categorical analysis. *Epidemiology* 1995;6:356–65.
19. Koepsell TD, Weiss NS. *Epidemiologic methods: studying the occurrence of illness*. New York, NY: Oxford University Press, 2003:220.
20. Schiff MA, Cummings P. Comparison of reporting of seat belt use by police and crash investigators: variation in agreement by injury severity. *Accid Anal Prev* 2004;36:961–5.
21. Glass RJ, Segui-Gomez M, Graham JD. Child passenger safety: decisions about seating location, airbag exposure, and restraint use. *Risk Anal* 2000;20:521–7.
22. Brookes ST, Whitely E, Egger M, et al. Subgroup analyses in randomized trials: risks of subgroup-specific analyses; power and sample size for the interaction test. *J Clin Epidemiol* 2004;57:229–36.
23. Goodman SN, Berlin JA. The use of predicted confidence intervals when planning experiments and the misuse of power when interpreting results. *Ann Intern Med* 1994;121:200–6.
24. Segui-Gomez M, Baker SP. Changes in injury patterns in frontal crashes: preliminary comparisons of drivers of vehicles model years 1993–1997 to drivers of vehicles 1998–2001. *Annu Proc Assoc Adv Automot Med* 2002;46:1–14.
25. Braver ER, Kyrychenko SY, Ferguson SA. Driver mortality in frontal crashes: comparison of newer and older airbag designs. *Traffic Inj Prev* 2005;6:24–30.
26. Arbogast KB, Durbin DR, Kallan MJ, et al. Injury risk to restrained children exposed to deployed first- and second-generation air bags in frontal crashes. *Arch Pediatr Adolesc Med* 2005;159:342–6.
27. National Highway Traffic Safety Administration, US Department of Transportation. *Fifth/sixth report to Congress—effectiveness of occupant protection systems and their use*. Washington, DC: National Highway Traffic Safety Administration, 2001.
28. Schneider L. Comparison of frontal crash protection for front seat occupants in pre-1998 and 1998 and new model vehicles. *Annu Proc Assoc Adv Automot Med* 2003;47:81–3.
29. Ferguson SA, Lund AK, Greene MA. *Driver fatalities in 1985–1994 air bag cars*. Arlington, VA: Insurance Institute for Highway Safety, 1995:1–9.
30. Zador PL, Ciccone MA. Automobile driver fatalities in frontal impacts: air bags compared with manual belts. *Am J Public Health* 1993;83:661–6.
31. Cummings P, Rivara FP. Car occupant death according to the restraint use of other occupants: a matched cohort study. *JAMA* 2004;291:343–9.
32. Cummings P. Association of seat belt use with death: a comparison of estimates based on data from police and estimates based on data from trained crash investigators. *Inj Prev* 2002;8:338–41.
33. Kindelberger JC, Chidester AB, Ferguson E. *Air bag crash investigations*. (NHTSA paper no. 299). Washington, DC: National Highway Traffic Safety Administration, 2003. (<http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv18/CD/Files/18ESV-000299.pdf>). (Accessed August 11, 2005).