

# Reducing Risks to Children in Vehicles With Passenger Airbags

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**ABSTRACT.** This review examines the risk that passenger airbags pose for children and discusses behavioral and technologic measures aimed at protecting children from airbag deployment. Although airbags reduce fatal crash injuries among adult drivers and passengers, this safety technology increases mortality risk among children younger than age 12. The magnitude of the risk is multiplied when children are unrestrained or restrained improperly. As new vehicles are resold to buyers who tend to be less safety-conscious than new car owners, the number of children endangered by passenger airbag deployment may increase.

For vehicles already in the fleet, strong measures are required to secure children in the rear seat and increase the proper use of appropriate restraint systems through police enforcement of laws. One promising strategy is to amend child passenger safety laws to require that parents secure children in the rear seats. For future vehicles, a mandatory performance standard should be adopted that suppresses airbag deployment automatically if a child is located in the front passenger seat. Other promising improvements in airbag design also are discussed. Major changes in passenger airbag design must be evaluated in a broad analytical framework that considers the welfare of adults as well as children. *Pediatrics* 1998;102(1). URL: <http://www.pediatrics.org/cgi/content/full/102/1/e3>; airbags, risk-benefit ratios, injury, restraint systems.

ABBREVIATION. NHTSA, National Highway Traffic Safety Administration.

Manufacturers of passenger cars and light trucks selling in the US market are now required to equip new vehicles with a passenger-side airbag as well as a driver-side airbag. This regulatory impetus has caused >60 million vehicles to be equipped with airbags in the United States from 1989 to 1997, half of them with driver-only airbag systems, the other half with dual systems that include a passenger-side airbag.<sup>1</sup> Even without legal requirements, the driver-side airbag has become widely available throughout the developed world. The passenger-side airbag also is beginning to penetrate new vehicle markets in Europe, Australia, and parts of Asia, but it is much less common.<sup>2,3</sup>

Real-world crash data indicate that US airbag de-

signs are reducing driver and adult passenger fatalities by ~10% to 15%, averaged over all crash types, with maximum effectiveness in frontal crashes.<sup>4,5</sup> When all vehicles in the United States are equipped with dual frontal airbag systems, ~3000 lives are projected to be saved annually among adults—~2300 drivers and 700 adult passengers.<sup>6,7</sup> Although the observed rate of airbag effectiveness is about two-thirds less than it was predicted 10 to 20 years ago,<sup>8-10</sup> driver airbag technology appears to have cost-effectiveness ratios that are comparable to many well-accepted medical and public health interventions. The cost-effectiveness ratio for the passenger-side airbag is closer to the high end of the range of acceptable investments.<sup>11</sup>

Hidden in the overall cost-effectiveness figures are serious adverse consequences for children who are now less safe because of passenger-side airbags. Children are the only subgroup of the population that is known to have experienced a net increase in risk of death attributable to the installation of airbags.<sup>4,12,13</sup> In this article, the risks of airbags to children are assessed and various strategies for reducing the risk to children are reviewed. We focus on children younger than age 12 because crash data (which lack information on the weight or height of the injured children) indicate that they are the children most at risk.<sup>4</sup>

## RISKS TO CHILDREN

Children are being killed and seriously injured by passenger-side airbags in relatively low-speed crashes that typically would not have proven fatal.<sup>14-16</sup> As of late 1997, the National Highway Traffic Safety Administration (NHTSA) had identified 52 passengers who, in the judgment of postcrash investigators, were fatally injured by passenger-side airbags. Forty-nine of these passengers were children younger than age 12. Twelve were infants in rear-facing child restraints; 34 were unrestrained; and 3 were restrained by at least the lap belt. Another 20 incidents are now under investigation, and many of these are likely to be classified as airbag-induced fatalities.<sup>6</sup> Postcrash investigations have not determined how many additional children have been harmed (but not killed) by airbags in higher-speed crashes.

Two scenarios appear to account for the childhood fatalities caused by deployment of passenger-side airbags.<sup>1</sup> First, when infants are seated in rear-facing infant restraints in the front seat, the head and neck

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are in close proximity to the airbag housing; fatal head and neck injuries result from the force of the rapidly inflating airbag against the child safety seat. Second, unrestrained or improperly restrained children who are forward-facing may be seated too close to the airbag housing or may be thrown forward during precrash braking, causing the head and neck to be placed in the deployment zone of the rapidly inflating bag. In addition, several restrained children have been killed or seriously injured by passenger-side airbags; the circumstances surrounding some of these incidents are uncertain, but the mechanisms of death are the same.<sup>14</sup>

Airbags may have saved the lives of some restrained children. If such cases exist, they will not be identifiable on a case-by-case basis because the protective effects of the safety belt or child restraint are difficult to distinguish from the protective effects of the airbag. Yet it is feasible to determine statistically whether the net impact of passenger-side airbags on child mortality—lives saved versus lives lost—has been positive or negative.<sup>4,17</sup>

In Tables 1 and 2, we present updated estimates of the net mortality risk to children from passenger-side airbags using US crash fatality data for 1990–1996 and the analytic method of double-paired comparison.<sup>18</sup> The ratio of child passenger deaths to driver deaths is computed for those fatal crashes in which both a child and driver were occupying the front seat. The ratio for vehicles with passenger-side airbags is compared with the ratio for vehicles with driver-only airbags and to vehicles with manual belts only. If passenger-side airbags save more lives of children than they kill, then the ratios for vehicles with passenger-side airbags should be less than the ratios for vehicles without passenger-side airbags. The presence of a passenger-side airbag in a vehicle is associated with a net 63% increase in child fatality risk. Furthermore, the data suggest that passenger-side airbags are not causing net reductions in fatality risk among children who were restrained in a child safety seat or safety belt when the crash occurred. Overall, any lives of children being saved by passenger-side airbags are being overwhelmed by the sub-

**TABLE 1.** Estimates of the Impact of the Passenger Airbag on Childhood Mortality (Age 0–12); Fatal Accident Reporting System 1990–1997 Model Year Vehicles, 1989–1996 Calendar Years

Controls	Child Deaths	Driver Deaths	Ratio	Risk of Dual Relative to Controls
Crashes of all directions				
Dual bags	102	77	1.32	—
Driver-only airbags	151	186	0.81	1.63*
Manual belts only	299	343	0.87	1.52*
Frontal crashes only				
Dual bags	71	42	1.69	—
Driver-only airbags	95	103	0.92	1.84*
Manual belts only	203	211	0.96	1.76**

\*  $P < .05$ ; \*\*  $P < .01$ .

Note: The unrestrained category includes those children known to be unrestrained or restrained improperly. Data obtained from the Fatal Accident Reporting System, NHTSA. Includes only those fatal crashes where both a driver and child passenger were located in the front seat.

**TABLE 2.** Child/Driver Death Ratios by Child Restraint Use—All Crashes

Controls	Unrestrained	Risk of Dual Relative to Control	Restrained	Risk of Dual Relative to Controls
Dual bags	2.30	—	0.82	—
Driver-only airbags	1.09	2.11*	0.67	1.22
Manual belts only	0.94	2.45**	0.79	1.04

\*  $P < .05$ ; \*\*  $P < .01$ .

Note: The unrestrained category includes those children known to be unrestrained or restrained improperly. Data obtained from the Fatal Accident Reporting System, NHTSA. Includes only those fatal crashes where both a driver and child passenger were located in the front seat.

stantial number of children killed by passenger-side airbags.

A recent regulatory analysis estimated that unless additional countermeasures are implemented, an additional 100 children younger than age 12 will be killed each year in the United States when all vehicles are equipped with passenger-side airbags.<sup>17</sup> This estimate may be too optimistic because more young children will be placed at risk as current vehicles with passenger-side airbags are resold over the next 20 years to less safety-conscious buyers who may have larger families and may place improperly restrained children in the front seats more frequently.

It has been suggested that among those airbag designs now in use, some passenger-side airbags are less safe than others.<sup>19,20</sup> Insufficient real-world data are available to evaluate that assertion, in part because information on the design parameters of airbag systems is not available publicly. The federal government is considering a new policy that will require manufacturers to furnish selected information about airbag designs to the government.

Overall, the benefit-risk ratio for passenger-side airbags is far worse than it is for driver-side airbags. For each child that has been fatally injured by airbags, the lives of 5 to 10 adult passengers have been saved.<sup>7,17</sup> The ratio of lives saved to lives lost for the driver-side airbag is ~75 to 1.<sup>7</sup> If life expectancy (or years of life) is used as the metric for evaluation (rather than lives saved), the benefit-to-risk ratio is no better than 5 to 1 for the passenger-side airbag.<sup>11</sup> We are aware of no mandatory measure in the history of preventive medicine that has been preserved with a benefit-risk ratio so close to 1 to 1, although the ratio for the passenger-side airbag may improve in the future, for reasons discussed below.

Even if the current ratio of benefit to risk were judged to be acceptable on grounds of economic efficiency, there are ethical problems with allowing or mandating children to face fatal consequences to make adults safer. A reduction in risk also may be necessary to sustain public confidence in airbag technology, the airbag regulation, and the public and private institutions that have brought this device to the marketplace.<sup>21–23</sup>

## STRATEGIES TO REDUCE RISK

The objective of any strategy should be to eliminate, or at least to reduce significantly, the risks to children through measures that do not compromise airbag effectiveness for adults. Below, we discuss five strategies that should have broad applicability throughout the world.

### Children Should Be Restrained Properly

Tremendous resources have been devoted to increasing child restraint and belt use over the past 20 years.<sup>24</sup> Rates of child restraint use in the United States have risen from 20% in 1980 to 79% in 1996.<sup>25,26</sup> The most recent data found that 93% of infants, 75% of toddlers, and 65% of subteens were restrained,<sup>26</sup> although this study did not measure the extent of misuse. Currently, approximately half of the deaths among infants and toddlers in the United States annually occur in crashes in which children are not restrained in child restraint devices.<sup>24</sup> Children from less educated, low-income, and minority families are less likely than other children to use child restraints and safety belts.<sup>27</sup>

Misuse of child restraint devices is a widespread problem, observed in as many as 80% of the children restrained in child safety seats.<sup>28–32</sup> Proper restraint refers here to the use of age- and weight-adequate restraint systems, the adequate restraint of the child to the system, and the adequate restraint of the child seat or booster to the vehicle seat.

Proper restraint use reduces a child's chances of being killed or seriously injured in a motor vehicle crash, even in vehicles without passenger-side airbags. Even accounting for misuse, the magnitude of the protective effect is substantial, probably greater than the 45% reduction in fatality risk attributed to adult use of lap and shoulder belts.<sup>24,33–35</sup> Proper child restraint use also dramatically reduces a child's risk of being killed or seriously injured by a passenger-side airbag (except if the child is in a rear-facing child seat). A properly restrained forward-facing child, positioned with the seat back as far as possible, has a minimal risk of death or serious injury from deployment of passenger-side airbags.<sup>1</sup>

The most promising strategy for achieving higher levels of proper restraint use is to replace secondary with primary enforcement laws, thereby permitting police officers to apprehend and fine drivers who allows occupants to ride in their vehicle unrestrained. Unrestrained drivers are particularly likely to allow their children to ride unrestrained in the front seat.<sup>36,37</sup> Thus, efforts to increase adult restraint use, which remains <65% in the United States,<sup>26</sup> may induce increased child restraint use. Controlled studies have demonstrated that highly visible educational and enforcement efforts can increase the rate of adult and child restraint use in a community.<sup>38–40</sup> In the future, more uniform and improved designs of child restraint systems (eg, uniform seat mountings and top tether requirements) should reduce misuse and facilitate compliance with child passenger safety laws.

Although efforts to increase the rate of proper child restraint should be a major priority, this strat-

egy alone is unlikely to be completely successful in protecting children from passenger-side airbags. Additional increases in child restraint use will come slowly. The residual unrestrained child population in the United States will be difficult to reach without substantial and well-targeted resources. Moreover, the widespread problem of misuse is more complicated to solve through education and is difficult for police to detect. The fact that several restrained children have been killed and seriously injured by passenger-side airbags cautions us against complete dependence on child restraint use and safety belts as measures to protect children from the dangers posed by passenger-side airbags.<sup>35</sup>

### Secure Children in the Rear Seat

Approximately one third of US children younger than age 12 traveling in motor vehicles are seated in the front seat.<sup>36,41,42</sup> The front-seating position is used more frequently by infants and toddlers than by young children and subteens. In the 1996 Controlled Intersection Study, 71% of infants and 67% of toddlers were observed riding in the front seat (NCSA, NHTSA, personal communication). However, these estimates may be upwards, and the percentage of infants and toddlers in the front seat has been declining gradually for 10 years.<sup>41</sup>

It is feasible to move large numbers of children from the front seat to the rear seat. In continental European nations, such as Germany, France, and Belgium, traffic laws prohibiting children from riding in the front were enforced from the mid-1970s to the early 1990s, well before the introduction of passenger-side airbags in Europe. In recent years, these laws have been relaxed following guidance from the European Commission.<sup>42</sup> Yet, it is still customary in many European countries for children to ride in the rear of the vehicle, even if the vehicle has only two occupants (a driver and a child). A recent roadside survey of vehicles occupied by at least one child in Frankfurt, Brussels, and Paris found <15% of such vehicles with a child in the front seat.<sup>43</sup> Even in the United States, where no such laws (until very recently) have existed, some states have twice the proportion of children riding in the front seat as other states.<sup>41</sup>

It is well established that the rear seat is intrinsically safer than the front seat for an occupant of any age.<sup>44,45</sup> In the absence of a passenger-side airbag, a child's average risk of fatality is 20% to 40% lower in the rear compared with the front seat.<sup>13,35</sup> The risk of injury also is diminished in the rear seat.<sup>34,45,46</sup> If a passenger-side airbag is present in the vehicle, the net safety advantage of the rear seat for children is enlarged, for both restrained and unrestrained children.<sup>13</sup>

The NHTSA recommended recently that states amend child passenger safety laws to require that children sit in the rear when a seat is available.<sup>47</sup> Rhode Island became the first state to enact such a law, albeit only for children younger than age six. Several states are now considering similar legislation.<sup>48</sup> Recent surveys have found that a large major-

ity of parents (including those with young children) have favorable attitudes toward the idea of requiring children to sit in the rear.<sup>22</sup> Reticence about new legislation in this area appears to revolve around three concerns discussed below.

First, parents with large families and car-pooling arrangements may have no choice but to allow one or more children to ride in the front seat. However, shortage of rear seating capacity is rarely a valid explanation for children riding in the front. Of the 17 000 fatal crashes involving US children seated in the front from 1985–1996, empty seats in the rear were available in >95% of the vehicles and, in 65% of the vehicles, the rear seat was completely unoccupied.<sup>41</sup> However, any laws on this matter should apply only to vehicles that have a rear seat and only in circumstances in which the rear seat is otherwise unoccupied.

Second, some older vehicles are equipped with only a lap belt in the rear seat; thus, it may seem safer to seat the child in the front, where both a shoulder belt and a lap belt are always available. The available data on this issue are limited. It may be appropriate to restrict the applicability of child seating laws to the vast majority of vehicles on the road in the United States that are equipped with lap and shoulder belts in the outboard rear seating positions. At a minimum, such laws should apply to any vehicle that is equipped with a passenger-side airbag, because all such vehicles also are equipped with lap/shoulder belts in outboard front and rear positions.

Third, to legislate where parents must seat their children in a vehicle may be viewed as an excessive intrusion on the part of government into the realm of parental choice. However, similar objections could be made against the existing child passenger safety laws that compel parents to purchase child restraint devices and use these devices in specified ways. Child seating laws would seem to have at least as much philosophical justification—rooted in the state's interest in protecting the rights and welfare of children—as child restraint use laws.

As additional resources are devoted to enforcing adult and child passenger safety laws in the states, it may be appropriate to coordinate such efforts with amendments to such laws that compel children to ride in the rear seat. Police officers will find it easier to observe where a child is seated than to observe whether a restraint is used and used properly. Laws against improper child seating position will provide police a clear and indisputable rationale for stopping a vehicle, thereby making more feasible stringent enforcement of child and adult restraint use laws. Once a vehicle is stopped, a police officer can make a more effective observation of restraint use in each seating position.

#### **Suppress Airbag Deployment Through Active or Passive Measures to Protect Children**

If significant numbers of children continue to ride in the front seat, it may become necessary to disarm passenger-side airbags to protect these children.

#### *Active Disarmament*

The NHTSA now permits dealers and mechanics to install a manual cutoff switch in passenger car vehicles with airbags that can be used by owners to disarm an airbag system temporarily. These switches already are available in pick-up trucks that do not have a rear seat. To obtain a cutoff switch, the owner must make a specific, written request to NHTSA, demonstrating that he or she falls into one of four prescribed at-risk groups. One of these groups includes owners who, because of car-pooling or the child's medical condition, must have a child in the front seat.

Offering choice about the operation of airbags to parents and caregivers is an idea that has met determined resistance in the United States.<sup>6</sup> Offering this choice contradicts the simple message that children should ride in the rear seat. Car dealers, airbag suppliers, and vehicle manufacturers fear additional liability. Moreover, in vehicles with passenger-side airbags, the shoulder belt is designed to allow greater excursion to reduce the risk of belt-related injuries; disconnecting the airbag leaves the occupant with a suboptimal shoulder belt system. Some people fear the potential regret felt by adults who make incorrect or negligent use of the freedom to arm or disarm airbags. There also are fears that the power to disarm and rearm airbags, whether done permanently or on a trip-by-trip basis, will not be used wisely by consumers. Adults who allow children to ride in the front seat unrestrained may tend to be the same adults who are least likely to make sure that the passenger-side airbag is disarmed for a child or rearmed when an adult passenger needs it. Research is needed to determine how vehicle owners exercise the limited freedom to purchase and use manual cutoff switches.

There is a precedent for the active disarmament approach in Sweden. In contrast to the US, Sweden is now making a strong push to promote use of rear-facing restraints in the front seat for both infants and toddlers. Use of the front seat for children is seen as a valued convenience for parents, whereas the rear-facing restraint design is considered safer than the forward-facing design for infants as well as toddlers. Parents with infants and toddlers are now encouraged by Swedish authorities to disarm their passenger-side airbag systems during the child's developmental years. When children are old enough, families are encouraged to have their passenger-side airbag rearmed.<sup>49</sup>

#### *Passive Disarmament*

Instead of relying exclusively on consumers to make informed decisions about protecting children from passenger-side airbags, vehicles can be redesigned to suppress airbag deployment if a child is seated in the front. For example, some airbag systems sold by Mercedes-Benz already have a weight sensor on the passenger side that prevents airbag deployment if no one is occupying the seat. The original purpose of this capability was to prevent unnecessary deployments and the corresponding

costs of system replacement. If the threshold for the weight sensor were set at some given weight, for example 80 pounds, it might be feasible to suppress airbag deployment when the seat is empty or when it is occupied by a child.

Any technologic solution must be evaluated with respect to error rates. False-negative errors, that is, failing to disarm when a child is in the seat, could occur if the child is holding something (eg, books, cargo, groceries) or is not sitting properly or is placed in a tightly grounded child restraint device. False-positive errors, that is, cases in which the system suppresses deployment when an adult is seated in the front, could arise from nuances in the way the adult is situated in the seat relative to a weight-sensing mechanism. Some suppliers believe that proximity sensors will ultimately prove to be more dependable than weight sensors. The passive disarmament approach to protecting children seems promising if both types of errors can be minimized at a reasonable cost.

A potential objection to passive disarmament is that restrained children should not be deprived of airbag protection. Although some experimental data suggest that injuries to restrained children can be mitigated by airbag deployment, the real-world data have yet to show overall significant benefit to restrained children.<sup>12</sup> If such benefits are proven, it should be feasible to disarm passenger-side airbags automatically only if the child in the front is unrestrained, although misuse of restraints will be difficult to detect, even by a smart airbag.

Passive disarmament should be mandated by the government directly or indirectly through a performance standard aimed at reducing risk to children. The American Association of Automobile Manufacturers already has formally requested that the NHTSA amend the airbag standard to include a compliance test involving an out-of-position child dummy,<sup>50</sup> and the risk of future liability claims may induce some manufacturers to voluntarily install airbag suppression systems that protect unrestrained children.<sup>51</sup>

#### **Raise Deployment Thresholds for Airbags to Prevent Unnecessary Firings**

When children experience fatal injuries from airbag deployment, the crashes often are relatively low-speed impacts that would otherwise not have been fatal.<sup>14</sup> This empirical observation led to the suggestion that deployment thresholds for airbags be raised from their current level of 12 miles per hour into a fixed barrier, with a range from 7 to 15 mph (or ~11 to 24 km/hour) to a considerably higher level (eg, near 18 mph or 30 km/hour). A case can be made that the threshold for firing on the passenger side should be set even higher than the threshold on the driver side, because there is no steering wheel on the passenger side.

Vehicle manufacturers and suppliers are currently reexamining where airbag deployment thresholds should be set. This decision is not governed directly by the NHTSA's regulations, allowing manufacturers design flexibility in this area.

A potential drawback to raising deployment thresholds, without improving the performance of crash sensors, is that airbags will take longer to deploy, particularly in so-called soft crashes (eg, a crash against a utility pole), where the crash pulses are attenuated and spread over time. A longer time interval from crash to bag inflation gives more opportunity for adults and children to slide forward into the airbag's deployment zone. As sensor performance is improved, either through placement of additional satellite sensors in the front of the vehicle or through advanced sensor technology, it should be feasible to raise deployment thresholds without delaying airbag deployment. A complementary solution may be to block airbag deployment if the time required to trigger inflation exceeds some preset time, gauged as the time during the crash that an unrestrained passenger takes to move into the airbag's deployment zone.

#### **Depower Airbag Systems and/or Install Dual-stage Inflators Linked to Crash Severity**

Manufacturers selling vehicles in Canada and the United States already have received permission from regulatory agencies to depower airbags by 20% to 35%.<sup>1</sup> Depowering refers to decreasing the energy of deployment and/or reducing the volume of the bags themselves. A study in the United States found little evidence that adult occupants who died in frontal crashes involving airbags died because their airbags had insufficient powering.<sup>52</sup> Some experimental models suggest that depowering can reduce significantly the rate and severity of airbag-induced injuries to children and adults.<sup>1</sup> In Australia, where rates of seat belt use exceed 90%, some depowered airbags, which are also small in volume (eg, the Holden bag), are in use. Early real-world data from Australia suggest that depowered airbags, in conjunction with other design features, inflict fewer and less severe injuries without sacrificing protection in high-speed crashes.<sup>3</sup>

Another notable refinement is dual-stage inflation. Once a collision is sensed and is of low-velocity, a first reduced charge of propellant is deployed into the airbag. Milliseconds later, if deceleration associated with what turns to be a more severe collision is detected, a second charge of propellant is released that makes the airbag larger and/or firmer. For decades, this approach was considered promising because it would mitigate airbag-induced injuries to out-of-position children and adults in low-speed crashes.<sup>15,28,53-56</sup> With this design, two deployment thresholds are required rather than one. An early version of the dual-stage inflator was used on the passenger side of 10 000 General Motors cars equipped with airbags during model years 1974-1976.<sup>57</sup> An elaboration of dual-stage inflation might entail allowing only first-stage deployments when a child is occupying the front passenger seat.

In recent offerings, BMW and Mercedes-Benz include two different thresholds of deployment based on whether the occupant is belted.<sup>56</sup> A properly belted occupant is less likely to need airbag protection in relatively low-speed impacts than is an

unbelted occupant. Despite these innovations, the BMW owners manual recommends that children younger than age 12 sit in the rear.<sup>58</sup>

There exists a formidable barrier to protecting children through use of precise adjustments in the inflation power of airbags. The child dummies currently used by suppliers, manufacturers, and government may not provide an accurate indication of the vulnerability of a child's head, brain, and neck, which may vary significantly from child to child. The minimum force on the neck necessary to fatally or severely injure a child is not very different from smaller forces on the neck that would not be associated with significant injury.<sup>59-61</sup> This narrow window needs to be defined precisely for children of different vulnerabilities and reflected in sophisticated child dummies.

Any child whose head is extremely close to the airbag when deployment occurs (<1 inch) is likely to suffer serious or fatal injury as long as the airbag is powered sufficiently to provide protection for large adults in a moderate-speed crash. A tradeoff between adult and child passenger protection has been recognized by airbag engineers for >25 years.<sup>62</sup> Dual-stage inflation, coupled with improved sensor technology and improved child dummies, should make this trade-off more favorable, but will not eliminate it.

## CONCLUSION

The introduction of the passenger-side airbag into motor vehicles has caused an increased risk of fatality to children occupying the front seat. The precise magnitude of the increase is unknown, but it is apparent that more lives of children are being lost than saved because of passenger-side airbags.

A variety of measures can be implemented to reduce the airbag's risk to children and thereby improve the airbag's overall of benefit-to-risk ratio. The fastest to implement and most effective measure entails moving children from the front seat to the rear seat. In >95% of crash situations when a child is in front, an unused seat is available in the rear. It also is critical to make sure that children are restrained properly, regardless of where in the vehicle they sit. Increasing the rate of adult restraint use should indirectly induce an increase in the rate of child restraint use, because the behaviors appear to be correlated.<sup>36,37</sup>

Public education is paving the way for progress on both proper child seating position and child restraint use. Yet dramatic and sustained changes in behaviors will require renewed vigor in police enforcement of child and adult passenger safety laws, including amendments to existing laws that compel children to be seated in the rear.

The NHTSA recently authorized an active approach to airbag suppression by permitting at-risk owners to install a manual cut-off switch. Research is needed to determine whether the limited freedom authorized by the new policy is used wisely by vehicle owners.

New technologies based on weight and proximity sensing are being developed that would suppress

airbag deployment automatically if a child is seated in front (or if any passenger is too close to the airbag). A governmental mandate to protect children with airbag suppression technologies may be necessary, because some vehicle manufacturers may see little commercial value in voluntary design changes aimed primarily at protecting unrestrained children. Other improvements in airbag design, such as higher deployment thresholds, dual deployment thresholds, and depowering of inflators, are being made and should reduce the number and severity of injuries to adults and children. Dual-stage inflation and improvements in the performance of sensors will play an important role in the design of advanced airbag systems and are likely to penetrate the marketplace in the near future, before regulatory requirements.

Major design changes in the passenger-side airbag system need to be considered part of a broader analytical framework that includes consideration of possible trade-offs between the welfare of adult and child passengers. It also should be understood that most technical improvements will only be feasible and cost-effective for new vehicles. Behavioral solutions, coupled with education and police enforcement, are essential for protecting children who will be riding in the 30 million vehicles now equipped with passenger-side airbags throughout their 20-year vehicle life.

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