Optimal Restraint Reduces the Risk of Abdominal Injury in Children Involved in Motor Vehicle Crashes

Michael L. Nance, MD,‡ Nicolas Lutz, MD,* Kristy B. Arbogast, PhD,‡ Rebecca A. Cornejo, MHS,‡ Michael J. Kallan, MS,§ Flaura K. Winston, MD, PhD,†‡ and Dennis R. Durbin, MD, MSCE†‡*

Background: The American Academy of Pediatrics has established guidelines for optimal, age-appropriate child occupant restraint. While optimal restraint has been shown to reduce the risk of injuries overall, its effect on specific types of injuries, in particular abdominal injuries, has not been demonstrated.

Methods: Cross-sectional study of children aged younger than 16 years in crashes of insured vehicles in 15 states, with data collected via insurance claims records and a telephone survey. A probability sample of 10,927 crashes involving 17,132 restrained children, representing 210,926 children in 136,734 crashes was collected between December 1, 1998 and May 31, 2002. Restraint use was categorized as optimal or suboptimal based on current American Academy of Pediatrics guidelines. The outcome of interest, abdominal injury, was defined as any reported injury to an intra-abdominal organ of Abbreviated Injury Scale ≥2 severity.

Results: Among all restrained children, optimal was noted in 59% (n = 120,473) and suboptimal in 41% (n = 83,555). An associated abdominal organ injury was noted in 0.05% (n = 62) of the optimal restrained group and 0.17% (n = 140) of the suboptimal group. After adjusting for age and seating position (front vs. rear), optimally restrained children were more than 3 times less likely [odds ratio 3.51 (95% confidence interval, 1.87–6.60, $P < 0.001$)] as suboptimally restrained children to suffer an abdominal injury. Of note, there were no abdominal injuries reported among optimally restrained 4- to 8-year-olds.

Conclusions: Optimally restrained children are at a significantly lower risk of abdominal injury than children suboptimally restrained for age. This disparity emphasizes the need for aggressive education efforts aimed not only at getting children into restraint systems, but also the importance of optimal, age-appropriate restraint.

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From the *Departments of *Surgery and †Pediatrics, Children's Hospital of Philadelphia; ‡TraumaLink, Children's Hospital of Philadelphia; and §Center for Clinical Epidemiology and Biostatistics, University of Pennsylvania, Philadelphia, PA.

Reprints: Michael L. Nance, MD, Department of Surgery, Children's Hospital of Philadelphia, 34th and Civic Center Boulevard, Philadelphia, PA 19104. E-mail: nance@email.chop.edu.

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Motor vehicle crashes represent the leading cause of death and disability in the pediatric and adolescent years.[1] Occupant restraint devices, such as seat belts and child restraint systems, have been shown to decrease mortality and reduce the incidence of serious injuries in children involved in motor vehicle crashes when compared with no restraint use.[2,3] These benefits have led organizations such as the American Academy of Pediatrics and the National Highway Traffic Safety Administration to provide guidelines outlining age-appropriate restraint for child occupants. Despite such guidelines, suboptimal restraint, particularly in children 4 to 8 years of age remains common.[4]

Previous studies have reported that suboptimal restraint use by children may lead to increases in abdominal hollow and solid organ injury and spinal cord injury.[5–8] These studies were primarily based on case reports and have not documented the risk of abdominal injury related to suboptimal restraint in a population-based sample. Therefore, the objectives of this study were to estimate the risk of abdominal injury to restrained children in motor vehicle crashes and to determine the effect of optimal versus suboptimal restraint on the estimated risk.

METHODS

Study Population and Data Collection

Data were collected as part of the Partners for Child Passenger Safety project from December 1, 1998 through May 31, 2002. A detailed description of the study methods has been published previously.[9] The Partners for Child Passenger Safety project is a large-scale, child-specific crash surveillance system. Insurance claims from State Farm Insurance Co. (Bloomington, IL) function as the source of subjects, with telephone survey 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 one child occupant ≤15 years of age. Qualifying crashes were limited to those that occurred in 15 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, Washington, DC; Midwest: Ohio, Michigan, Indiana, Illinois; West: California, Nevada, 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.

A stratified cluster sample was designed to select vehicles (the unit of sampling) for the conduct of a telephone survey with the driver. Vehicles containing children who received medical treatment following the crash were oversampled so that the majority of injured children would be selected while maintaining the representativeness of the overall population. If a vehicle were sampled, the "cluster" of all child occupants in that vehicle was included in the survey.

Drivers of sampled vehicles where at least one child received medical treatment were contacted by phone and screened via an abbreviated survey to verify the presence of at least one child occupant with an injury. All vehicles with at least one child who screened positive for injury and a 10% random sample of vehicles in which all child occupants screened negative for injury were selected for a full interview. A 2.5% sample of vehicles in which no children were treated was also selected for a full interview. The full interview involved a 30-minute telephone survey with the driver of the vehicle and parent(s) of the involved children. Only adult drivers and parents were interviewed. The median length of time between the date of the crash and the completion of the interview was 6 days.

For cases in which child occupants were seriously injured or killed, in-depth crash investigations were performed. Cases were screened via telephone to confirm the details of the crash. Contact information from selected cases was then forwarded to a crash investigation firm (Dynamic Science Incorporated, Annapolis, MD), and a full-scale onsite crash investigation was conducted using custom child-specific data collection forms. Among cases selected for investigation, 97% were completed. For the purposes of this analysis, these cases were used to examine the validity of information obtained from the telephone survey.

Variable Definitions

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 (kappa = 0.99, $P < 0.0001$).

Restraint status of children was first classified as either restrained or unrestrained as determined from the telephone survey. All children identified as unrestrained were excluded from further analysis. Among children who were restrained, their status was further classified as optimal or suboptimal for their age and size based on current American Academy of Pediatrics recommendations.[10]

Optimal restraint included child safety seats for children 4 years of age, belt-positioning booster seats for children age 4 to 8 years of age, and 3-point seat belts for children 8 years of age. Suboptimal restraint included the use of any seat belt for children $\leq$8 years of age or the use of a lap belt only for children $>$8 years of age.

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 and have been previously validated for their ability to distinguish AIS $\geq$ 2 injuries from those less severe.[11] For the purposes of this study, an abdominal injury included those with an AIS score of $\geq$2 for any intra-abdominal organ.

Separate verbal consent was obtained from eligible participants for the transfer of claim information from State Farm to CHOP/Penn, for the conduct of the telephone survey, and for the conduct of the crash investigation. 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

The primary purpose of these analyses was to compute the relative risk of injury for children who were suboptimally restrained for their age and size as compared with children who were optimally restrained. 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.[12] To account for this potential bias, analytical methods were used to account for sampling weights, sampling strata, and sampling units.

To compute P values and 95% confidence intervals to account for the stratification of subjects by medical treatment, clustering of subjects by vehicle, and the disproportional probability of selection, Taylor Series linearization estimates of the logistic regression parameter variance were calculated using SAS-callable SUDAAN: Software for the Statistical Analysis of Correlated Data, version 8.0 (Research Triangle Institute, Research Triangle Park, NC, 2001). Results of logistic regression modeling are expressed as unadjusted and adjusted odds ratios with corresponding 95% confidence intervals. Adjustments included seating position (front vs. rear seat) and age of the child.

RESULTS

During the 42-month study period, complete survey data were obtained on 17,132 children representing 210,926 children involved in 136,734 crashes. The mean age of the population was 6.9 years and was 48.4% male. Unrestrained

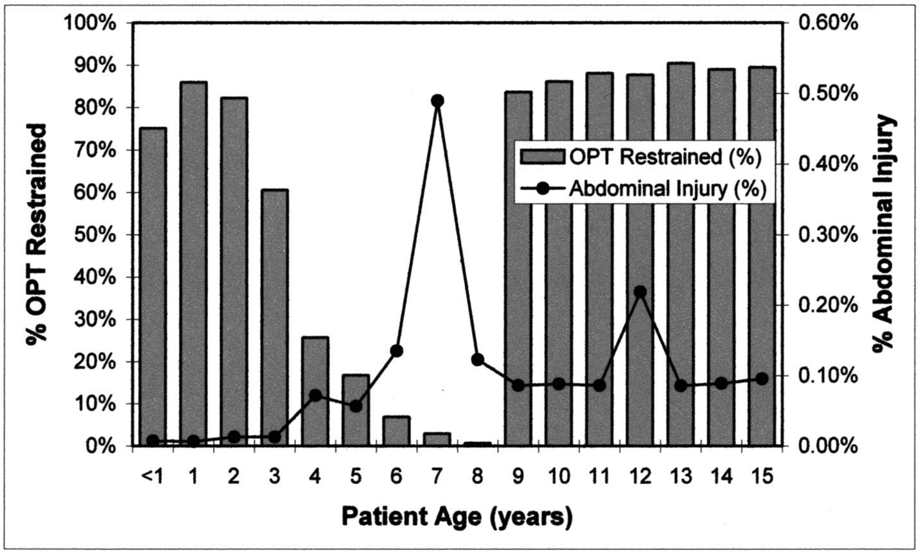

FIGURE 1. Percentage of child occupants optimally (OPT) restrained (left-hand y-axis) by age and percentage of children with an abdominal injury (right-hand y-axis) by age.

children comprised 3.3% (N = 6897) of the population and were excluded from further analyses. Thus, the study population was comprised of the 204,028 restrained child occupants involved in motor vehicle crashes. Among restrained child occupants, optimal was recorded in 59% (N = 120,473) and suboptimal in 41% (N = 83,555). Optimal restraint varied by age of the child (Fig. 1), with the lowest rate of optimal restraint reported for children from 4 to 8 years of age.

Abdominal injuries were noted in 0.10% of all restrained children, including 0.05% of those with optimal restraint and 0.17% of those with suboptimal restraint. After adjusting for age and seating position, children with suboptimal restraint were 3.5 times as likely to sustain an abdominal injury than optimally restrained children (odds ratio = 3.51, 95% confidence interval = 1.87–6.60, $P < 0.001$).

Because the definition of optimal restraint varied by the age of the child, the effect of optimal restraint on risk of abdominal injury was examined separately for age groups of children with common definitions of optimal restraint (Table 1). The absolute risk of abdominal injury varied by age group, from 0.01% among 0 to 3-year-olds to 0.17% among 4- to 8-year-olds. As previously noted, 4- to 8-year-olds had the highest rate of suboptimal restraint. The relative risk of abdominal injury with suboptimal restraint was fairly consistent across the age groups but only had sufficient sample size to achieve statistical significance for the overall restrained population and for the 9- to 15-year-old age subgroup. Of note, there were no reported abdominal injuries among optimally restrained 4- to 8-year-olds (those using belt-positioning booster seats).

The abdominal organ injuries sustained by the children in this study are presented in Table 2. Hollow organ injuries (stomach, intestine, bladder) were most frequently encountered with 127 injuries. Solid organ injuries (liver, spleen, kidney, pancreas) were noted in 62 child occupants. The specific organ injured was not described in 43 children.

TABLE 1. Risk of Abdominal Injury by Restraint Type and Age

Age (yr)	All Restrained (% abdominal injury)	Optimal Restraint (% abdominal injury)	Suboptimal Restraint (% abdominal injury)	Odds Ratio (95% CI, *P*)
0–3	0.01	0.01	0.02	3.15 (0.63–15.65, $P = 0.16$)
4–8	0.17	0.00	0.19	NA*
9–15	0.11	0.09	0.24	2.75 (1.06–7.10, $P = 0.037$
Total	0.10	0.05	0.17	3.26 (1.67–6.38, $P = 0.001$)

*If single child added to abdominal injury category for OPTR age 4–8 years, odds ratio = 14.61 (1.79–119.45, $P = 0.012$).

TABLE 2. Organs Injured in Restrained Child Occupants

Organ Injured	Optimal Restraint [N (%)]	Suboptimal Restraint [N (%)]	Total [N (%)]
Stomach/intestine	17 (21.5)	101 (65.2)	118 (50.4)
Kidney	15 (19.0)	10 (6.5)	25 (10.7)
Spleen	12 (15.2)	8 (5.2)	20 (8.5)
Liver	6 (7.6)	10 (6.5)	16 (6.8)
Bladder	6 (7.6)	3 (1.9)	9 (3.8)
Genitals	2 (2.5)	0 (0.0)	2 (0.9)
Pancreas	0 (0.0)	1 (0.7)	1 (0.4)
Other/unknown	21 (26.6)	22 (14.2)	43 (18.4)

DISCUSSION

Our results of a large population-based sample of children in crashes suggest that the overall risk of abdominal injury among restrained children is low, although abdominal organ injury is 3.5 times less likely in optimally restrained children as compared with suboptimally restrained children. In the 4- to 8-year-old children, belt-positioning booster seats virtually eliminated abdominal injuries. These results provide further evidence to support the current recommendations for age-appropriate restraint of children.

Until now, determining the true risk of abdominal injury among restrained children in crashes has been difficult. Previous studies have most commonly examined only children seeking medical care and have suggested that approximately 1% of such children will have an abdominal injury.[13] As abdominal injuries overall are uncommon, a large population-based study to quantify the differential abdominal organ injury risk associated with optimal versus suboptimal restraint is thus necessary. The specific role that optimal restraint plays in mitigating overall risk of injury, particularly head injuries, has been previously described using the same source of data as the current study[4] In that study, among 2- to 5-year-olds, those children suboptimally restrained in seat belts were 3.5 times as likely to be injured as children optimally restrained in child restraint systems. More recently, Valent et al examined the risk of injury to properly and improperly restrained children and found that, compared with unrestrained children, those properly restrained were 67% less likely to suffer abdominal injuries.[3] Information regarding the comparative efficacy of optimal versus suboptimal restraint use was not available. In addition, Valent et al studied a national sample of children in crashes between 1995 and 1999. The current study began data collection in late 1998; thus, our results may be considered more relevant to the current fleet of vehicles and types of child restraints currently in use. For example, at the time of the Valent et al study, very few children between 4 and 8 years of age were using belt-positioning booster seats. Therefore, they were unable to specifically examine the effectiveness of this particular restraint in reducing the risk of abdominal injury. Our results suggest that belt-positioning booster seats virtually eliminate intra-abdominal injuries.

Belt-positioning booster seats, either with or without a high back, raise the child up to improve the fit of both the lap and shoulder portions of the seat belt. The lap portion of a seat belt fits properly when it is low across the child's hips and is held in place by the anterior superior iliac spines.[14] When children are "prematurely graduated" to seat belts, the lap portion of the belt rides up over the abdomen and the shoulder portion crosses the neck or face.[14] Many children place the shoulder portion of the belt either behind their back or under their arm. Rapid, "jack-knife" bending or "submarining" about a poorly positioned vehicle seat belt increases the risk of intra-abdominal injuries to children.[15] In conjunction with injuries to the lumbar spine, this complex of injuries to belted children is known as "seat belt syndrome."[8] Belt-positioning booster seats have small handles, guides, or a slot that helps to position the lap portion of the belt low and flat across a child's upper thighs.[15] The bottom cushions of belt-positioning boosters are also shallower than the vehicle seat, allowing the child's knees to bend comfortably at the edge of the booster. This encourages a child to sit up straight in the seat with his back against the seatback.[16]

Abdominal injury can be the nemesis of the trauma surgeon. As the management of blunt abdominal injuries has increasingly been nonoperative, accurate assessment of the abdomen in children injured in motor vehicle crashes is essential. It is clear that nonuse of a restraint device increases the risk of morbidity and mortality for children in crashes.[3] Our data suggest that inappropriate use of child restraint devices also increases the morbidity of child occupants involved in motor vehicle crashes. Thus, knowledge of both the type and appropriateness of the restraint used by the child may help in the initial assessment of children following a crash. In those children reported to be restrained, the added knowledge regarding whether the restraint was optimal versus suboptimal should help to adjust the index of suspicion for intra-abdominal injury. Such refinement in the injury history may help paint a more accurate picture of suspected injuries for child occupants and guide clinical assessment.

Limitations

Several limitations in the interpretation of our results must be considered. The surveillance system is limited to children occupying model year 1990 and newer vehicles insured in 15 states and the District of Columbia. Thus, to the extent that older or uninsured vehicles differ substantially from newer insured vehicles with regard to the protection afforded to restrained children, results of this study may not be generalizable to occupants of these vehicles. Nearly all of the surveillance information was obtained via telephone interview with the driver/ parent of the child and is potentially subject to recall bias. As noted previously, ongoing comparison of parent-reported seating position to evidence from crash investigations has demonstrated excellent accuracy of the parent report.

Surveillance data of the nature presented in this study are crucial for identifying the magnitude and nature of risk for injury to restrained children in motor vehicle crashes. However, to elucidate the specific mechanisms by which children are injured in these crashes, more detailed information on the nature and severity of the injuries as well as the location and direction of crash impact and crash severity is required. This detailed information can only be obtained from on-site crash investigations. Future work will extend the results obtained from the surveillance portion of the Partners for Child Passenger Safety project by using the crash investigation component to fully understand the mechanism of these injuries and further delineate predictors of abdominal organ trauma.

CONCLUSION

Optimally restrained children are at a significantly lower risk of abdominal injury than children suboptimally restrained for their age. This disparity emphasizes the need for aggressive educational campaigns aimed not only at getting children into restraint systems, but also the importance of optimal restraint use. Restraint use alone is no longer an adequate educational message. The need for optimal, age-appropriate restraint use for child occupants needs to be emphasized.

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