Not All Child Safety Seats Are Created Equal: The Potential Dangers of Shield Booster Seats

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ABSTRACT. Objective. Children are safest when traveling in a child safety seat appropriate for their age and size. Previous research indicates that children are often transitioned to shield booster seats (SBSs) before reaching the 40-lb weight limit for their forward-facing child safety seat (FFCSS). These children could have otherwise been restrained in a FFCSS as is currently recommended by the American Academy of Pediatrics and the National Highway Traffic Safety Administration. The objective of this study was to compare the injury patterns among children who were restrained in SBSs and FFCSSs. Children in FFCSSs were chosen as a comparison group because SBS are predominately used to restrain children who are <40 lb and could have been restrained in an FFCSS, and SBSs are no longer certified for use in children who are >40 lb.

Methods. This is a cohort study involving restrained crash victims who were admitted to a level 1 pediatric trauma center between 1991 and 2003. Patients were older than 1 year, weighed between 20 and 40 lb, and were restrained in an SBS ($N = 16$) or an FFCSS ($N = 30$). Injury Severity Score, Abbreviated Injury Scale, Glasgow coma score, intensive care admission, length of stay, and acute care charges served as outcomes of interest.

Results. No significant differences regarding crash and occupant characteristics were found (mean Delta V, crash type, passenger compartment intrusion, driver restraint use). Odds of severe injury were greater for children in SBSs compared with children in FFCSSs as measured by Injury Severity Score >15 (odds ratio [OR]: 8.3; 95% confidence interval [CI]: 2.1–33.6), intensive care admission (OR: 5.5; 95% CI: 1.5–20.5), length of stay >2 days (OR: 6.3; 95% CI: 1.6–24.6), and Abbreviated Injury Scale ≥3 (OR: 4.4; 95% CI: 1.2–16.1). Furthermore, SBS cases had greater odds of head (OR: 4.5; 95% CI: 1.2–17.3), chest (OR: 29.0; 95% CI: 3.1–267.3), and abdominal/pelvic injury (25% vs 0%).

Conclusion. This study provides information about the increased risk of injury associated with shield boosters when compared with FFCSSs. The challenge for pediatricians is not only to promote the use of child restraints but also to ensure that parents use the most appropriate restraint for their child's age and weight. *Pediatrics* 2004;113:e153–e158. URL: http://www.pediatrics.
org/cgi/content/full/113/3/e153; *shield booster seats, children, motor vehicle crashes, injury patterns, injury severity.*

C hildren are safest when traveling in a child safety seat that is appropriate for their age and size.[1–4] Because relative anatomic proportions change with age, several different child restraints are available to accommodate a growing child's safety needs.[5] The National Highway Traffic Safety Administration's best practice child passenger safety guidelines recommend the use of a forward-facing child safety seat (FFCSS) with a 5-point harness for children who are older than 1 year and between 20 and 40 lb (Fig 1) and a belt-positioning booster seat for children who have outgrown FFCSSs (>40 lb).[6] Recent research indicates that booster seat use peaks at 3 years, an age at which most children should still be restrained in FFCSSs.[7] Moreover, not all booster seats are created equally, and the types of booster seat that parents choose for their children can be critically important.

There are 2 different types of booster seats currently on the market, each with a fundamentally different mechanism of restraining the child: shield booster seats (SBSs) and belt-positioning booster seats. SBSs have a padded shield that locks across the front of the device to secure the child in the seat; the shield is designed to decelerate the child in the event of a crash while preventing contact with the passenger compartment (Fig 2). Conversely, belt-positioning booster seats elevate a child so that a vehicle's 3-point lap and shoulder belt fits properly (Fig 3). With the increased emphasis on child passenger safety for children 4 to 8 years of age and the subsequent passage of state booster seat laws,[8] surveillance projects have reported that shield boosters compose nearly half of all booster seats in circulation.[7] Furthermore, shield boosters are predominantly used to restrain children who are <40 lb despite best practice recommendations that these children be restrained in a FFCSS with a 5-point harness.[7,9]

Growing concern has been raised regarding the safety of SBSs. A series of rollover crash tests demonstrated that dummies that weighed <18 kg (40 lb)

Fig 1. Child safety seat with 5-point harness. Children should be restrained in FFCSSs only when they are at least 1 year of age and weigh >20 lb. FFCSSs should then be used to restrain children until they outgrow the manufacturer's weight limit for the seat.

Fig 3. Belt-positioning booster seat. Belt-positioning booster seats should be used in conjunction with the vehicle's 3-point lap and shoulder belt to restrain children who are >40 lb and have outgrown FFCSSs. Belt-positioning booster seats should be used until the child is tall enough for the vehicle's 3-point lap and shoulder belt to fit correctly, usually at ~57 inches in height.

Fig 2. Shield booster seat.

had a much greater risk of ejection.[9] Similarly, the results of several isolated crash investigations involving children in SBSs reported inadequate upper body restraint, increased abdominal loading, and increased head excursion in rollover, side, and frontal crashes.[10–12] Moreover, observational data from child seat check-up events indicates that, compared with belt-positioning booster seats, shield boosters are more likely to be used incorrectly (68% vs 20%).[13] On the basis of these studies, the American Academy of Pediatrics discourages the use of SBSs, stating that they do not provide the best protection to children who are involved in motor-vehicle collisions.[14] Beyond these isolated events, little is known about the injury patterns that occur with SBSs.

The purpose of this study was to compare injury patterns among children who were restrained in SBSs and FFCSSs. Children in FFCSSs were chosen as a comparison group for 2 reasons: 1) SBSs are predominantly used to restrain children who are <40 lb and could have been restrained in an FFCSS,[4,7] and 2) SBSs are no longer certified by the manufacturer for use in children who are >40 lb and therefore are not viable restraint options for children in this weight group.[15]

METHODS

Case Identification and Selection

This is a cohort study involving 46 restrained crash victims who were admitted to a level 1 pediatric trauma center. Children who

were >1 year, weighed between 20 and 40 lb, were injured in motor vehicle crashes between 1991 and 2003, restrained in either an SBS or an FFCSS, admitted to Children's National Medical Center (CNMC), and enrolled in the Crash Injury Research and Engineering Network (CIREN) study project were included in this study. For this study, FFCSSs with 3-point harness and shield were classified as an FFCSS. CNMC is a participant in the National Highway Traffic Safety Administration sponsored CIREN which links crash reconstruction with medical data to provide in-depth assessments of biomechanical forces leading to injury among restrained occupants.[16]

Data Collection Procedures

Detailed information on restraint use, seating position, factors precipitating the crash, and age and status of other passengers in the vehicle was obtained from multiple sources, including police accident reports, emergency medical service transport reports, and interviews with on-scene providers and the child's parent/guardian. Injury data and medical treatment information was collected for each child prospectively during hospital admission. All external injuries were photographed, and copies of positive radiologic images were obtained and entered into the database to confirm the presence of internal injury.

Certified crash reconstructionists conducted vehicle and crash scene inspections to verify restraint use and seating position. Reconstructionists also photographed and measured important crash variables such as principle direction of force, ΔV (a measurement of crash severity based on the change of velocity during impact), and vehicle intrusion (the displacement of any interior compartment surfaces). The interior of each vehicle was photographed, and physical evidence of occupant contact points, such as skin, hair, and blood transfers or deformations of interior padding were labeled. Crash reconstruction methods are based on the data collection process used by the National Automotive Sampling System of the US Department of Transportation.[17,18]

Monthly case review meetings were held among pediatricians, pediatric surgeons, orthopedists, radiologists, nurses, crash reconstructionists, and traffic safety experts to achieve consensus regarding restraint use/misuse, to determine the specific biokinetic mechanism of each injury, and to ascertain occupant contact points for each injury sustained. Potential occupant contact area determinations for each injury were based on the principle direction of force generated during the crash and physical evidence identified in the vehicle. Data collection was conducted with written permission from the child's parent/guardian under the supervision of the CNMC CIREN principal investigator and the CNMC Institutional Review Board.

Variables Analyzed

Only children who were older than 1 year, between 20 and 40 lb, and restrained in a safety seat were included in the analysis. Cases were classified as FFCSSs or SBSs, with all other restraint types excluded from analysis. Cases were also excluded when evidence from crash reconstruction indicated that the safety seat was not anchored to the vehicle.

Vehicle information was analyzed for each case, including vehicle model year, ΔV, passenger compartment intrusion, and crash type (frontal impact, side impact, or other). Vehicle occupant variables were also analyzed, including driver age, number of passengers, driver restraint status, driver fatality, and passenger fatality. Demographic information including gender, age, and seating position were collected for each patient.

Physiologic and anatomic indicators of injury severity, both overall and by specific body regions, were measured using the Abbreviated Injury Scale (AIS; 1990 Revision)[19] and the Injury Severity Score (ISS).[20,21] ISSs were calculated in a standardized manner for each patient based on AIS. Each injury is assigned an AIS code that ranges from 1 (minor) to 6 (fatal). The ISS equals the sum of the squares of the highest AIS codes in each of the 3 most severely injured body regions. For statistical analysis, ISS was dichotomized into ISS >15 (ISS >15 = seriously injured). Glasgow Coma Score (GCS) was used as a measure of neurologic compromise. GCS was categorized into a dichotomous variable: GCS <9 (severely neurologically compromised): yes/no. Injuries were classified by body region and the maximum, AIS severity score was calculated for each injury. Injuries by AIS severity level and body region were treated as binary variables (AIS2+ injury: yes/no, AIS2+ head injury: yes/no).

Data Analysis

Means and standard deviations were calculated for all continuous variables, and frequency distributions were obtained for all categorical variables. For more closely approximating a normal distribution, log transformations were performed on continuous variables that had a skewness value more than twice the standard error. Testing for statistical significance was performed using the χ^2 test of independence, Fisher exact test, and t test. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated, comparing the risk of various outcomes among children in SBSs with those in FFCSSs. SPSS 10.0 was used to conduct this analysis.[22]

RESULTS

Data from 30 FFCSS cases were compared with data from 16 SBS cases. Crash and vehicle occupant characteristics were similar between the 2 groups. There were no significant differences between children who traveled in FFCSSs and SBSs with respect to vehicle model year or crash severity indicators, including passenger compartment intrusion and ΔV. Children in SBSs were involved in side-impact collisions more often than children in FFCSSs (57.1% vs 28.6%), but this difference was not statistically significant (Table 1). In regard to vehicle occupant characteristics, the drivers of children in SBSs were slightly older and more often reported using passenger restraints, although this difference was not statistically significant. One driver fatality occurred in each of the groups; 3 fatalities occurred among the FFCSS cases, whereas there were no fatalities among the SBS cases (Table 1).

TABLE 1. Crash and Vehicle Occupant Characteristics by Restraint Type

	FFCSS (N = 28)*	SBS (N = 14)*	P Value
Median vehicle model year	1992 (1984–2002)	1993 (1984–2000)	.65
Mean Δ V, mph	24.4 ± 9.0	25.4 ± 12.6	.80
Crash type			
Front impact, %	60.7	28.6	.13
Side impact, %†	28.6	57.1	.13
Other, %	10.7	14.3	.13
Passenger compartment intrusion, %	57.1	64.3	.75
Mean no. of passengers	3.1 ± 1.0	3.5 ± 1.2	.33
Mean driver age, y	30.0 ± 9.2	35.4 ± 15.2	.20
Driver restrained, %	89.3	100.0	.54
Driver fatality, %	3.6	7.1	1.00
Any passenger fatality, %	10.7	0.0	.54

* Number of crashes (number of FFCSS cases = 30; number of SBS cases = 16).
† 66.7% of SBS cases seated on near side of impact versus 60% of FFCSS cases.

TABLE 2. Case Occupant Characteristics by Restraint Type

	FFCSS (N = 30)	SBS (N = 16)	P Value
Mean age, y	2.2 ± 1.0	3.4 ± 1.4	.009
Mean weight, lb	30.9 ± 6.0	35.2 ± 4.8	.011
Boys, %	60.0	62.5	1.000
Right front seat, %	16.7	6.3	.650
Rear seat, %	83.3	93.8	.650

The distribution of boys and girls was very similar for both groups. Compared with children in FFCSSs, children in SBSs were approximately 1 year older (3.4 years vs 2.2 years; $P < .01$) and had corresponding higher weights (35.2 vs 30.9 lb; $P = .01$). Children in SBSs were also more often restrained in the rear seating positions (93.8% vs 83.3%), although this difference was not statistically different (Table 2).

With regard to injury severity and crash outcomes, children in SBSs had nearly 8 times the odds of being seriously injured (ISS >15) compared with children in FFCSSs (Table 3). Hospital stays and acute care charges trended to be higher among children in SBSs. The mean length of stay for children in SBSs was 5.8 days (1–25 days) compared with 2.6 days (1–16 days) for children in FFCSSs, and the mean acute care charge for children in SBSs was $28 985 ($2928–$191 841) compared with $9072 ($270–$39 335) for children in FFCSSs. Furthermore, children in SBSs had 5 times the odds of being admitted to the intensive care unit (OR: 5.5; 95% CI: 1.5–20.5) and 16 times the odds of being hospitalized for >2 days (OR: 16.1; 95% CI: 1.9–140.0). Children in SBSs also trended toward having greater odds of being discharged to a rehabilitation facility (OR: 1.3; 95% CI: 0.2–8.6; Table 3). At each of the AIS injury severity levels, a larger proportion of children in SBSs were represented. As the injury severity level increased, children in SBSs had 4 times the odds of sustaining an AIS3+ injury (OR: 4.4; 95% CI: 1.2–16.1) and 8 times the odds of sustaining an AIS4+ injury (OR: 8.3; 95% CI: 2.1–33.6). When looking at injury patterns by body region, children in SBSs were more likely to sustain an AIS2+ injury to the head, chest, and abdomen/pelvis (Table 4). Children in SBSs had 4 times the odds of sustaining a head injury (OR: 4.5; 95% CI: 1.2–17.3) and 29 times the odds of sustaining a chest injury

TABLE 3. Case Occupant Injury Severity by Restraint Type

	FFCSS (N = 30)	SBS (N = 16)	OR	95% CI
ISS >15, %	16.7	62.5	8.3	2.1–33.6
GCS, %				
<15	36.7	37.5	1.0	0.3–3.6
<12	16.7	31.3	2.3	0.6–9.5
<9	13.3	25.0	2.1	0.5–10.1
Admission to intensive care, %	23.3	62.5	5.5	1.5–20.5
Discharge to home, %	90.0	86.7	1.3	0.2–8.6
Length of stay >2 d, %*	25.9	68.8	6.3	1.6–24.6
Any AIS2+ injury, %	73.3	93.8	5.5	0.6–48.2
Any AIS3+ injury, %	31.3	68.8	4.4	1.2–16.1
Any AIS4+ injury, %	16.7	62.5	8.3	2.1–33.6

* Excluded deceased cases (adjusted FFCSS N = 27; adjusted SBS N = 16).

(OR: 29.0; 3.1–267.3). Moreover, only children in SBSs sustained injuries to the abdomen and/or pelvis (25% vs 0%; $P = .01$).

DISCUSSION

This is the largest cohort of pediatric crash victims in SBSs reported in the literature to date. The findings from this study support previous isolated reports that children who travel in SBSs are at increased risk for crash-related injury.[9–12] SBSs accounted for all of the abdominal and pelvic injuries and a significantly greater proportion of head and chest injuries. Although there were 3 fatalities among the FFCSS group, the FFCSSs had been modified or the harnesses had not been secured properly. These misuses resulted in severe traumatic brain injury. Even with inclusion of these cases in the analysis, children who traveled in an SBS had proportionally more severe injuries, more intensive care unit admissions, and longer lengths of stay. Furthermore, the purpose of this study was to compare cases of SBSs among children in a weight category in which an FFCSS could have been used. No previous studies have been able to use accurate, comprehensive medical data to demonstrate the injury patterns between these 2 child restraint systems.

SBSs were originally designed for use in vehicles in which a 2-point lap belt was the only restraint available for children who had outgrown FFCSSs (>40 lb); the shield was thought to decelerate the head and chest and redistribute the load otherwise concentrated on the lap belt to a broader area of the abdomen. Since 1989, all vehicles are required by law to have 3-point restraints in the outboard rear seating positions. This requirement has reduced the need for SBSs, because children over 40 lb now almost always have a 3-point lap and shoulder belt available for use with a belt-positioning booster seat. In those rare situations in which a child >40 lb has only a lap belt available, there are now FFCSSs with 5-point harnesses that can support children up to 80 lb.

Earlier SBS models were certified for use in children 30 to 60 lb, because a 3-year-old (33 lb) test dummy was used to test compliance with federal motor vehicle safety standards. In September 1996, the 6-year-old (47 lb) crash test dummy was introduced and used to test safety performance of child restraints labeled for use in children >40 lb. None of the SBSs currently on the market met the minimum performance criteria with the heavier crash test dummy, and all were decertified by the their manufacturer for use in children >40 lb.[15] As a result, SBSs no longer have any role in child passenger safety. Although SBSs are now obsolete, the results of this study are not. Older SBS models labeled for use in children >40 lb are still in circulation, and 1 particular SBS continues to be manufactured and marketed for use in children 30 to 40 lb.

In 1996, the Federal Motor Vehicle Safety Standard 213 (FMVSS 213) set new standards for child restraint systems, which led to design changes in SBSs. Concerns about whether these engineering changes have led to improved safety are still being discussed. In this data set, 11 of the SBS cases were manufac-

TABLE 4. Case Occupant Injury Severity by Restraint Type

	FFCSS (N = 30)	SBS (N = 16)	OR	95% CI
Any AIS2+ head injury, %	40.0	75.0	4.5	1.2, 17.3
Any AIS2+ chest injury, %	3.3	50.0	29.0	3.1, 267.3
Any AIS2+ abdomen/pelvic injury, %	0.0	25.0	–*	–
Any AIS2+ extremity injury, %	13.3	25.0	2.2	0.5, 10.1

* Fisher's exact test P = .011.

tured before 1996, and for the remaining cases, the exact date of manufacture was not available. Thus, additional analysis of differences among pre- and post-1996 manufactured SBSs cannot be addressed with our current data.

This study presents evidence-based research drawn from real-world crash data indicating the potential dangers of SBSs. The data in this study point to the increased risk of injury to the head, chest, and abdominal/pelvic region among children who are restrained in SBSs. Clearly, SBSs used in this study do not provide the best protection compared with FFCSSs for children <40 lb.

The crash reconstruction methods used in this study involve a multidisciplinary approach to understanding the biomechanics of injury that draws on the combined expertise of mechanical engineers, crash investigators, clinicians, and safety advocates. The greatest limitation of analyses based on crash reconstruction methods is the lack of data on restrained passengers who were uninjured in motor vehicle collisions. For example, the group of children in FFCSSs had an absolute risk of serious injury of 16.7% and children in SBSs had an absolute risk of injury of 62.5%. These values are much higher than the 1% risk of serious injury reported from a more population-based cohort.[3] These differences in absolute risk support that children in this study may not be a representative sample. It may be possible that the selection bias in one restraint type, such as FFCSSs, may be different from that for SBSs. To the extent that there are many more nonadmitted children in FFCSSs than SBSs, this study likely underestimates the potential increased risk of injury for children in SBSs.

Regarding crash circumstances, the relatively small sample size reduces our ability to identify associations among the smaller subgroups within our sample, thus increasing the likelihood that associations may go unrecognized. For this reason, it is impossible to make unbiased assertions about the performance of the restraint systems or overall injury risks for different crash mechanisms. However, several databases contain population-based data on less severely injured children, which can complement CIREN data.[23] Although the considerable expenses involved with in-depth crash investigation limit the size of the study sample available for analysis, this method provides accurate data on crash severity, occupant contact points, and restraint use that are not available in other databases. Furthermore, information on restraint usage, especially on restraint misuse, is not dependent on parental reports or police accident reports, both of which have been shown to be biased.[24]

CONCLUSION

Our research provides pediatricians and families with important information regarding the potential dangers of SBSs. Previous studies demonstrated the level of premature use of booster seats among young children. This study provides additional information regarding the increased risk of injury associated with SBS use compared with FFCSSs among children 20 to 40 lb. The challenge for pediatricians is not only to promote the use of child restraint systems but also ensure that parents are using the most appropriate child restraint for their child's age and weight.

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