INJURIES TO CHILDREN IN FORWARD FACING CHILD RESTRAINTS

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ABSTRACT

The applicability of the federal safety standard that governs child restraints (FMVSS 213) has recently been called into question. Population- based estimates of the risk of injury to children in child restraints and a description of the patterns and mechanisms of injury are necessary to evaluate this standard and identify areas of needed improvement. A probability sample of children 12 to 47 months in crashes was identified in an on-going crash surveillance system (1998-2002) which links insurance claims data to telephone survey and crash investigation data. The risk of injury in forward facing child restraints (FFCRS) was estimated and a series of cases was examined using in-depth crash investigation to identify the mechanisms of these injuries. Although children in FFCRS are well protected in crashes, further reductions in serious injuries might be achieved by reducing head, neck, and extremity injury risks. These results have implications for the current efforts to upgrade the current FMVSS 213 and better protect child passengers.

Keywords: child occupant injury mechanisms, child restraint, head injury mechanism, lower extremity injury, neck injury

The number of children fatally injured as passengers in motor vehicle crashes has decreased by 20% over the past 25 years (Insurance Institute for Highway Safety 2001). These benefits have been achieved, in part, by an increase in restraint use and through implementation of federally regulated safety standards for child

restraint systems (CRS) and vehicles. Since 1971, all child restraint systems designed for use by children up to 22.7 kg in motor vehicles and on aircraft must meet the minimum performance standards detailed in Federal Motor Vehicle Safety Standard 213. (National Highway Traffic Safety Administration 2001) The standard evaluates the performance of CRS in dynamic tests simulating a 30-mph frontal impact and specifies which child surrogates ("anthropometric dummies") should be used to mimic different sized children. These tests are performed on a bench-type vehicle seat representative of a 1970's vehicle with limited ability to assess contact of the child with other interior vehicle structures. The rule specifies criteria that translate engineering measures obtained during testing to a risk of injuries to the head and chest.

Recently, the applicability of FMVSS 213 to the current fleet of vehicles and child restraints has been called into question. (Fitzgerald 2001) Specific concerns include the applicability of the bench-type seat, the accuracy of translating data measured from the dummies to injury risk in real children, and restriction of the test procedure to one impact direction. A review of the on-going applicability of standards must incorporate a scientifically rigorous analysis of real world crashes that includes both epidemiological surveillance and in-depth biomechanical investigation. Population-based surveillance that includes estimates of injury risk is needed to provide a benchmark on which to evaluate the current standard and to compare future performance. Through in-depth investigations, the crash conditions under which injuries occur can be identified and reproduced using laboratory test procedures.

Previous data are inadequate to evaluate the current performance of FMVSS 213. Studies have identified a pattern of injuries in children in forward facing CRS that include the head and the spine. (Agran, Dunkle et al. 1985; Tingvall 1987; Fuchs, Barthel et al. 1989; Huelke, Mackay et al. 1991; Kelleher-Walsh, Walsh et al. 1993) This previous work, conducted between 1980 and 1992, utilized police report or emergency department visits to identify cases. Thus, the cases represent older vehicles and child restraints, and the analyses examined a limited range of crash and injury severities. As a result, these studies are unable to provide estimates of risk of injury in child restraints that are population based and although they identified patterns of injury, they did not focus on a biomechanical analysis of the mechanisms. The National Highway Traffic Safety Administration's National Automotive Sampling System and Fatality Analysis Reporting System are two current sources of crash surveillance data. Both are limited by the inclusion of insufficient numbers of children in crashes and inadequate data regarding child restraints. Trauma center-based research, another source of child crash data, can be used to describe injuries suffered but is limited in providing effectiveness estimates because they lack an exposure base on

which to compare these estimates. Therefore, the objectives of this study were to use a novel database of children in crashes to provide population- based estimates of the risk of injury to children in forward-facing CRS and to describe patterns and mechanisms of injury.

METHODS

Data collected from December 1, 1998 to August 31, 2001 as part of Partners for Child Passenger Safety (PCPS) form the basis of this study. Detailed descriptions of the study population and methods involved in data collection and analysis have been previously published. (Durbin, Bhatia et al. 2001) Briefly, PCPS consists of a large scale, population based, 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. The telephone interviews provide data for a surveillance system used to describe characteristics of the population including risk factors for injury while the crash investigations provide detailed mechanisms of injury.

Vehicles qualifying for inclusion in the surveillance system were those involving at least one child occupant $\leq$ 15 years of age riding in a model year 1990 or newer State Farm-insured vehicle. Qualifying crashes were limited to those that occurred in fifteen states and the District of Columbia, representing three large regions of the United States (East: NY, NJ, PA, DE, MD, VA, WV, NC, DC; Midwest: OH, MI, IN, IL; West: CA, NV, AZ). For this specific study, analyses were limited to crashes involving children aged 12 through 47 months riding in forward facing convertible seats.

On a daily basis, data from qualifying and consenting claims were transferred electronically from all involved State Farm field offices to researchers at The Children's Hospital of Philadelphia and University of Pennsylvania (CHOP/Penn). Data in this initial transfer included contact information for the insured, the ages and genders of all child occupants, and a coded variable describing the medical treatment received by all child occupants.

SURVEILLANCE SYSTEM – A stratified cluster sample was designed in order to select vehicles (the unit of sampling) for the conduct of a telephone survey with the driver. If a vehicle was sampled, the "cluster" of all child occupants in that vehicle was included in the survey. Drivers of sampled vehicles 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. 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 six days.

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. The ability of parents to accurately distinguish AIS 2 or greater injuries from those less severe using this instrument has been previously validated for all body regions of injury. (Durbin, Winston et al. 1999) For the purpose of this study, injury was defined as any AIS 2 or greater injury excluding concussions. Concussions were excluded due to the difficulty in diagnosing this injury in a primarily pre-verbal population. AIS 2 or greater injuries include serious head and brain injuries, all internal organ injuries, spinal cord injuries, and extremity fractures. All AIS 2 or greater injuries were independently reviewed and verified by a trauma physician who was blinded to the focus and objectives of this study.

Restraint status of children was determined from the telephone survey. Questions related to restraint status required the respondent to describe characteristics of the restraint and how it was used. Based on the patterns of responses, we could construct the type of restraint used rather than relying on a parent's knowledge of the product names. Among the 164 children for whom paired information on restraint use was available from both the telephone survey and crash investigations, agreement was 89% between the driver report and the crash investigator (kappa=0.38, $p<0.0001$).

Crash severity was determined both by the driveable status of the vehicle (i.e., whether or not the vehicle was towed from the crash scene) as indicated in the insurance claims data, as well as by driver report of any intrusion into the occupant compartment of the vehicle via the telephone survey. A three-level categorization of crash severity was then created (from highest to lowest severity): 1) any intrusion, 2) no intrusion and nondriveable, and 3) no intrusion and driveable.

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 7.5 (Research Triangle Institute, Research Triangle Park, NC, 1999).

CRASH INVESTIGATIONS - In order to gain more detailed information about the kinematics of child occupants and the mechanisms of injury, cases are chosen for in-depth crash investigation based on manual review of claims files. The criteria for selection for an in-depth crash investigation included children

admitted to the hospital with serious injuries and those children fatally injured in the crash.

Eligible cases were screened via telephone with the policyholder to confirm the restraint status and medical details of the case. Contact information from selected cases was then forwarded to a crash investigation firm and a full-scale on-site crash investigation was conducted using custom child-specific data collection forms.

Crash investigation teams were dispatched to the crash scenes within 24 hours of notification to measure and document the crash environment, damage to the vehicles involved, and occupant contact points according to a standardized protocol. The on-scene investigations were supplemented by information from witnesses, crash victims, physicians, hospital medical records, police reports, and emergency medical service personnel. From this information, reports were generated that included estimates of the vehicle dynamics and occupant kinematics during the crash and detailed descriptions of the injuries sustained in the crash by body region, type of injury, and severity of injury. Delta v, (the instantaneous change in velocity) an accepted measure of crash severity, was calculated using WinSmash and crush measurements of the vehicles involved.

A retrospective review of 457 completed crash investigations completed to date identified six which met the selection criteria for this specific study (a child occupant between the ages of 12 and 47 months riding in a forward facing child restraint who sustained an AIS 3 or greater injury). The Institutional Review Boards of both The Children's Hospital of Philadelphia and The University of Pennsylvania School of Medicine approved the conduct of this project.

RESULTS

SURVEILLANCE DATA- Completed survey data were obtained on 1,722 children 12 through 47 months in age seated in forward-facing child restraint systems, representing 25,774 children involved in 24,088 crashes. Table 1 provides basic descriptive information about these children. 51.7% of these children were female. Most children (98.5%) were seated in a rear seat row and just over half of the children (50.2%) were riding in a passenger car. 48.3% were involved in a frontal collision and 8.9% were in a crash which resulted in intrusion. 43 (0.17%) children in FFCRS experienced AIS 2+ injuries (excluding concussions).

The distribution of injuries by body region for the children in FFCRS is shown in Figure 1. Among the 43 children, there were 47 AIS 2+ injuries. 96 % of the injuries were limited to the head, the spine, and the extremities. Specific injuries included fractures to the skull, face, neck, spine or extremities, cerebral contusions, and intracranial hemorrhages. Of note, 67% of those

in FFCRS with serious injuries were females, in comparison to 52% of those in the group with no or minor injuries.

CRASH INVESTIGATIONS- Details of crash investigations conducted on a sample of 6 children, who sustained AIS 3 or greater injuries, are contained in Table 2. The average delta v was 42 kph indicating that these crashes were moderate to severe. Five of these crashes had substantial intrusion (average intrusion = 55 cm) which compromised or altered the occupant space.

The six children ranged in age from eleven to thirty-nine months (mean = 27 months). They were equally divided among the left rear, center rear, and right rear seating positions and three of six were in compact sedans. All but one of the children had a documented misuse of the child restraint system: either the harness was loose or the seat was not tightly attached to the vehicle.

Four children had AIS 3 or greater head or neck injuries; some children experienced multiple injuries to this body region. These injuries included atlanto-occipital distraction, subdural hematoma, epidural hematoma, frontal skull fracture, and a frontal lobe contusion. Two of these injuries were fatal (both were atlanto-occipital distraction). Three children had AIS 3 or greater leg injuries. These injuries included two fractures of the femur and a comminuted fracture of the tibia. Each case presented unique injury mechanisms and is discussed separately below.

CASE 1- A 14-month-old child was restrained in the center rear in a sideswipe type crash focused on the right front door at approximately 30 kph. The intrusion forced the right front seat rearward into the child's seating position. The child was fatally injured with an atlanto-occipital distraction. In this crash, severe bruising on the child's upper arms and thighs provided direct evidence that the harness was loose. As a result, this child would have moved independently of the child restraint towards the right front of the vehicle. When the harness straps pulled taut due to her excursion, her torso was stopped while her head and neck continued to move forward, putting large tension loads on the cervical spine. It is not clear in this case whether the head sustained contact. There was a penetrating wound in the submandibular area however the source of that injury was unclear. The child restraint used in this crash was most likely attached tightly as it was installed recently at a child seat checkpoint and not removed from the vehicle since. It is important to note that this case was a survivable crash; the restrained adult driver suffered only minor back pain.

CASE 2- A 37-month-old child was restrained in the left rear in a rear impact crash at 45 kph. The child suffered a skull fracture extending from left frontal bone to the left orbit, as well as an epidural hematoma. The rear impact caused the rearward displacement of the driver's seat back and the forward

displacement of the left rear seat back from intrusion. The child's head excursion possibly exacerbated by a loose harness, allowed contact between the child's head and the driver's seat back causing the skull fracture and epidural hematoma.

CASE 3- A 24-month-old child was restrained in the center rear in a right side impact crash at 34 kph. This child sustained both head and leg injuries. Significant rotation of the CRS towards the right side impact combined with increased head excursion from misrouting of the harness allowed the head and face to contact the intruding right rear door. This contact caused the right frontal lobe contusion and associated facial fractures. This child also sustained a comminuted fracture to the left distal tibia as well as a buckle fracture to the left fibula. These injuries were most likely due to the heel of the foot being loaded in compression by the intruding right front seat back as the child rotated towards the point of impact.

CASE 4- A 39-month-old child was restrained in the right rear in a right side impact crash at 37 kph. The child was fatally injured with an atlanto-occipital distraction. The severe right side intrusion caused the CRS and the child to rotate towards the intruding vehicle. Similar to case 1, looseness of the harness allowed relative movement between the child's torso and head/neck complex causing tensile loading of the neck, resulting in atlanto-occipital distraction. In addition, evidence existed that the child's head contacted the windowsill of the right rear door leading to critical head injuries.

CASE 5- A 36-month-old child was restrained in the right rear in a rear impact crash at 56 kph. The child suffered a fractured femur. Similar to case 2, a severe rear impact caused forward intrusion of the right rear seat back and rearward deformation of the driver's seat back. In contrast to case 2, the harness was tight and therefore controlled the child's head movement. However, the child's knee loaded the driver's seatback causing a fracture to the femur.

CASE 6- An 12-month-old child was restrained in the left rear in a frontal impact crash at 53 kph. This child sustained a spiral fracture of the left subtrochanteric femur. He was restrained in a T-shield child restraint which consists of a roughly triangular or "T"-shaped pad that is attached to shoulder straps, fits over the child's abdomen and hips and latches between the legs. In this purely frontal crash, loose harnesses allowed the child's upper torso to extend up and over the T-shield. Additional movement was restricted by the lower edge of the T-shield impinging on the femur causing the fracture.

DISCUSSION

This paper provides current population-based characteristics of a large number of children in FFCRS, including their overall risk of serious injury. In addition, detailed

information on the mechanisms of several serious injuries are provided. Although injuries to children in FFCRS are rare, our data point to deficiencies of the current regulation and provide direction for providing increased protection for children in this restraint system. Specifically, the results suggest that further reductions in serious injuries might be achieved by reducing head, neck, and extremity injury risks.

HEAD INJURIES- Nineteen percent of the children in FFCRS with injuries sustained injuries to the head. The head injuries included both contact induced injuries as well as inertial injuries. Injuries such as skull fracture, epidural hematoma, and frontal lobe contusion are contact injuries (Gennarelli 1986; Gennarelli 1993) that are most likely due to excursion of the head and subsequent impact with the vehicle interior. The in-depth cases demonstrated that substantial intrusion alters the space available for the child, thus allowing for contact.

Another contributing factor to head contact is looseness of both the vehicle seatbelt attaching the child restraint and of the child restraint harness. These two misuses are the most common in our study as well as others (Bull, Stroup et al. 1988; Decina and Knoebel 1997; Hummel, Langwieder et al. 1997; National Safe Kids Campaign 1999) and have been shown to increase head excursion (Henderson 1994; Hummel, et al. 1997). One role of the vehicle seat belt is to allow the occupant to "ride down" the rapidly changing velocity of the vehicle during a crash, thus spreading the energy of impact over a longer period of time. With loose vehicle belt attachment, the time and space for ride down is reduced. With a loose CRS harness, the thoracic spine is allowed to flex and there is relative movement between the torso of the child and the back of the child seat.

Children in FFCRS also sustained inertial injuries to the head such as subdural hematomas. Similar to head excursion, looseness of the child restraint harness and vehicle seat belt has been shown to increase head acceleration (Hummel, et al. 1997) thus contributing to this type of injury.

CERVICAL SPINE INJURIES- Injuries to the cervical spine of children in motor vehicle crashes are rare. (Tingvall 1987; Fuchs, et al. 1989; Huelke, et al. 1991; Kelleher-Walsh, et al. 1993; Myers and Winkelstein 1995; Weber 2002) However, the biomechanical structure and properties of the upper cervical spine of the young child place the neck at increased risk for acceleration-induced injury. (Huelke, et al. 1991; Myers 1995; Weber 2002; Yoganandan, Kumaresan et al. 2002) The ligaments are lax, the vertebrae are not ossified and are more likely to separate, the facets are predominantly horizontal thus providing limited restriction of subluxation, and the posterior-lateral contours of the vertebral bodies are not developed to restrict flexion-rotation forces. (Fuchs, et al. 1989; Janssen, Nieboer et al. 1991; Weber 2002; Yoganandan, et al. 2002) As a result, the upper cervical spine lacks the structural integrity to protect the

spinal cord and serve as an adequate connection between the head and the torso when the child's head when subject to large accelerations.

Atlanto-occipital distraction in children in FFCRS has been identified previously in high severity crashes (Fuchs, et al. 1989; Huelke, et al. 1991). These authors described a mechanism where the entire skull-C1-C2 complex is lifted off the torso by separation of vertebrae, which have not yet formed a solid interlocking structure through ossification and geometric changes. The spinal cord is fatally damaged either by extreme stretching or complete transection. This theory is supported by the injury pattern in Case 1 and Case 4. In case 4 there is clear evidence of head contact and in case 1 there is potential head contact suggesting that there may be an interplay between the tensile loading of the neck and concurrent head contact in injury causation.

LOWER EXTREMITY INJURIES- Both the surveillance data as well as the in-depth cases point to the occurrence of lower leg fractures in children in FFCRS. Injuries to the lower extremity have previously been described in children in FFCRS. (Uphold, Harvey et al. 1991) Uphold et al identified two case reports of children in FFCRS with bilateral fractures to the proximal tibia, however little attention was paid to understanding the mechanisms of these injuries. Since the lower extremities of a child in a FFCRS are free to move during a crash event, multiple injury mechanisms may exist. Our in depth cases elucidate two of these potential mechanisms – interaction with a component of the child restraint due to a loose harness (case 6) or interaction with intruding vehicle components (case 3). Case 6 illustrates a pattern of injury associated with a particular harness type, the T-shield. Other researchers have suggested that the T-shield may be hard to adjust to a tight fit in young children. (Weber, 2002) This case points to a specific injury that may be a result of this loose coupling between the child and CRS. A further understanding of the lower extremity injury pattern and associated mechanism for children in FFCRS is needed.

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 users of FFCRS, 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, on-going comparison of parent-reported restraint use and seating position to evidence from crash investigations has demonstrated excellent accuracy of the parent report. Although two cases of fatal injuries were identified in our

study, injuries of this severity are likely underrepresented in our study sample.

IMPLICATIONS FOR REGULATION- The surveillance data in this paper support that child seats designed to the current FMVSS 213 standard provide excellent overall protection in most crashes. However, as NHTSA examines the applicability of the standard for the future protection of children, our results point to potential areas for further improvements through enhanced test procedures and dummy design.

Head injuries remain of prime importance and should be mitigated by minimizing head excursion and acceleration. Child restraints should be tested in configurations that more closely mimic real world conditions to accurately measure head injury risk. Specifically, the potential for head contact with the rear of the front seat and other interior vehicle structures should be evaluated. Excursion and acceleration should also be minimized by evaluating ease of use with regard to harness tightness and CRS tightness in vehicles. Harness designs should be easy for parents to adjust to ensure tight fit. New designs of CRS that include a top tether should reduce the head excursion, and field data must be monitored to determine if these new designs reduce the incidence of these injuries.

Neck injuries, although rare, are of concern due to high likelihood for functional impairment or fatality. Data on the biomechanical response of the pediatric neck to trauma is severely limited and as a result, the neck of current child anthropometric dummies may not be representative of the real child. (Yoganandan, et al. 2002) Efforts to include pediatric neck tolerance levels in other regulatory efforts (FMVSS 208 – Frontal Impact Protection) are scientifically premature. More research is needed to understand the movement of the child's neck in traumatic events and the likelihood for injury before enacting regulatory standards, but our results indicate that this work is of paramount importance.

The occurrence of head and neck injuries in these children provides supporting data to suggest that an extension of the current recommendation to keep children rear facing beyond 1 year of age may be appropriate. In this configuration, the CRS shell itself provides restraint and protection for the neck as the crash forces are transferred to the entire torso of the child. (Weber 2002) This result is supported from data from Sweden which shows that keeping children rear facing up to age three or four years reduces all types of serious injuries not just those to the head and neck. (Isaksson-Hellman, Jakobsson et al. 1997) Changes in the rear facing recommendation may require changes to FMVSS 213, however, to allow for variations in CRS designs and attachment systems to accommodate larger children in this orientation. Further, as with head injuries, the influence of top tethers on the occurrence of the neck injuries should be monitored.

Currently, no measure of leg injury risk is part of FMVSS 213. PCPS data highlight the importance of incorporating pediatric leg kinematics when measuring injury risk in FFCRS. Biomechanically, a child's bone is different from that of an adult bone. During development, the long bones of the body change structurally from weak woven bone to strong lamellar bone. (Beaty and Kasser 2001) In addition, the geometry of the bone changes with age – increasing in length and diameter. Both the geometrical and structural changes lead to increased strength as the child ages. The relationship of these biomechanical changes to tolerance to fracture would need to be understood before lower extremity injury criteria could be incorporated in current testing protocols.

Lastly, it must be recognized that the CRS functions as only one part of the safety system. In the majority of the cases investigated, the occupant space was altered substantially by large intrusions. Effort to minimize intrusion into the occupant space for adult passengers will also translate to benefits for child passengers. The rear seats need to be recognized as seating locations for children and must be the focus of child safety interventions and testing. The CRS relies on the vehicle, through the vehicle seat and the seat belt, to provide protection to the child. This interface must be optimized.

This study provided a current population-based estimate of the risk of injury to children in FFCRS in real world crash events as well as detailed information about the types of injuries sustained and their mechanisms. The data revealed that child restraints are very effective restraint devices and further identified areas of regulatory improvement. With these data, continued evaluation and enhancement of the entire safety system and the standards that regulate it is possible to improve the safety of the youngest passengers.

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Table 1- Descriptive information on the study sample of children in FFCRS (n = 25,774)

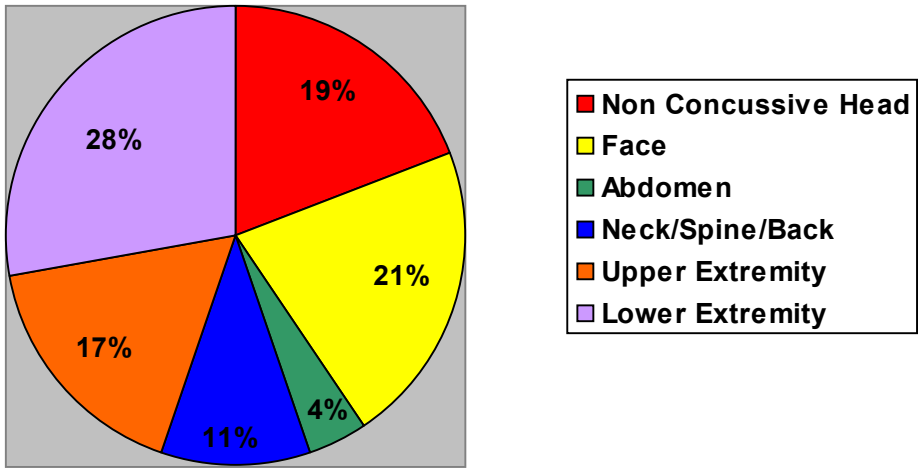
Gender	
Male	12,452 (48.3%)
Female	13,322 (51.7%)
Age (months)	
12 – 23 months	9527 (37.0%)
24 – 35 months	9578 (37.2%)
36 – 47 months	6669 (25.9%)
Seating Position	
Front Row Passenger	382 (1.5%)
Rear Row Middle	6736 (23.1%)
Rear Row, Outboard	18,656 (72.4%)
Direction of Impact	
Front	12,448 (48.3%)
Side	3547 (13.8%)
Rear	7591 (29.5%)
Other/Multiple POFC	2187 (8.5%)
Vehicle type	
Small Passenger Car	5723 (22.2%)
All Other Cars	7285 (28.3%)
Large Vans	696 (2.7%)
Pick-Up Trucks	919 (3.6%)
Sport Utility Vehicles	5162 (20.0%)
Passenger Vans	5989 (23.2%)
Crash severity	
Intrusion	2305 (8.9%)
No Intrusion, Non-Driveable	7577 (29.4%)
No Intrusion, Driveable	15,893 (61.7%)
Injury Severity	
Serious injury	43 (0.2%)
No or Minor Injury	25,731 (99.8%)

Table 2- Case details of in-depth crash investigations of children in FFCRS with AIS 3 or greater injuries

	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**
Case vehicle type	Compact 4-door sedan	Compact 4-door sedan	Full size 4-door sedan	Minivan	Mid size 4-door sedan	Compact 4-door sedan
Vehicle 2 type	Sports car	Tractor trailer	Full size van	Sport utility vehicle	Sport utility vehicle	No vehicle 2 – impacted a tree
PDOF (deg)	30	180	60	70	180	360
Delta v (kph)	29	45	34	37	56	53
Max intrusion (cm) - location	28 – B pillar	Severe override – not calculated	36 – RR door	117 – RR door	76 – C pillar	16 – toe pan
Age (months)	14	37	24	39	36	12
Height (inches)	27	38	35	Unk	Unk	27
Weight (lbs)	30	35	28	Unk	Unk	23
Seat position	Center rear	Left rear	Center rear	Right rear	Right rear	Left rear
Harness type	5-point	5-point	5-point	T-shield	5-point	T-shield
Serious injuries	Atlanto-occipital distraction, left subdural hematoma, mandibular fracture – died 4 days post crash	Skull fracture from left frontal bone to L orbit, epidural hematoma	Right frontal lobe contusion, right orbital rim fracture, right maxillary fracture, left fibular fracture, comminuted left tibia fracture	Atlanto-occipital distraction, fatal at scene	Fractured femur	Spiral fracture of left subtrochanteric femur

Misuse	Seat tightly installed at checkpoint, harness loose	Harness loose	Harness in wrong slots for forward facing; seat at 45 angle to the right after the crash	Harness loose and twisted	None noted	No locking clip used when needed; seat twisted to the left post crash; harness loose
Mechanism	Forward motion of the child independent of CRS due to loose harness Neck in tension then flexion	Rearward displacement of left front seat back and forward displacement of rear seatback caused head to impact left front seatback	Significant CRS rotation and head excursion led to head/face contact with intruding RR door; left leg impacted RF seatback	Loose harness allowed increased head excursion and contact with intruding vehicle 2	Intrusion of RR seatback pushed child towards deforming LF seatback	Loose harness allowed child's upper torso to extend over T shield loading proximal femur

Figure 1- The distribution of moderate to severe injuries by body region for the children in FFCRS from the surveillance system cases (n=47 injuries)



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