INJURY MECHANISMS IN REAR SEATED CHILDREN AGED 9-17 YEARS AND THE IMPLICATIONS FOR ASSESSING REAR SEAT PROTECTION IN CRASH TESTS

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ABSTRACT

This study examines injury mechanisms among rear seated restrained child occupants between 9 and 17 years of age using in-depth crash investigation. It was intended to determine whether current crash assessment protocols could be improved to better represent non-booster seat using children in the rear seat of cars.
Rear seat occupants aged older than 9 years were recruited from 6 major NSW trauma and paediatric hospitals. A detailed review of injury mechanisms, crash and restraint factors and injury outcome was conducted.

The case series consists of 20 occupants aged 9-17 years, 14 were in frontal impacts, 5 in side impact and 1 rear impact. Three occupants used a lap only belt and the remainder used lap sash belts. Thoracolumbar spine, chest and abdominal injuries were the most common injuries in frontal crashes. Head and pelvic injuries featured in side impacts. A neck injury was present in a rear impact case. Thoracolumbar spine injuries were associated with lumbar flexion in combination with submarining; and with axial compression, caused by excessive chest loads. Abdominal and chest injury was associated with belt loading. In side impact, contact with intruding structures was the primary mechanism of injury.

Although this case series is not representative of all rear seated children in crashes, the high proportion of thoracolumbar spine and abdominal injuries observed indicates a need for greater focus on preventing these injuries in older children using the rear seat. During vehicle crash testing, the inclusion of lumbar spine injury measures in dummies would allow for a greater understanding of the effectiveness of safety technologies in the rear seat, as would validated measures of abdominal injury.

Dummy measurements in front seat assessment focus on head, neck, chest and femur loads. While protecting these regions is important for all occupants, this study has demonstrated other body regions that require assessment when addressing rear seat occupant protection. Further the majority of injury in this case series would not be captured using existing front seat dummy protocols.

The results indicate different injury sources for rear occupants than reported for front occupants. Simply extending existing front seat assessment protocols to the rear seat may not adequately assess injury risk for older children in the rear seat.

INTRODUCTION

In-depth crash investigation studies have long been used to determine injury mechanisms and guide the development and ongoing evaluation of injury countermeasures through vehicle safety technologies.

Changes in front seat safety systems over the last decade have improved protection offered to front seat occupants as compared with rear seat occupants [1-6]. The relative risk of injury to rear seat occupants compared to front seat occupants has been shown to be greater for occupants aged 16 years and older, and also relatively greater in newer model year vehicles [1]. The addition of supplementary airbags and seat belt load limiters, as well as improved vehicle structural design, may explain improved relative protection offered to front seat occupants.

While a significant amount of research has focused on injury prevention to children in dedicated child restraints [7-10], there is little published literature on in-depth injury mechanisms to rear seat occupants aged 9 and older. It is likely that injury types and mechanisms vary by age and crash direction, but this has not been documented. While a number of studies have highlighted commonly injured regions, there is a lack of detailed information on specific injuries and their associated mechanisms.

The advocated seating position for children too large for booster seats is the rear seat. These children have no option other than the in-vehicle seat belt system, and problems faced by these occupants in achieving good seat belt fit and seated posture in most vehicles are well known[11-13]. The move towards inclusion of a 5th percentile

dummy in the rear seat of consumer crash testing in a number of countries may motivate vehicle manufacturers to address this issue. However, the assessment protocols being adopted for rear seated dummies mimic the protocols for front seated dummies. Injury mechanisms for older rear seated child occupants may differ from front seated adults. Using assessment protocols designed for optimizing protection of adult front seat occupants may not achieve the desired improvement in crash protection for older child occupants.

This study examines injury mechanisms among rear seated restrained child occupants between the ages of 9 and 17 years using an in-depth crash investigation. The findings are discussed in terms of implications for crash test assessment protocols.

METHODS AND DATA SOURCES

Rear seat occupants aged 9 years and older were recruited from six major NSW trauma and paediatric hospitals as part of a larger study. Participants and drivers were interviewed, vehicles and crash scene inspected and medical records reviewed. The principal direction of force (PDOF) involved was estimated, the vehicle's change in velocity (Δv) calculated and injury sources assigned from the data collected.
A subset of occupants aged between 9 and 17 years was extracted for this analysis.

RESULTS

Rear seat occupant sample characteristics

A series of 20 rear seated children aged from 9 to 17 years were analyzed, from 17 crashes. The sample had an average age of 12.15 years and median age of 12 years. There were similar numbers of males (n=9, 45%) and females (n=11, 55%). Further detail on each case is provided (see table 1).

Restraint status

Seat belt usage was noted and categorized into lap-sash seat belts (n=17, 85%) and lap-only belts (n=3, 15%). Of these 20 cases, 11 were seated in the rear left seat, 4 in the rear right seat and 5 in the rear centre seat.

Crash characteristics

Frontal impacts were most common (n=14, 70%), followed by side impacts (n=5, 25%) and rear impact (n=1, 5%). 19/20 cases were single impacts, and 1 case involved two impacts. Crash severity ranged from minor to severe, with Δv varying from 16km/h to 117 km/h, with an average of 49 km/h.

Vehicles

Vehicle model year ranged from 1989 to 2007 (mean = 1999). 15 vehicles (88%) were 4 or 5 door sedans, hatchbacks or wagons. The remaining 2 were a 2/3 door van and one four wheel drive vehicle (SUV).

Injury Outcome

The average injury severity score (ISS) was 9, and ranged from 1 to 29. The majority of maximum AIS (MAIS) scores for occupants fell into either the minor (MAIS 1 – 40%), moderate (MAIS 2 – 15%) or serious (MAIS 3 – 40%) categories, whilst one was classified as severe (MAIS 4 – 5%). There were no fatalities in this sample.

Injuries by crash direction - frontal impacts

There were 14 cases of frontal impact. In these cases AIS 2+ injuries were most commonly observed in the thoracolumbar spine (n=5), followed by the chest (n=4), abdomen (n=3), head (n=2),neck (n=1) and pelvis (n=1).

Thoracolumbar injuries were observed exclusively in frontal impact. One case involved a 13 year old occupant restrained with a lap-only belt. The occupant was seated in the centre-rear and sustained a L2 depressed superior end plate fracture. The remaining four cases involved occupants in 3-point seat belts. All cases had a component of spinal flexion with some cases having an additional component of spinal compression. There was evidence of associated head contact (AIS 1 head injuries) in all thoracolumbar cases. These injuries- a bleeding nose, scalp laceration, lacerated lip, chipped tooth and lip bruising- were ascribed to impacting with the front seat back. All cases of thoracolumbar injury to rear seat occupants, restrained by a 3-point seat belt, occurred in crashes with Δv greater than 60 km/h.

The primary mechanism for chest injury was loading from the seat belt, which was observed in 6 of the 7 total (86%) chest injuries. The injuries ranged from a pneumothorax, a mediastinal haematoma, and multiple anterior and posterior rib fractures. The source of the other chest injury, involving posterior rib fractures, was less clear but may have been due to contact with the seat back support on rebound A total of 3 of the 4 chest injury occupants had either single or multiple rib fractures.

Seat belt loading was attributed to all 5 abdominal injuries, which were sustained by 3 occupants

restrained with a 3-point seat belt. The injuries included liver and kidney lacerations, haematoma of the gallbladder, free fluid around the spleen and a duodenum contusion.

One case of abdominal injury in frontal impact was a 12 year-old female seated in the nearside rear and restrained by a 3-point seat belt (Case #12). The change in velocity Δv was calculated as 40km/h with a PDOF of 0º. The occupant sustained AIS 2 and 3 thoracic injuries (left mid-clavicle fracture and right rib fractures 5-9 with bilateral pneumothoraces) and an AIS 2 abdominal injury (duodenum contusion) with associated lower abdominal abrasion. These injuries were all linked to interaction with the seat belt.

There were two frontal impact cases with AIS 2+ head injuries. The first case involved a nasal bone fracture from a frontal impact with an occupant restrained in a 3-point seat belt. This was due to excessive forward torso displacement, possibly associated with torso rollout from the sash belt and subsequent contact with the B-pillar in a crash with a high change in velocity (Δv=62 km/h) oblique impact (PDOF=20º). The second case was a head on impact with a pole. The occupant was only restrained by a lap belt and sustained a nasal wall and orbital floor fracture from impacting another seat back (Δv=29.7 km/h, PDOF=0º).

The final frontal impact case sustained a pelvic injury. The pelvic injury involved a right iliac crest fracture and was associated with loading from the seat belt webbing from a lap-only belt.

Injuries by crash direction- side impacts

Out of the 5 children involved in side impacts, there was one AIS2+ head injury. This was associated with the head striking the impacting vehicle. For four of these five cases, intruding structures (side door, a power pole and another vehicle) were the sources of injury. The other source of injury resulted from seat belt webbing.

The apparent mechanism of head injury in side impact was by impact with an intruding external object- in this case another vehicle. The case was one of a child in an oblique side impact despite the presence of side curtain airbags (case #19). The occupant, a 12 year-old female, was seated in the nearside rear (struck-side) of a medium size hatchback. She was 153cm and weighed 32kg. The occupant was restrained by a 3-point seat belt and side (curtain) airbags deployed. The case vehicle was attempting to make a right turn from a two-lane divided road at traffic lights when it was struck on the nearside by a heavy truck. The PDOF was estimated at -75º and was considered an oblique side impact. The Δv was calculated as 28km/h. The maximum recorded intrusion was 170mm at the cant rail. The occupant sustained a number of head injuries as well as numerous extremity contusions, abrasions and lacerations. Head injuries included a left parietal haematoma (AIS 3), left parietal bone fracture (AIS 2) and a subarachnoid haemorrhage (AIS 2). The curtain airbag should have prevented head contact with the external impact partner (truck), however the curtain airbag inflation pattern was estimated to cover only the most rearward 20% of the window area, with the remainder of the window covered by a non-inflatable region of airbag fabric that provided no head protection. With an oblique impact, it is expected that the occupant would have travelled diagonally forward, missing the inflated region of the curtain airbag and contacted either the intruding vehicle or the window sill.

Injuries by crash direction- rear impacts

There was only one case of a rear impact with the 10 year old occupant sustaining an AIS 3 neck injury, which was a complete bilateral dislocation of the facet joints of the C2 and C3 vertebrae. This was a severe rear impact (Δv = 57km/h, PDOF=150º). Although the mechanism of injury is not clear it was believed to be due to the occupant impacting with the C pillar as they were seated in the rear left. Other minor facial injuries- bruising of the left temple, left cheek and two broken teeth, support this assumption.

Table 1.
Rear seat vehicle accident cases of occupant children aged 9-17 years.
Case numbers labelled with an * had a head injury with an Abbreviated Injury Scale (AIS) score of 1

									Presence of AIS 2+ Injuries					
Case No	**Age**	**Sex**	**Vehicle MY**	**Crash Type**	**PDOF**	**DeltaV (km/h)**	**Seat Belt**	**ISS**	**Head Injury**	**Neck Injury**	**Chest Injury**	**Thoraco-lumbar Injury**	**Abdominal Injury**	**Pelvic Injury**
1*	10	Female	1995	Rear	-150	56.8	Lap-sash belt	11		X				
2*	15	Male	1995	Frontal	0	35.6	Lap-sash belt	6					X	
3*	9	Male	2000	Frontal	5	117	Lap-sash belt	10						
4*	11	Female	2000	Frontal	5	117	Lap-sash belt	22			X	X		
5*	17	Female	2001	Frontal	0	N/A	Lap-sash belt	29		X		X		
6*	17	Male	2001	Frontal	0	N/A	Lap-sash belt	21			X	X		
7	13	Male	1989	Frontal	0	29.7	Lap belt	13	X					X
8	10	Male	2002	Struck side	30	N/A	Lap-sash belt	2						
9*	11	Female	2000	Struck side	-60	24.3	Lap-sash belt	2						
10	12	Male	2001	Frontal	60	39.7	Lap-sash belt	1						
11	14	Female	1994	Struck side	15	21.6	Lap-sash belt	1						
12*	12	Female	1998	Frontal	10	39.6	Lap-sash belt	17			X		X	
13	10	Female	1993	Frontal	20	62.3	Lap-sash belt	17	X			X	X	
14	12	Male	2005	Frontal	10	55	Lap-sash belt	1						
15	10	Female	2007	Struck side	30	18.3	Lap-sash belt	2						
16*	13	Female	1994	Frontal	30	67.4	Lap belt	5				X		
17*	10	Male	1994	Frontal	30	67.4	Lap-sash belt	1						
18*	14	Male	2004	Frontal	0	36.5	Lap-sash belt	2						
19	12	Female	2006	Struck side	-75	28.5	Lap-sash belt	10	X					
20*	11	Female	2002	Frontal	#1: 90, #2: 0	#1: 16.1	Lap belt	6			X			

DISCUSSION

The key findings of this study indicate that thoracolumbar, chest and abdominal injuries occurred in rear seated children in frontal impacts. These injuries were primarily associated with seat belt loading. Head injuries were observed in both frontal and side impacts and were primarily associated with contacting rigid internal structures or the crash partner. For one severe rear impact case, neck and minor head injuries were found.

For frontal impacts, the primary mechanism of injury was loading from the seat belt. The results of this work suggest a need to control loads exerted on the pediatric chest from the seat belt, and to design countermeasures to reduce abdominal injury.

The high incidence of chest injuries to rear seat occupants is consistent with a number of studies of NASS-CDS for adults [2, 6]. However, previous studies have reported an absence of chest injury to children restrained with a lap-sash seat belt [14]. In contrast the results of this study reported AIS 2+ chest injuries in 15% of rear seated children aged 9-17 years wearing a lap-sash belt; further demonstrating the need to control belt loads on the chest of rear seat occupants.

Abdominal injuries in frontal impacts were also commonly observed, and all were directly associated with seat belt loading. Younger occupants have been shown to have the highest risk of abdominal injury [15] and are commonly reported in studies of rear seated children in mass-crash databases [14, 16, 17]. These results demonstrate the need to address abdominal injuries in the rear seat for older children that are not using booster seats to control belt geometry.

There were a number of thoracolumbar spine injuries from frontal impacts (25%) in this case series. Lumbar spine injuries resulting from children using lap-only belts, such as the single case reported in this study, have been commonly observed [18]. Lumbar spine injuries have also been observed in children using 3-point seatbelts, particularly when the occupant submarines under the lap belt [15, 17]. The presence of thoracic and lumbar spine injuries in restrained adults has been reported to increase with Δv greater than 50 km/h [19]. This pattern was consistent with our case series of rear seated children where Δv varied from 62-117km/h for thoracolumbar injuries. Although thoracolumbar spine injuries have previously been shown to be rare in restrained front seat occupants [19], this study has shown a relatively high number of this injury type for rear seated child occupants and demonstrates a need to address thoracolumbar spine injuries for this group.

Head injuries withan AIS 2+ were observed in rear seat occupants in both frontal and side impacts. They were all associated with contact with rigid side structures such as the B pillar, seat back or the impact partner. Methods introduced in the front seat, such as side curtain and thoracic airbags have the potential to reduce injury to such occupants, but full coverage of the rear window area is needed.

Implications

Regulatory control of the rear seat is limited to the requirement of 3-point seat belts in all (or nearly all) seating positions in most jurisdictions. In Australia, there are currently no performance requirements for rear seat dummies in the consumer test program, Australasian New Car Assessment Program (ANCAP). The Japanese New Car Assessment Program (JNCAP) recently introduced the Hybrid III 5th% adult female into the rear seat of the offset frontal impact test. Injury measures assess head, neck chest and abdominal injury. The assessment of abdominal injury is based upon whether the lap belt slides over the pelvis and penetrates the abdominal cavity. JNCAP also includes a static assessment of the rear seat that analyses the position of the upper seat belt anchorage. The European New Car Assessment Program (EuroNCAP) assesses the performance of the rear seat environment, but this is currently limited to head and chest injury measures in an 18-month old and 3 year-old dummy restrained in a dedicated child restraint. EuroNCAP have announced that they will begin to assess rear seat protection with a 5th percentile Hybrid from 2014[20].

The results from this study suggest that there is potential benefit in following the lead of JNCAP to include a dummy in the rear seat that is restrained by the adult seat belt, such as the Hybrid III 5th% adult female. The Hybrid III 5th% adult female approximates a 12 year-old child in stature, and while the age distribution of the occupancy of the rear seat isn't clear in Australia, the 5th% adult female allows the assessment of injury to both older child occupants and small elderly occupants. These two occupant types have been identified by this research and others [4] as groups that require improved protection in the rear seat.

Thoracolumbar spine injuries appeared quite frequently in this small sample, despite the use of 3-point seat belts. The inclusion of lumbar spine injury measures in dummies would allow for a greater understanding of the effectiveness of safety technologies in the rear seat. Abdominal injury was also commonly observed in rear seat occupants, particularly in younger occupants, and more robust injury measures need to be developed beyond the

current measures of simply whether the lap belt penetrated the abdomen. This is certainly one area in which substantial research needs to be conducted, as work to date has focussed on child dummies for assessment of dedicated child restraints. Additionally, studies have recommended reducing the rear seat cushion depth to better accommodate rear seat users [11, 12], and to reduce the likelihood of a child choosing a slouched posture, which results in poor initial belt position.

CONCLUSION

This study has demonstrated that there are common injury mechanisms for rear seated older children that are likely to be amenable to prevention by improved rear seat and belt design, together with injury countermeasures to minimise head injury risk, such as curtain airbags. The results support the need for consumer and or regulatory consideration of the rear seat environment.

ACKNOWLEDGEMENTS

This work was funded by an ARC Linkage grant with partner funding from the NSW Centre for Road Safety. Lynne Bilston and Julie Brown are supported by NHMRC fellowships.

The authors would also like to acknowledge Stuart Newstead, Michael Fitzharris and the ANCIS program for data sharing of rear seat occupant cases.

REFERENCES

1. Bilston, L.E., W. Du, and J. Brown, *A Matched-Cohort Analysis of Belted Front and Rear Seat Occupants in Newer and Older Model Vehicles Shows That Gains in Front Occupant Safety Have Outpaced Gains for Rear Seat Occupants.* Accident Analysis and Prevention, 2010. **42**(6): p. 1974-1977.
2. Parenteau, C. and D. Viano, *Field Data Analysis of Rear Occupant Injuries-Part I: Adults and Teenagers.* SAE Technical Paper, 2003(2003-01-0153).
3. Kuppa, S., J. Saunders, and O. Fessahaie. *Rear Seat Occupant Protection in Frontal Crashes*. in *19th International Conference on the Enhanced Safety of Vehicles*. 2005. Washington, D.C.
4. Kent, R., et al., *Rear Seat Occupant Protection In Frontal Crashes And Its Feasibility*, in *20th International Conference on the Enhanced Safety of Vehicles*2007: Lyon, France.
5. Forman, J., et al., *Occupant Restraint in the Rear Seat: ATD Responses to Standard and Pre-tensioning, Force-Limiting Belt Restraints.* Association for the Advancement of Automotive Medicine, 2008. **52**: p. 141.
6. Esfahani, E. and K. Digges, *Trend of Rear Occupant Protection in Frontal Crashes over Model Years of Cars.* Stapp Car Crash Journal, 2009. **53**: p. 75-91.
7. Arbogast, K.B., et al., *An Evaluation of the Effectiveness of Forward Facing Child Restraint Systems.* Accident Analysis & Prevention, 2004. **36**(4): p. 585-589.
8. Durbin, D., M. Elliott, and F. Winston, *Belt-positioning Booster Seats and Reduction in Risk of Injury Among Children in Vehicle Crashes.* Journal of the American Medical Association, 2003. **289**(21): p. 2835.
9. Brown, J., et al., *Serious Injury is Associated with Suboptimal Restraint Use in Child Motor Vehicle Occupants.* Journal of paediatrics and child health, 2006. **42**(6): p. 345-349.
10. Brown, J. and L. Bilston, *Child Restraint Misuse: Incorrect and Inappropriate Use of Restraints by Children Reduces their Effectiveness in Crashes.* Journal of the Australasian College of Road Safety, 2007. **18**(3).
11. Bilston, L. and N. Sagar, *Geometry of Rear Seats and Child Restraints Compared to Child Anthropometry.* Stapp Car Crash Journal, 2007. **51**: p. 275-298.
12. Huang, S. and M. Reed, *Comparison of Child Body Dimensions With Rear Seat Geometry.* SAE Technical Paper, 2006. **115**(6): p. 1078.
13. Klinich, K.D., Pritz, H.B., Beebe, M.S., and Welty, K. E. . *Survey of older children in automotive child restraints.* in *38th Stapp Car Crash Conference*. 1994. Warrendale, PA: Society of Automotive Engineers.
14. Parenteau, C. and D. Viano, *Field Data Analysis of Rear Occupant Injuries Part II: Children, Toddlers and Infants.* SAE Technical Paper, 2003(2003-01-0154).
15. Arbogast, K., et al., *Predictors of Pediatric Abdominal Injury Risk.* Stapp Car Crash Journal, 2004. **48**: p. 479.
16. García-España, J. and D. Durbin, *Injuries to Belted Older Children in Motor Vehicle Crashes.* Accident Analysis and Prevention, 2008. **40**(6): p. 2024-2028.
17. Durbin, D., K. Arbogast, and B. Moll, *Seat Belt Syndrome in Children: a Case Report and Review of the Literature.* Pediatric Emergency Care, 2001. **749**(5161/01): p. 1706-0474.
18. Arbogast, K.B., et al., *Evaluation of Pediatric Use Patterns and Performance of Lap Shoulder Belt Systems in the Center Rear.* Annual proceedings/Association for the Advancement of Automotive Medicine.

Association for the Advancement of Automotive Medicine, 2004. **48**: p. 57-72.
19. Richards, D., et al., *Incidence of Thoracic and Lumbar Spine Injuries for Restrained Occupants in Frontal Collisions.* Annual Proceedings from the Association of the Advancement of Automotive Medicine, 2006. **50**: p. 125-139.
20. *EuroNCAP 2013-2016 Desktop Roadmap*. 01/03/2013]; Available from: http://www.carhs.de/etc-doc/EuroNCAP_Desktop_Roadmap_2013-2016.pdf.