SPINAL INJURIES IN REAR SEATED CHILD OCCUPANTS AGED 8 – 16 YEARS

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Paper No 07-0461

ABSTRACT

While spinal injury in child occupants is relatively rare, the significance of these injuries is high. For children too big for booster seats the best available protection is adult belts in the rear seat. This paper presents a case series of 27 rear seated restrained child occupants aged between 8 and 16 years diagnosed with a injury to the spinal region, and discusses the current lack of regulatory or consumer assessment of injury risk to child occupants too big for booster seats.

Data was collected from retrospective medical record review of all children treated at two major children's hospitals over a five year period. Cases were collected using spinal trauma related ICD 10 codes and all restrained child occupants between the ages of 8 and 16 years (inclusive) were extracted. All types and severities of spinal injuries were included. Restraint, seating position and crash details were taken from ambulance reports.

Most children sustained minor injuries (56%), however 13 of the 27 sustained moderate to severe spinal injuries. These include spinal cord injuries, vertebral fractures and dislocations and major ligamentous damage. Most minor injury occurred in the cervical region, and most serious injury occurred in the lumbar region. Almost all children were using the available lap sash seat belt (23/27).

There was more serious spinal injury among those children aged 8 – 12 (9/18) than there was among the older children aged 13-16 (3/9), and more than half of those younger children with serious injury (5 of 9) had associated abdominal injuries, while associated abdominal injury was not a feature among the older children.

International booster seat use legislation, the lack of regulatory and consumer assessment of injury potential to older rear seated children and the need for more widespread evaluation of rear safety for older child occupants is discussed.

INTRODUCTION

Spinal trauma in children is rare but the significance both in terms of financial and community cost is high. The most common cause in children is motor vehicle crashes [1-5]. For child occupants younger than approximately 8 years there are a number of different restraints that have been designed for the anatomical and anthropometric immaturity of children. Other authors have investigated spinal injury in children using dedicated child restraints [6-11], and in children using adult belts who should have been using dedicated child restraints [12-13]. However few have looked at this issue in older children for whom the adult lap sash seat belt is the best available restraint.

There are anatomical differences in the maturing spine compared to that of an adult, and while changes continue well into adulthood, most literature suggests much is complete by about 8 years. Anatomically then there is no reason to suspect any inherent difference in spinal injury risk in children from this age up. However, the overall growth of children continues until somewhere between 16 and 18 years, and since adult occupant restraint systems are designed for adult anthropometry there is likely to be some consequence for smaller occupants using these restraint systems.

Adult seat belts are effective in providing crash protection for child occupants compared to no restraint at all [14-16], but for children up to age 8, the overall level of protection has been found to be much better in restraints specifically designed for the smaller anthropometry of these children [17-18].

There are particular injury types associated with seat belt use, and this includes some forms of spinal injury. The 'seat belt syndrome' is a well established pattern of injuries involving the lumbar spine and and/or abdomen in occupants using adult belts and is attributed to a mechanism involving hyperflexion of the upper torso around a poorly positioned lap belt. While this syndrome was originally described in adult occupants using lap only belts [19-20], it has also been frequently discussed in terms of child occupants [18, 21].

The primary measure introduced to counter the seat belt syndrome has been the replacement of 2 point lap only belts with 3 point lap sash belts. However in many cases, these types of injuries have been described in association with both lap only belt use and lap sash belt use [21-23]. Similarly cervical injury has also been associated with seat belt use [6, 24].

In 1994, Lane [21] noted that improvements to seat belt and seat design were required to further reduce these types of injuries in 3 point lap sash belts.

This paper presents a sample of child occupants aged 8-16 years diagnosed with a spinal injury following involvement in a crash, illustrating the significance of seat belt like syndrome injuries in these children.

METHODS

Medical records for all children aged 0-16 years treated at the Children's Hospital Westmead and the Sydney Children's Hospital from 1999 to 2004 with ICD 10 codes for all types and severities of spinal trauma were retrospectively reviewed. The ICD codes included all those for cord injuries, vertebral fractures and dislocations, ligamentous injury and internal and external soft tissue injuries. All cases where the child had been injured as a passenger in a motor vehicle were then selected for inclusion in the overall data set. A case series of rear seated restrained children aged 8 – 16 years was then constructed from this data set.

Information related to the child's age, gender, height, weight and detailed injury descriptions were then extracted. Detailed information related to the crash, seating position and restraint type and quality was also extracted. The ambulance report was used for this purpose wherever possible, and where conflicting information was recorded in the ambulance report and the medical record, details from the ambulance report was used. Crash data in the ambulance report includes a description of the crash, details of the extent and location of damage to the vehicle, and an estimation of impact severity as low, medium or high, based on the extent of damage. This was used to compile case descriptions.

Quality of restraint use was classified incorrect if ambulance officers noted misuse of the restraint. All other cases were classified as correct.

Spinal injuries were coded according to the Abbreviated Injury Scale (AIS:90), and classified as minor or serious. Minor injuries consisted of external and soft tissue injuries analogous to AIS 1 injuries. Major spinal injuries were those injuries that posed some risk to the integrity of the spinal column or cord and included cord injuries, bony fractures and dislocations, and rupture of spinal ligaments. Associated injuries were also recorded.

Age in months was estimated using date of birth and date of hospital attendance, and then rounded to the nearest whole year.

The study methodology was approved by the Human Ethics Committees at the Children's Hospital at Westmead and the Southeastern Area Health Service, and ratified by the University of NSW, Human Research Ethics Committee.

CASE SERIES OVERVIEW

Overall, data was collected for 81 child occupants aged between 2 and 16 years, (with a mean age of 8.5 years) who had been diagnosed with an injury to the spinal region. There were 40 restrained children aged between 8 and 16 years, 27 rear seated, 12 front seated and one child whose seating position could not be determined. The median age of front and rear seated children was 12 and 11 years respectively. This case series contains details for all those known to be rear seated. Each case is summarised in Table 1.

Almost two thirds of the case series were female, and all but one child (Table 1 #11) was using an adult belt. This child was using a booster seat in combination with an adult lap sash belt. Of the 26 using adult belts, 3 were using lap only belts (Table 1 #9,10 & 27). The remaining 23 were using lap sash belts however incorrect use of the sash portion of the belt was identified in 2 cases (Table 1 #3 & 13).

Twenty of the 26 children occupied outboard seating positions (11 in the left rear and 9 in the right rear) and 5 occupied the centre rear position (Table 1 #9, 10, 13, 18 &27). The exact seating position of two rear seated children could not be determined (Table 1 #14 & 24).

The most frequent crash type was frontal (12 cases). There were 2 side impacts, 7 rear impacts, 3 roll overs; and 2 cases where impact direction was unknown. All cases involving roll over involved either an impact with a fixed object or another vehicle prior to or after rolling. More than half of the cases (17/27) were classified as high severity. There were 7 cases involving single vehicles, and all of these involved impacts with fixed road side objects such as trees or poles.

Of the children, approximately half had minor AIS 1 external injuries and 13/27 sustained significant spinal trauma. No child with external AIS 1 spinal injury sustained any significant injury to other body regions while most (10/13) with more serious spinal trauma did. These associated injuries primarily involved abdominal and head regions. Overall, the cervical level was most frequently involved (17/27) followed by the lumbar region (7/27). There were 3 children with thoracic spinal injury. However almost all injury to the cervical region involved external AIS 1 injuries (14/17) whereas almost all lumbar injury (6/7) and all thoracic injury involved serious spinal trauma.

Proportionally more serious injury occurred in high severity impacts (73%) compared to other severities (10%); single vehicle impacts (80%) compared to multiple vehicle impacts (40%); and impacts with fixed objects (83%) compared to impacts with other vehicles (37%). There was less difference in outcome by seating position (50% serious in outboard positions compared to 60% in the centre position) and restraint type (45% of lap sash users with serious injury compared to 33% of lap only users). All children identified to be using their restraint incorrectly sustained the more serious types of injuries. There was a fairly even split of minor and serious injury in frontal and side impacts. All cases involving rollover involved serious injury, while no cases involving rear impact involved serious injury.

There was more serious injury among those children aged 8-12 (50%) than among the older children (33%). However, there was little difference in the proportion of younger and older children in single vehicle crashes and impacts with fixed roadside objects. Older children were more often in high severity crashes (67% compared with 50%).

While there was a greater frequency of younger children seated in centre rear positions, the proportions of younger and older children using lap only belts was similar. In other words most of the younger children seated in centre rear positions were using lap sash seat belts.

Serious spinal injury among the younger children also often involved an associated abdominal injury, and this involved serious abdominal (AIS3+) injury in 44% of cases. There was no serious abdominal injury among the older children.

DETAILED DESCRIPTIONS OF CASES WITH SERIOUS SPINAL TRAUMA

As described above, there were 13 children who sustained significant spinal trauma. This included 1 child using a booster seat, 1 child using a lap only belt, and 10 children using lap sash belts. Incorrect use of the sash belt was definitively identified in 2 cases.

Booster Seat

This case (Table 1, #11) involved a 9 year old male in the right rear of an SUV using a lap sash belt with the booster. The vehicle rolled over an embankment at high speed, and then hit a tree on the right side. Both the child and the booster were reported to have been ejected out of the right window. The child sustained an atlanto-occipital dislocation and extradural hematoma in the cervical region. There was also degloving of the skin over the left scalp and diffuse axonal injury within the child's brain.

Lap Only

One of the three children using lap only belts sustained serious spinal injury. This (Table 1, #10) was a 9 year old female seated in the centre rear of a vehicle that hit a power pole side on (angle unknown) at high speed, breaking the pole. The child sustained a wedge fracture of L1with no ongoing neural deficits and abdominal abrasion with internal abdominal injury, and a forehead abrasion.

Incorrect Lap Sash Use

Incorrect use of the sash in children using lap sash belts was reported in two cases and both involved serious injury. In the first (Table 1, #3), an 8 year old female was seated in the right rear of a vehicle involved in a high severity frontal impact. The child sustained an L2 chance fracture with ligament rupture and intradural haemorrhage causing displacement at the cauda equina nerve roots. There was also grazing of the left upper abdomen, bruises to the right lower abdomen and internal abdominal organ contusions.

The second case (Table 1, #13) involved a 10 year old male seated in the centre rear of a vehicle fitted with a lap sash belt in this position. This child also failed to use the sash part of the belt and also sustained an L2 chance fracture with external contusions, this time in a high severity single vehicle impact with a tree. The orientation of this impact was not reported.

Correct Lap Sash

Five of the nine children with serious spinal injury correctly using lap sash belts also sustained lumbar and or thoraco-lumbar junction fractures.

No	AGE	Crash Details	Seat & Restraint	Quality	Spine Injury	Other injuries
1	Female, 8 yrs	Low severity multiple vehicle side impact o/s	Left rear, Lap sash	Correct use	Minor sorft tissue	abdominal contusion, pain
2	Female, 8 yrs	High severity single vehicle frontal impact with fixed object	Left rear, Lap sash	Correct use	small graze left side of neck anteriorly. Lumbar soft tissue hematoma (L1)	belt abrasions bilaterally
3*	Female, 8 yrs	High severity multiple vehicle frontal impact	Right rear, Lap sash	Incorrect use, sash not used correctly	Chance fracture L2 with ligament ruptue and intradural haemorrhage causing anterior displacement at the cauda equina nerve roots. Soft tissue oedema posterior to the entire spine and in the interspinous reqion of C1/2	grazing left upper abdomen; bruises right lower abdomen; pancreatic contusion; mesenteric contusion
4	Male, 8 yrs	Medium severity single vehicle frontal impact with fixed object	Left rear, Lap sash	Correct use	bruise neck	nasal fracture
5	Male, 8 yrs	Unknown severity multiple vehicle frontal impact	Right rear, Lap sash	Correct use	graze right side of neck	contusion behind left ear
6	Female, 9 yrs	Low severity multiple vehicle rear impact	Right rear, Lap sash	Correct use	minor soft tissue only	nil
7*	Female, 9 yrs	High severity multiple vehicle frontal impact	Right rear, Lap sash	Correct use	lateral chance type injury at T12/L1 and weakness/parathesis left leg	rupture left kidney with retroperitoneal haematoma; associated rib fractures left side 10-11; large left side pulmonary contusion with pleural effusion
8*	Female, 9 yrs	High severity single vehicle frontal impact with fixed object	Left rear, lap sash belt	Correct use	Chance fracture L1 with anterior wedging, fracture through pedicles, paraspinal hematoma	Significant small bowel injury, retorperitoneal heamatoma; bilary tree perforation, transverse bruise across abdomen at level of umbilicus; fracture lateral aspect of right 10th rib
9	Female, 9 yrs	Medium severity multiple vehicle rear impact	Centre rear, Lap only	Correct use	transient right arm numbness, called neck sprain	nil
10*	Female, 9 yrs	High severity single vehicle frontal impact with fixed object	Centre rear, Lap only	Correct use	wedge fracture L1 spinous process with extension through the superior articular facets of L2 vertebral bilaterally and subluxation of L1-2 facet joints	abdominal abrasion; oedema and fluid in root of the mesentry, paracolic gutter and pelvis; abrasion forehead
11	Male, 9 yrs	High severity single vehicle roll over then side impact with fixed object	Right rear, Booster, lap sash	Ejected out window	atlanto occipital dislocation with extra dural hematoma extending anteriorly to C1 and in a prevertebral distribution to the level of C4, and associated ligament damage	DAI left frontal lobe, left temporal lobe, basal ganglia and right internal capsule regions; deglove injury left scalp and eye region; fracture right clavicle; fracture right pubic ramus
12	Female, 10 yrs	High severity, multiple vehicle impact, unknown	Left rear, lap sash	Correct use	fracture pedicle of C2 and lamina on left. Distraction of fragments on right. Anterior slip of C2 on C3	Liver laceration associated with a subscapular hematoma

Table 1. Case series of spinal injuries in rear seated child occupants

No	AGE	Crash Details	Seat & Restraint	Quality	Spine Injury	Other injuries
13*	Male, 10 yrs	High severity, single vehicle impact with fixed object	Centre rear, lap sash	Incorrect Use	L2 chance fracture, chance fracture L2 and anterior wedging of L1	hematoma left side of back; anterior abdominal and right chest bruising; wrist contusion
14	Female, 12 yrs	Medium sevrity, Multiple vehicle rear impact	unknown rear, lap sash	Correct use	minor soft tissue only	nil
15	Female, 12 yrs	Medium severity, Multiple vehicle frontal impact	Left rear, lap sash	Correct use	minor soft tissue only	nil
16	Female, 12 yrs	High severity impact details unknown	Left rear, lap sash	Correct use	Ligamentous injury and fracture superior body T2 with transient neurological deficiet	Left adrenal hematoma, pulmonary contusion, liver contusion
17	Female, 12 yrs	High severity side impact o/s and impact with fixed object	Left rear, lap sash	Correct use	Crush fractures T4 - T9. MRI; Extensive soft tissue oedema posteriorly and ligamentous injury.	open fracture mandible; minor facial & neck abrasions; fracture right scapular, small pleural effusions
18*	Female, 12 yrs	High severity, Multiple vehicle frontal impact	centre rear, lap sash	Correct use	Wedge fracture L1/2.	abdominal abrasion,; abrasion r forehead
19*	Female, 13 yrs	High severity, Multiple vehicle frontal impact and then roll over	Left rear, lap sash	Correct use	Wedge compression fracture T12 and L1 vertebral bodies, with ligamentous injury	fracture right humerus
20	Male, 13 yrs	Medium severity, Multiple vehicle rear impact	Right rear, lap sash	Correct use	soft tissue injury, intial parasthesia right hand that resolved	nil
21*	Male, 13 yrs	High severity frontal impact with fixed object	Right rear, lap sash	Correct use	wedge compression of L3, Chance fracture L1/2 with sensoral changes scaral region	seat belt mark across abdomen
22	Female, 14 yrs	High severity, Multiple vehicle rear impact	Right rear, lap sash	Correct use	minor soft tissue only	nil
23	Female, 14 yrs	High severity near side impact and then roll over	Left rear, lap sash	Correct use	Lateral mass C1 fracture, crush fracture T8	Long deep lacerations to right cheek and ear, glass in left eye
24	Male, 14 yrs	Medium severity, frontal impact	Rear unknown, lap/sash	Correct use	Neck sprain	Abrasions and contusion knees
25	Male, 14 yrs	High severity, Multiple vehicle frontal impact	Left rear, lap sash	Correct use	soft tissue neck injury	abrasion left to right over neck; abrasion lumbar area
26	Female, 14 yrs	Medium severity, Multiple vehicle rear impact	Right rear, lap sash	Correct use	lateral neck contusion, neck pain	nil
27	Male, 15 yrs	High severity, Multiple vehicle rear impact	Centre rear, lap only	Correct use	transient tingling in arms, neck pain	abdominal pain

Table 1. Case series of spinal injuries in rear seated child occupants (continued)

In case #7 (Table 1), a 9 year old female sustained a lateral chance type injury at T12/L1 with residual neural deficits, together with a ruptured left kidney and retroperitoneal haematoma, left side rib fractures left side 10-11 and a large left side pulmonary contusion with pleural effusion. This child was seated in the right rear of a vehicle involved in a high severity head on collision with another vehicle. A similar pattern of injuries was observed in case #8, (Table 1), where another 9 year old female using a lap sash belt, this time in the left rear, sustained significant abdominal injuries, rib fracture and a chance fracture of L1. This child was in a vehicle that was clipped by another vehicle before running off road and impacting a pole head on.

A male aged 13 years (Table 1, #21) sustained a wedge compression fracture of L3, and a chance fracture of L1/2 with sensoral changes in the sacral region. There was also a seat belt mark across the abdomen. He was seated in the right rear of a vehicle that was involved in a high severity frontal offset collision with a power pole. A female aged 12 years also sustained a wedge fracture of L1/2 (Table 1, #18) and abdominal abrasions. This child also sustained a forehead contusion and was seated in the centre rear of vehicle involved in a high severity multiple vehicle frontal impact. A 13 year old female (Table 1, #19) sustained a wedge compression fracture of T12 and L1 vertebral bodies, with associated ligamentous injury and fractured right humerus in a vehicle that was involved in a high severity frontal impact before rolling over. She was seated in the left rear.

Two children sustained different types of fractures in the thoracic region. One child, a 12 year old female sustained crush fractures of T4-T9 (Table 1, #17) while seated in the left rear of a vehicle that was t-boned by a heavy vehicle and then impacted a power pole on the off side of the vehicle. The child also sustained facial and scapular fractures and a small pleural effusion. The other, (Table 1, #24) also a 12 year old female, sustained a fracture to the superior body of T2 together with ligamentous injury, transient neurological deficit, a left adrenal hematoma and pulmonary and liver contusions.

There were also two of the nine children using lap sash belts who sustained cervical fractures. The first, a 10 year old female (Table 1, #12) sustained a fracture of the pedicle of C2 and a liver injury. This child was seated in the left rear of vehicle involved in a high severity multiple vehicle impact. The second was involved in a high severity near side impact with another vehicle before rolling over (Table 1, #23). This child, a 14 year old female, was seated in the left rear and sustained a lateral mass fracture of C1, and a crush fracture of T8. She also sustained a long deep laceration over the right cheek and scalp.

DISCUSSION & CONCLUSIONS

This case series presents details of 27 rear seated children aged 8-16 years with spinal injury who presented to the two major children's hospitals in Sydney over a five year period. These children, together with the 13 front seated children who were not included in this series, represent all child occupants within this age range who were diagnosed with spinal trauma throughout this time. While these relatively small numbers, and even smaller numbers of serious injury, reiterate the relative rarity of spinal trauma in child occupants, the problem should not be underestimated. Involvement in a motor vehicle crash as an occupant is one of the most common causes of spinal injuries in children of this age [1-5]. A recent five year estimate of the costs to the New South Wales Compulsory Third Party Scheme for children 16 years and under with spinal trauma was approximately $AUS68 million. Lifetime cost for a single child with a catastrophic spinal injury is estimated to be in the order of $AUS4.5 million (personal communication J Edwards NSW Motor Accidents Authority, August 2006).

Furthermore, from a road safety perspective, these small numbers might mean that spinal injury among child occupants may have historically merited a lower priority than more frequently occurring injuries. However as more and more vehicle safety improvements have been introduced (with concomitant reductions in casualties) the need for identifying the further scope for reducing casualties increases.

Unlike injuries to other body regions, spinal injuries are often mechanistically associated with restraint interaction. In this sample there are at least 8 such cases (indicated in Table 1), and all would fit the classic "seat belt syndrome".

The seat belt syndrome is a well established pattern of injuries that links trauma to the lumbar spine and thoraco-lumbar junction with restraint factors [18-21]. Originally the term referred to a pattern of injury seen in adults using poorly positioned lap only belts, but over the last few decades it has often been reported in children in both lap only and lap-sash belts. However, there has been little investigation of the mechanism of this injury in lap sash belts.

Notably in the 8 'seat belt syndrome' cases in this series, 7 children were using lap sash belts, although incorrect use of the sash was reported in 2 of the cases. A lap only belt was being used by only one child. All cases involved frontal impacts.

Gotschall et al [24] compared the risk and pattern of injury among children using lap sash and lap only belts and reported observing abdominal injuries in the same frequencies in the two types of belt system but not lumbar fractures. They concluded that lap sash belts appear to be protective for lumbar fracture. This does not appear to be the case in this series. Gotschall et al did however discuss possible mechanisms of belt induced abdominal injury in lap sash belts suggesting that it is difficult to obtain good sash belt fit in small children and that a loose fitting sash belt might result in the crash loads being applied predominately to the lap portion of the belt. This might also explain the mechanism involved in lumbar fracture, if the lumbar part of the belt is positioned above the bony pelvis.

There are primarily two ways, acting together or alone, that the lap part of a correctly tightened belt might be positioned improperly. There may be improper positioning initially i.e. from poor fit and/or poor lap belt anchorage geometry, or the belt might move upwards if the buttocks slide forwards during the impact (i.e. submarining).

"Submarining" of the pelvis was also proposed as a possible mechanism of lumbar (and lower thoracic) fracture in lap sash belts by Huelke et al [25]. These authors suggested that there were several mechanisms that might on their own, or in combination, be responsible. They believe that if the occupant (regardless of age) is in a pre- crash slumped position, the thoraco-lumbar spine is in already in a flexed or 'pre-flexed' position. Any rotation of the pelvis under the lap belt (or submarining) further flexes these areas of the spine.

Poor initial positioning of the belt and poor pre-impact positioning is not unexpected in small children hence the need for dedicated child restraints and booster seats. However this sample includes only children 8-16 years, and all of the lumbar injury was among children aged 8-13 years. For most of these, the adult belt is likely to have been the only restraint available. While the most commonly cited guideline for achieving good adult belt fit is a height of 145cm [26], the timing of the transition from a booster seat to an adult belt is defined differently in different jurisdictions. In some places the transition is advised through recommended practices and elsewhere specific height or weight limits are legislated (see Appendix 1). Based on these recommendations and regulations, transition times will vary between 6 and 12 years depending on the jurisdiction. However, booster seats and booster cushions design mass limits effectively (based on mass alone) limit booster seat use to children from approximately age 8. Currently the upper most mass limit for boosters is in the vicinity of 36 kg, based on anthropometric data [27] would mean that 11% of 8 year olds, 22% of 9 year olds, and more than half of children over age 10 would be above the design mass limit (personal communication M Paine, Vehicle Design & Research, 2006). Therefore, for most children between the ages of 8 and 16 years, the lap sash belt is the only available restraint, and using this in the rear seat is the best option for good crash protection.

A vital ingredient to good initial lap belt positioning is a seat cushion length that discourages a slouched seating posture [26]. Recent Australian work [Bilston unpublished data, 2006] suggests that based on thigh length (buttock to popliteal measurements), children are unlikely to achieve good lap belt fit until approximately 13 years of age. Huang & Reed [28] in a similar study, reported that the median seat cushion length in a sample of North American vehicles are too long for most people using the rear seat, and the posture needed to encourage good lap belt fit would be a problem for 83% of children aged between 4 and 17 years, and 24% of adults.

In 2005, Tylko & Dalmotas [29] reported results obtained from rear seated small adult and child dummies included in full frontal compliance testing and offset frontal research testing. In these the 5th percentile female (anthropometrically equivalent to a 12 year old child); the 10 year old and six year old child hybrid III dummies were restrained in lap sash belts in different vehicles. This work demonstrated variations between vehicle models in lap belt motion during the test, with a number of examples of 'abdominal penetration' occurring. With the 5th percentile female, the authors noted variations in the distribution of loads between the sash and lap parts of the belt that appeared to correlate with the upward motion of the belt, the lumbar response measured in the dummy and an associated forward pivoting motion of the torso. The authors also reported undesirable behavior of the sash portion of the belt. With the Hybrid III 10 year old, the sash portion of the belt was seen to slip off the shoulder (when the dummy was in a booster seat), and translate up the neck (when the dummy used the belt alone). They concluded that the motion of the upper torso was controlled almost exclusively by the geometry of the sash anchorage.

These sorts of observations from the laboratory together with clear evidence of a seat belt syndrome like mechanisms occurring in the real world suggest further work is required to understand the role seat properties and belt geometry might play in preventing lumbar fracture.

Good sash belt geometry requires the sash to pass over the centre of the shoulder and maintain this position during impact. Failure to achieve this sort of fit might lead to the types of sash behavior reported by Tylko et al. [29] where the shoulder comes free and the torso can flex over the lap belt resulting in the lumbar injuries described above. Sash belts that sit too high across the neck, or move into this position during the impact can lead to cervical injuries. Bilston (unpublished data, 2006), recently investigated the relationship between the anthropometry of children and sash belt anchorage of a sample of Australian cars and found that good sash belt fit is unlikely to be achievable by many children. Furthermore, this work illustrated significant variations in the match between anthropometry and sash geometry between different models of vehicles.

In this sample there was only one case where a cervical fracture occurred in a frontal impact without evidence of a head strike. This child was 10 years old and this case might provide an example of the type of injury that could occur when the sash sits across the neck.

Apart from the lumbar 'seat belt syndrome' cases and this single cervical fracture, there were only 3 other cases of serious spinal injury in this sample. Two of these cases involved roll over and one a high severity side impact with a fixed road side object.

Road safety advocates in many countries recommend the rear seat for child occupants regardless of restraint type used. In NSW Australia, recent observational studies indicate that 60% of rear seat occupants are aged 14 years or less (personal communication D Carseldine NSW Roads and Traffic Authority 2005). In North America, Huang and Reed [28] analyzed NASS-GES data to determine the age distribution of rear seat occupants and found that approximately 70% are children less than 18 years old. Despite this the work by Tylko and Dalmotas [29]cited above is one of the very few published pieces of work critically examining the protection offered in the rear seat by existing restraint systems to rear seat occupants, and/or rear seated child occupants in adult seat belt systems. This is distinctly different to the situation for young children and dedicated child restraint systems, and for adult front seat occupants.

Also in contrast to dedicated child restraint systems and crash protection systems provide din front seating positions, in most jurisdictions, there is no regular review (either regulatory or consumer based) of the protection offered to these larger children in the rear seat. Yet evidence from recent work cited here, suggests that there is likely to be significant variations in the level of protection currently being provided to these occupants by different makes and models of vehicle.

The case series presented here illustrates the scope for significantly reducing spinal trauma among children through addressing mechanisms associated with seat belt like syndrome injuries. To realize these reductions, vehicle manufacturers need to acknowledge that for older children, the rear seat and its restraint systems are the only protective systems available, and design the rear seat environment with this in mind. Vehicle safety advocates should encourage manufacturers to do this. One obvious way to encourage improved protection for older children is to include rear seated surrogates for these occupants in consumer based test programs.

Limitations

There are a number of potential problems associated with using data extracted from medical records to evaluate crash details. However, in recent work using a similar methodology [30] accuracy of the crash and restraint data collected in this way was cross-validated against that obtained from an in-depth crash investigation in a larger sample of crashes and was found to be adequate in approximately 60-85% of cases, depending on the crash factor.

ACKNOWLEDGEMENTS

Parts of this work were funded by the NSW Motor Accidents Authority.

The authors also thank Michael Griffiths for information regarding international child occupant legislation and Michael Paine for access to an analysis of CDC [27] anthropometry and booster seat mass limits.

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APPENDIX 1: Summary of International Child Occupant Legislation (personal communication M Griffiths Road Safety Solutions Australia 2007).

Country	Legislation
Australia	Children 0 – 12 months in dedicated child restraint but currently under review.
New Zealand	Children up to age 5 in dedicated child restraint
Canada (British Columbia)	Children 0-9kg in rear facing restraint. Children from 9 – 18 kg in dedicated child restraint system but if no CRS available can use lap part of belt. Children from 18kg -6 years of age required to be in lap part of seat belt.
USA	Every state has own regulations All states require dedicated restraint use by children up to 3 years. Many have or are moving towards requirements for dedicated restraint use by children up to 60 or 80lb (approximately 6 or 8 years)
European Union	All members of the European Union have dedicated child restraint use up to 1.35 or 1.5m
Germany	Dedicated child restraint use up to 12 years or 1.5m tall
UK	Dedicated child restraint use by children 0-1.35m or 12 years for front and rear occupants. There are exemptions for rear seated children on short trips.
France	Dedicated child restraint use up to 12 years and under 1.35m.
Italy	Children from 0-1.5m must use and appropriate restraint but appropriate restraint includes adult belt
Spain	Children 0 -3 required to use dedicated child restraint, Children 3 years to 1.5 m are required to use dedicated child restraint in front seat but may use adult belt if in the rear seat.
Sweden	Children up to 1.35m must be in appropriate child restraint system
Switzerland	Children 0-7 years in dedicated child restraint system.
Japan	Children from 0-5 in dedicated child restraints
Israel	Children from 0 -8 in dedicated child restraint.