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The Child in the Centre Seat

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Abstract

Lap belts, fitted to centre seats of Australian cars for the past fifteen years, have come under criticism as being injurious to children. The weight of evidence is that they provide substantial protection, though less than three point belts. A specific injury, the seat belt syndrome (SBS), to abdominal viscera and/or lumbar spine, has been associated with lap belts, an association confirmed by two studies in Melbourne. The incidence of SBS was calculated from Transport Accident Commission claims. The centre rear seat (lap belt) carried three times the risk of SBS as outboard rear seats (three point belts) which in turn have 2.7 times the risk of the outboard front seat. The number of SBS cases in Victoria has increased with penetration of the fleet by post 1971 cars. The annual estimated number of cases, for 1987, is 186 adults and ten children. Suggestions are made for improvements in the restraint system.

Keywords

seat belts, injury, spine, abdomen, adults, child, seat belt syndrome, centre seat, child restraints.

Notes

(1) Fors reports are disseminated in the interest of information exchange.

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THE CHILD IN THE CENTRE SEAT

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Accident Research Unit.

EXECUTIVE SUMMARY

For the past twenty years Australian Design Rule 5A has required cars and station wagons to be fitted with three point (lap-sash) seat belts in all seats except for the front and rear centre seats, which have lap belts. Lap belts have come under criticism on the ground that, in rear seats, they provide little effective protection and, more recently, because of an association with a particular injury, the so-called seat belt syndrome (SBS).

In a review of the literature, the great weight of evidence indicates that lap belts provide substantial protection, ranging from 18% to 50% reduction in injuries, though less protection than three point belts in comparable crashes. Reports from Sweden and USA show that lap belts provide protection for children and the elderly. Regarding disbenefits of belts, the "seat belt syndrome" (injury to abdominal organs and/or the lumbar spine) occurs with both three point and lap belts. SBS is a serious injury usually requiring emergency surgery. A certain number of occupants with spine fractures may suffer paraplegia. Case reports suggest a special association with lap belts: this association also appears to exist for the 69 child cases reported in sufficient detail in the English language literature.

The association of SBS and lap belt wearing has been confirmed in two small series of cases in Melbourne, one from the Royal Children's Hospital, the other from the Monash Crashed Vehicle survey.

The literature, though extensive, does not provide quantitative information on the incidence of SBS, though it appears to be numerically small.

A file of Victorian Transport Accident Commission (TAC) claims arising from crashes to post-1975 cars was interrogated to provide SBS case numbers for the years 1978 to 1988. The number of cases of SBS among both children and adults was found to be increasing during the period. This finding was associated with the increasing proportion of cars in the vehicle fleet built after January 1971, and thus equipped with seat belts in the rear.

VicRoads has conducted surveys of belt use which yield rates of occupancy and belt use in the various seats by age of occupant. This information was used together with the TAC case numbers to calculate the relative risks of SBS for various seat positions and type of restraint. The centre rear seat (with a lap belt) was found to carry about three times the risk of the rear outboard seats (with three point belts) for adults and twice the risk for children. Unexpectedly, the rear outboard seats had two and a half times the SBS risk of the left front seat, also with three point belts. This increased risk is ascribable to known

shortcomings in rear belt installations, having to do with the difficulty of fastening the lap part of the belt low over the hips.

The biomechanics of SBS have been extensively investigated. In some cases SBS may be caused by improper positioning of the lap belt or lap part of the three point belt over the abdomen, though perhaps less frequently in recent years. More importantly it is caused, in the case of lap belts, by the flexing of the body over the belt and the tensile load placed on the lumbar spine by the inertia of the upper part of the body. In three point belts, it is caused by a process termed "submarining", in which the lower part of the body partly slips under the lap part of the belt assembly.

This process can be prevented or reduced by arranging the geometry of the belt installation so that the lap belt, when fastened, has a steeper angle in relation to the horizontal, by providing a ramp profile in the seat pan and by using rather less yielding seat cushions. For lap belts the only effective measure is to provide means of upper body restraints. Some production sedan cars have three point belts in the centre rear seat.

For children, the following options are available. In decreasing order of child size they are: adult three point belt; adult three point belt with tethered booster, lap belt plus child harness with tethered booster; child forward-facing seat, rear-facing seat or infant capsule.

The focus of this investigation was on children in centre seats, but, in fact, twice as many children sustain SBS in seats with three point belts than in centre seats, because the greater number of children occupying outboard seats outweighs the extra risk associated with the centre seat.

In addition, the TAC data show that many (eighteen times) more adults sustain SBS than do children.

Because the number of cases per year has been increasing, the incidence can best be expressed by the estimated number of cases for a given year. In Victoria these numbers for 1987 are ten children and 186 adults. These totals may include an uncertain number of non-belt-wearers.

In summary:

Belt-wearing occupants of post-1971 cars in Victoria sustained an estimated number of SBS injuries (for 1987) of ten children and 186 adults.

Though they are less protective than three point belts, lap belts should always be used when no better restraint is available. Lap belts are better than no belt.

Both lap and three point belts are liable to cause SBS (abdominal visceral injury and/or lumbar spine injury). Lap belts risk causing SBS at a rate about three times higher than three point belts. The evidence suggests that children are less at risk than adults.

SBS among wearers of three point belts is caused not only by the improper use of belts on the body, but also by defects of the geometry of the installation in the vehicle and the properties of the seat. For wearers of lap belts, the risk of SBS is raised by the absence of upper body restraint.

About two thirds of SBS cases in centre seat occupants could be eliminated by the installation of three point belts for use by centre-seated adults and larger children. For smaller children one of the other options for securing upper body restraint would be needed.

Reduction of SBS in general requires improved seat and belt design.

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1 BACKGROUND.

In the nineteen fifties researchers of the Cornell University Crash Injury Project showed, from a study of highway accidents, that occupants of crashing cars were often ejected from the vehicle, usually through a door that had opened. Ejectees were at substantially greater risk of injury than those who were retained in the car. **This discovery pointed to** two countermeasures - improved door latches and belts to restrain occupants (Tourin, 1958; Wolf, 1962).

Although the initial purpose of belts, in those days two-point lap belts, was to retain the occupants within the car, it became apparent that belts served to prevent some occupant impacts with the car's interior. In time lap belts came to be regarded as inferior to three point, lap-sash belts (Vulcan, 1966) and were supplanted by them in the front seat.* In some countries, particularly the USA, lap belts continued to be fitted to rear seats, in others, such as Sweden and Australia, outboard seating positions in both front and rear were fitted with lap-sash belts.

While belts were beneficial to wearers overall, certain injuries came to be associated with belt-wearing, notably fractures of the ribs and sternum in the case of the lap-sash and injuries of the abdominal organs with lap belts. The earliest report of abdominal injury was that of Kulowski and Rost in 1956. Over the years it has been followed by many other reports, mainly in the medical literature. Not infrequently abdominal injuries were accompanied by damage to the lumbar spine. The first accounts concerned adult car occupants but, later, reports of children were added.

Recently, in this country, attention has been called to an apparent increase in the frequency of child belt-wearers with abdominal or lumbar spine injuries (Taylor, Henderson and Trinca, 1990; Taylor and Cummine, 1991).

The following account attempts to review the available information on the "seat belt syndrome" (so called by Garrett and Braunstein in 1962), with particular reference to lap-belted children, in order to:

- establish the nature, extent and consequences of the problem in Australia;
- examine the relative propensity of lap and lap-sash belts to cause injury;
- summarise knowledge on the mechanism of injury;
- to suggest appropriate countermeasures, or lines of investigation leading to countermeasures.

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* [The terms lap-belt and two point belt will be used as synonyms: lap-sash belt, three point belt and lap with shoulder belt will be used as synonyms].

2 BENEFITS OF LAP BELTS

Since the seat belt syndrome (SBS) has been particularly associated with two point lap belts - whether this association is justified will be examined later - it is appropriate to consider first the effectiveness of lap belts as a protective device.

For car occupants in general, lap belts are generally regarded as having an injury-preventing effect, but in a report on the performance of lap belts, based on 26 severe accidents, the U.S. National Transportation Safety Board (1986) concluded that lap belted occupants fared no better than unbelted occupants. [An extended summary is given by Smith, 1987]. Though it has been trenchantly criticised (Campbell, 1987), this report prompted some valuable analyses of mass crash data.

Campbell, from a pool of 1.2 million crash-involved vehicles, showed that rear seat lap belts were effective against serious injury or fatality over a range of impact severity, but the protective effect was exhausted at the most severe impact levels. The fatal-injury reducing benefit, controlled for crash severity, amounted to a reduction of 25% to 30%. For serious injury alone, the reduction was about 50%.

Kahane (1987) applied the double pair comparison method to 1975-1979 data from the Fatal Accident Reporting System and to 1982-1985 Pennsylvania accidents. Lap belts reduced the risk of: fatality by 17% to 26%; serious injury by 33% and injuries of any severity by 11%. He found that lap belted occupants had a lower head injury risk but higher torso injury risk than unrestrained occupants.

In Canada, using data from the Traffic Accident and Data System for Alberta and Ontario, Dalmotas and Krzyzewski (1987) found that the likelihood of serious or fatal injury was reduced in lap-belted rear occupants by 20% to 50%. (The reduction for front seat occupants with three point belts was 40% to 50%).

For adult fatalities only, Evans (1988) applied the double pair comparison method to Fatal Accident Reporting System data for 1975 through 1985. Average restraint system effectiveness for the two outboard rear seating positions (with lap belts for US cars in the years studied) was estimated at 18 $\pm$ 9%. There were insufficient data for estimates in front or rear centre positions.

Data from crashes involving Volvo cars, 1976-1990, yielded the following injury rates for the centre rear seat: AIS 1-6 lap-belted 28.4%, unrestrained 33.8%; AIS 2-6 lap-belted 5.1%, unrestrained 10.7% (Lundell, Carlsson, Nilsson, Persson and Rygaard, 1991).

2.1 Studies related to children

Morris reported in 1983 on analyses of data from the Fatal Accident Reporting System (FARS) and from four American states. "*Rates of injury at any given severity level are uniformly and monotonically declining in the following order: unrestrained, front seated; unrestrained, rear seated; restrained, front seated and restrained, rear seated.*" This was true for the 5 to 12 child as well as for all ages. The rates of injury for the 5 to 12 year old child were, however, lower than those for all ages. The data came from 1975 to 1982 crashes. In all these cars the rear seat belts were lap belts, whose effectiveness, for various injury levels, ranged from 43% to 89%.

Estimates derived from FARS were used by Partyka (1988) to yield a benefit (injury reduction) to "toddlers" (age 1 through 4) from using adult belts of 35% in the front seat and 37% in the rear seat. Since, in this time interval, U.S. cars had lap belts only in the rear seats, this estimate can be interpreted as the benefit to toddlers from using adult lap belts in the rear seat. (The corresponding figure for child safety seats in the rear seat was 45%).

The effect of the two types of belt restraints for children and adults separately has been investigated by Krafft, Nygren and Tingvall (1989) using insurance data from a large number (about 80,000) of accidents (property damage as well as injury producing) supplemented by questionnaires sent to drivers (Table 1).

TABLE 1
RISK OF INJURY IN REAR SEATS FOR RESTRAINED AND UNRESTRAINED OCCUPANTS

	forward facing child restraint		adult seat belt 3 pt		2 pt		no restraint	
Age	N	% inj	N	% inj	N	% inj	N	% inj
-14	556	6.5	425	9.2	85	7.1	1274	17.0
15-			613	11.6	60	15.0	1690	18.9

"% inj" refers to the % injured in each restraint group
Source: Krafft et al, 1989

From these data the effectiveness of the two restraint systems can be calculated, as shown in Table 2.

TABLE 2
RESTRAINT EFFECTIVENESS IN PREVENTING INJURY

		EFFECTIVENESS	CHI-SQUARE*	
Children	3 pt v unrest	58%	5.7	
	2 pt v unrest	56%	14.5	
Adults	3 pt v unrest	39%	17	
	2 pt v unrest	20%	0.57	ns

the chi-square values are all significant except 0.57

It is evident that both three point and two point belts are effective in protecting children from injury, but the comparison is still imprecise because restraint type is confounded with seating position. In Sweden, as in Australia, the outboard rear seats have three point belts, the centre seat lap only. In comparing the two restraints the effect of seat position is less serious than in the comparison of front and rear seat belts, because one of the two outboard positions is at a disadvantage to the centre seat only in a side impact. The injury severity also was lower, in both adults and children, when restraint was used than when no restraint was used

While these studies make it clear that wearing a lap belt is to be preferred to remaining unrestrained, they do not provide information on the relative performance of lap belts and lap sash belts regarding the seat belt syndrome.

A comparison of restraint and no restraint in the back seat has been made by Orsay, Turnbull, Dunne, Barrett, Langenberg and Orsay (1989). This derives from 1364 patients from motor vehicle accidents presenting to emergency medical departments at four Chicago area hospitals during a six-month period in 1986. The belt wearing rate was 58% overall. Pediatric patients were defined as those aged 18 or younger and "elderly" as those aged 65 or older. The effect of restraint use is shown in Table 3.

TABLE 3
MEAN INJURY SEVERITY SCORES (ISS) IN RESTRAINED VERSUS UNRESTRAINED PATIENTS ACCORDING TO POSITION IN VEHICLE

	RESTRAINED	UNRESTRAINED	% RED'N	P
Pediatric				
front seat N=103	1.56 ± 0.27	3.51 ± 0.59	55.6	0.003
back seat N=57	0.59 ± 0.14	2.57 ± 0.89	77	0.092
Elderly				
front seat N=62	2.77 ± 0.60	7.95 ± 1.94	65.2	0.002
back seat N=11	1.50 ± 0.50	7.4 ± 1.67	79.7	0.161

Source: Orsay et al (1989)

In U.S. practice, the front seats of cars were equipped with lap-sash belts and all rear seats with lap belts. Thus the results in the rows labelled "back seat" in general represent lap belt versus no restraint. It is not stated whether there were any child seats in the pediatric back seat series. For pediatric patients (as defined) the observed benefit from lap belt restraint approaches but does not reach statistical significance (the sample size is small, N=57).

A series of studies with an approximately known base population have been made by Agran and Dunkle (1982), Agran, Dunkle and Winn (1984, 1985, 1987a, 1987b), Agran and Winn (1987), Agran, Winn and Dunkle (1989) and Agran, Castillo and Winn (1990). These data are based on pediatric patients at emergency rooms of nine hospitals (and the Coroner's Department) serving a community of 1.9 million people. Many of these children had, in fact, no injuries, having been referred for a "check-up" after being passengers in a vehicle accident.

There were 1642 children, initially, of whom 191 were wearing belts. Later this number was increased to 229 (88 in the front seat wearing three point lap-sash belts, 141 in the rear with lap belts). Eighteen lap-sash wearers had "spinal strain" which may have been whiplash.

In a subset of children aged less than 4 years (N=494), those in a child safety seat fared best with regard to reduced injury. The next best served were those wearing seat belts and the most likely to be injured were the unrestrained. Evidently an adult belt is better than no belt at all.

The specific issue of lap versus lap-sash belts was investigated from a subset drawn from the period 1980-1985. Eighty eight wore a lap-sash belt in the front seat and 141 a lap belt in a rear seat. There were no significant differences in injury severity, anatomic site of injury or rate of hospitalisation between the two groups. Here, again, because of the American practice, the effects of belt type and seating position are confounded.

A contrary view of the lap belt is that of Foret-Bruno, Song, Oudenard, Tarriere, Got and Patel (1991) who made an analysis of the expected effect on fatalities of wearing a lap belt in the centre rear seat. (In French practice, this seat has not been fitted with any restraint). Their conclusion was that wearing a lap belt in this seat would increase fatalities. This analysis is not easy to follow. It depends considerably on using the NTSB data as if they constitute a statistical sample, an interpretation against which the NTSB authors make a caveat.

For occupants in general, for children and for the elderly, the weight of evidence indicates, however, that wearing lap belts confers a substantial benefit in reduced injury.

3 DISBENEFITS OF LAP BELTS

An association between lap belts and injury was first suggested, in 1951, by Teare who had carried out autopsies on 28 victims of an airliner crash. He attributed ruptured aortas to flexure over the lap belt. The injuries were consistent with massive blunt impact on the chest and there were no injuries of the hollow abdominal viscera. Teare's interpretation was criticised especially by DuBois (1952), who pointed out that there was a predominance of fractures of the head and upper part of the body.

The occurrence of serious injury in car accidents presumptively associated with the belt itself was first reported, as noted above, by Kulowski and Rost. An attempt to estimate the incidence of the visceral injury was made in 1962 by Garrett and Braunstein, who coined the term "seat belt syndrome" (SBS).

They analysed data from the Cornell Crash Injury Research files of highway accidents in which at least one occupant was wearing a belt - lap belts at that time. Of 3325 belt wearers, 944 were injured and, of these, seven had "*reported or possible*" abdominal injuries, seven had pelvic injuries and twelve had lumbar spine injuries. In many of the lumbar spine cases the crash had unusual features such as impact on the seat back by an unrestrained rear occupant.

Rutherford, Greenfield, Hayes and Nelson (1985) analysed a large sample of hospital admissions in England, Wales and Northern Ireland for the year before and the year after the introduction of a law requiring belts to be worn in the front seats of cars. They found an increase in injuries to abdominal and pelvic organs in the after period, except for kidney injuries, for which there was a decrease. Change in the occurrence of lumbar spine injuries were inconsistent. The conclusions of this study were largely confirmed by the analysis of a separate data set by Tunbridge (1989).

Anderson, Rivara, Maier and Drake (1991) analysed the records of 303 car occupants treated at a trauma centre for spine and/or abdominal injuries, over a five year period (1984-88) during which seat belt usage increased substantially (for drivers, in Seattle, from 21% to 67%). The numbers of casualties with both Chance and other lumbar spine fractures also increased (there were no Chance fractures in 1984 and 1985). Two thirds of the Chance fractures were in occupants of the rear seat (with lap belts) and 81% used restraint. By contrast 86% of all occupants with cervical spine injuries were unrestrained.**

The frequency of injuries to the small and large intestine increased during the study period (while injuries to the other viscera remained constant) and these injuries were associated with lap belt restraint. Among seven children less than age 16 with lumbar Chance fractures, only one did not have injury to a hollow abdominal organ.

It is tacitly assumed in many clinical papers that the observed injury (abdominal or spinal) is caused by the restraint, usually a lap belt. Rutledge, Thomasson, Oller, Meredith, Moylan, Clancy, Cunningham and Baker (1991) describe the distribution of (mainly) abdominal injuries in a large sample of hospital admissions from motor vehicle crashes. There were 3901 who could be classified as to belt use. The proportions of many injuries usually described as seat belt injuries were the same in the belted and unbelted groups. Those that occurred more frequently in the belted group were gastro-intestinal injuries (3.4% and 1.8%): lumbar spine injuries were not significantly different (5.3% and 5.0%). On the other hand head injuries were less frequent in the belted group. **The occupants were classified as passenger or driver** and no distinction was made between two point and three point restraint, so the sample was probably heavily biased in favour of three-point restraint. The quoted percentages are of admitted casualties. Since an occupant had to be sufficiently injured to be admitted to hospital - and to the series - the data do not provide estimates of risk to the various classes of occupant. They do, however, indicate that many injuries thought to be due to belts occur frequently also in unbelted occupants.

** Chance fracture: A more or less horizontal fracture through the posterior part of a vertebra extending into or through the body of the vertebra with tearing of the interspinous ligaments. It is considered to be a failure in tension usually with flexion of the spine. So named by Nicholl (1949), for a radiologist, Chance, who first described the fracture in 1948.

Thus kidney injuries should be excluded from the list of injuries associated with belts. Injuries of the spleen, when the only visceral injury, should probably also be excluded because of the propensity of this organ to be damaged in any blunt impact. But, because of practical difficulties of reclassification, in the following account the various authors' classifications will be accepted and the seat belt syndrome (SBS) defined as injury to the abdominal viscera and/or injury to the lumbar spine.

Other early accounts of SBS are those of Aiken, 1963; Lister and Milson, 1963; Cocke and Meyer, 1963; Williams and Sargent, 1963; Tolins, 1964 and Howland, Curry and Buffington, 1965. Snyder (1970) reviewed the case literature up to 1970, most of which referred to lap belts. In the past 30 years many other papers have accumulated in the medical literature. They include some Australian accounts: Brownstein, 1984; Christophi, McDermott, McVey and Hughes, 1985; Holt, 1976; Pohl and Cook, 1980, Ryan and Raggazon, 1979 and Vellar, Vellar and Mullany, 1976.

3.1 SBS in Children

Most papers refer to vehicle occupants in general, but others refer specifically to children. Taylor, Henderson and Trinca (1990) reported fifteen cases, collected over nine years, all rear-seated and wearing lap or lap-sash belts. Taylor and Cummine (1991) added four more cases from 1990.

A search of the English-language literature yielded single cases or small series in which individual cases are detailed, with a total of 69 restrained children suffering SBS. (Anderson, Henley, Rivara and Maier, 1991; Asbun, Irani, Roe and Bloch, 1990; Blaisier and Lamont, 1985; Braun and Dion, 1973; Bull, Bruner-Stroup and Gerhart, 1988; Burke, 1971; Czyrko, Weltz, Markowitz and O'Neill, 1990; Gallagher and Heinrich, 1990; Gloyns and Rattenbury, 1989; Gumley, Taylor and Ryan, 1982; Hardacre, West, Rescorla, Vane and Grosfeld, 1990; Hope and Houghton, 1986; Hubbard, 1974; Huelke and Chewning, 1969; Huelke and Kaufer, 1975; Huelke, Sherman and Elliott, 1987; Johnson and Falci, 1990; LeGay, Petrie and Alexander, 1990; Lowne, 1974; Moskowitz, 1989; Mure, Unkle, Doolin and Ross, 1990; National Transportation Safety Board, 1986; Newman, Bowman, Eichelberger, Gotschall, Taylor, Johnson and Thomas, 1990; Reid, Letts and Black, 1990; Ritchie, Ersek, Bunch and Simmons, 1970; Rogers, 1971; Ryan, Wright, Hinrichs and McLean, 1988; Smith and Kaufer, 1969; Sripathi and King, 1991; Taylor and Eggli, 1988; Upadhyay, 1989; Vandersluis and O'Connor, 1987 and Wheatley and Cass, 1989). The earliest reports appear to be those dated 1969: Huelke and Chewning and Smith and Kaufer. Many are quite recent; 20 of the 33 listed above have appeared in the past five years. Twenty are from the U.S.A. These cases are summarised in Appendix 1.

These tabulated casualties were restrained and located as shown in Table 4. Age and sex distributions are given in Table 5 and injury versus outcome in Table 6.

There are other accounts in which the individual cases are reported in insufficient detail or cannot be disaggregated. These include Atlas, Allard, Denis and Farkouh, 1984; Burke, 1974; Burke,Burley and Ungar, 1985a; Cameron, 1986; Grosfeld, Rescorla, West and Vane, 1989; Hoffman, Spence, Wesson, Armstrong, Williams and Filler, 1987; Hoy and Cole, 1991; Ibrahim, Mosley and Gillespie, 1981; Kakos, Grosfeld and Morse, 1971; Langwieder and Hummel, 1989; Sivit, Taylor, Newman, Bulas, Gotschall, Wright and Eichelberger, 1991 and Stylianos, ter Meulen, Latchaw and Harris, 1988.

TABLE 4
SEAT POSITION AND RESTRAINT TYPE

	Unstated	"F Pass"*	LR	CR	RR	"R Pass"	"Pass"	T
Unstated						2	3	5
3pt		5						5
2pt	8	5	7	4	7	23	2	56
Sash of 3pt	1							1
Lap of 3pt			1					1
Ch harness						1		1
TOTAL	9	10	8	4	7	26	5	69

* "F Pass" means passengers in the front row, seat position unstated; LR is left rear; CR centre rear; RR right rear; "R Pass" passengers in rear seat position unstated; "Pass" passenger, position unstated.

Sources: authors cited

The individual papers are characterised by their origin and the clinical interests of the authors. The data cannot be considered in any sense a sample, but some useful impressions may nonetheless be gathered. Too much regard should not be given at this point to the preponderence of two point restraint (lap belts) as a majority of papers are from the USA where belt installation practice has been until very recently to fit lap belts in all rear seat positions.

TABLE 5
AGE AND SEX

AGE	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	T
Unstated					1											1
Male			1	1		1	2	2	1	4	1	3	5	3	5	29
Female	2			1	3	4	8	5	2	3	1	1	1	5	3	39
TOTAL	2		1	2	4	5	10	7	3	7	2	4	6	8	8	69

TABLE 6
INJURIES OF CONCERN

INJURY*	CASES	OUTCOME Not stated	Recovery	Disability	Fatal
Visceral only	19	3	8		8
Spinal only	11	6	4	1	
Viceral & Spinal	39	6	20	11	2
TOTAL	69	15	32	12	10

* additional injuries not listed

Sources: authors cited

3.2 Clinical Studies

The clinically based pediatric studies of Agran and associates have been referred to above. From the main series, ten percent of lap sash belt wearers and twelve percent of lap belt wearers had "abdominal contusions", but one patient had a bowel laceration and another had an injury to the spleen. These were the only cases sustaining serious injury from the belt. There were no spine fractures or dislocations or cord injuries. In a subset of restrained children aged 4 to 9 (N=131) from accidents with a single impact involving two passenger vehicles, the serious injuries were usually head injuries. There were no serious abdominal injuries.

In the subset of belt wearers drawn from 1980-1985, the 141 lap belt wearers included one case of small bowel laceration and in the 88 lap sash wearers there was one case of ruptured spleen (these are evidently the two cases noted above). In addition, there were three cases of bladder contusion in the lap-belted group. There were no spine fractures. All the abdominal injuries were in children under five years of age.

None of the 160 pediatric and 74 elderly cases studied by Orsay et al sustained a visceral or lumbar spine injury (Orsay, 1991, personal communication).

3.2.1 Royal Children's Hospital series

Pediatric casualties from motor vehicle accidents admitted to the Melbourne Royal Children's Hospital for the period 1984 to 1989 have been reviewed by Hoy and Cole (1991). Of 541 casualties, 29 had belt injuries of the abdomen and of these seven had Chance fractures of the spine. One had a cord injury without radiological abnormality. Hoy and Coles's data can be arranged as in Table 7.

TABLE 7
SBS AND OTHER CASUALTIES FROM MOTOR VEHICLE ACCIDENTS

		SBS INJURY		
PERIOD	ALL CASES	fo	fe*	RATE/100 CASES
81-84	208	4	11.15	1.9
85-89	333	25	17.85	7.5
	541	29	29	5

* fo is the observed frequency, fe is the frequency expected on the hypothesis of no association between time periods and incidence of abdominal injury. Chi-square=7.5; $.01<p<.001$.

Source: Hoy and Cole, 1991

It therefore appears that there has been a significant increase (nearly four-fold) in SBS cases in children admitted to the Royal Children's Hospital as a consequence of motor vehicle accidents over this nine year period. It is uncertain whether there had been any concurrent change in the readiness of other hospitals to transfer child motor accident casualties.

The kinds of restraint in use in the SBS case are shown in Table 8. Lap belts were used by 19 of the 28 cases for which the type of restraint was ascertained. The accidents generating the casualties tended to be severe: 21 came from vehicles in which at least one occupant was killed. Most of the child casualties had severe injuries in addition to abdominal or spine injuries.

TABLE 8
TYPE OF RESTRAINT USED

RESTRAINT TYPE	CASES	
LAP/SASH	8	(3 IN FRONT SEAT)
SAFETY SEAT	1	
LAP WITH BOOSTER	1	
LAP ONLY	18	
TOTAL	28	

Source: Hoy & Cole, 1991

For rear seated children (the child in a safety seat excluded) 19 were in the centre (lap belt) seat and 5 in outboard seats (with lap-sash belts). It will be seen later that there are more child occupants in outboard than centre seats, so the above results indicate that there was a pronounced tendency for SBS injuries to be associated with lap belts.

The Royal Children's Hospital in Melbourne admits children (up to age 16) directly or on transfer from the whole State of Victoria. It treats a great majority of the more seriously injured children from road accidents. The Spinal Unit at the Austin Hospital, also in Melbourne, is responsible for nearly all patients with spinal cord damage from Victoria and Tasmania.

To check whether there may have been children with spinal cord lesions not present in the Royal Children's Hospital series, an analysis was made of Spinal Unit's records from 1976 to May 1991. This analysis revealed that there were no children (less than 15 years) wearing belts with lower thoracic or lumbar spine injuries (Ungar, 1991, personal communication).

3.3 Accident Based Studies

Corben and Herbert (1981) studied 231 crashes in which at least one child less than eight had been transported by ambulance. There were 46 children wearing restraints, including 29 three point and eight two point belts. None suffered SBS.

Another accident-based series was reported by Langwieder and Hummel (1989). Accident data were compiled from questionnaires solicited by newspaper advertisement. 870 usable reports gave information on 288 unrestrained and 865 restrained children, 0 to 12 years. The restrained children suffered four cases of SBS (0.5%), with abdominal injuries rated AIS 2-6, while there were proportionately more abdominal injuries (4, 1.3%) in the 288 unrestrained children. No lumbar spine injuries were reported.

3.3.1 The Crashed Vehicle Series

Information on injuries, seat position and restraint status is drawn from 227 passenger car crash vehicles, with 269 occupants, involved in accidents in Melbourne and rural Victoria (the Crashed Vehicle Study). The sampling procedure has been described in Fildes, Lane, Lenard and Vulcan (1991) but the essential criterion was that one occupant should have been admitted to hospital. **These data mainly pertain to** adults because of sampling procedures and participating hospitals. Nevertheless the injury patterns are of direct interest.

The question is: do lap belted occupants, of any age, in the rear seat have proportionally more SBS than lap-sash belted occupants? The analysis is based on Table 9.

TABLE 9
SBS IN RESTRAINED REAR SEAT OCCUPANTS, ALL AGES

	SBS	NO SBS	TOTAL	SBS/100 casualties
3pt	3	10	13	23
lap	5	1	6	83
TOTAL	8	11	19	

Source: Fildes et al (1991), unpublished data.

The seat location of one 9 year old occupant with questionable SBS is uncertain and this case was omitted, as was that of a one year old in a child harness.

Fisher's Exact Probability of the observed arrangement or one more extreme, under the hypothesis of no interaction between belt type and SBS occurrence, is 0.0237; ie. the interaction is statistically significant. It appears that the relative risk of SBS in a lap-belted rear occupant is 3.6 times that in a lap-sash belted occupant in this sample.

4 MASS DATA ANALYSIS

In the State of Victoria, injury compensation of casualties for motor vehicle accidents is the function of the Transport Accident Commission and its predecessor, the Motor Accidents Board. These agencies have amassed a great volume of data on casualties, to which access was provided to the Monash University Accident Research Centre for mass data analysis. The financial entry threshold to the TAC system effectively eliminates minor injury claims.

For estimating the incidence of SBS, a file was used containing casualty information from July 1978 to June 1988 derived from crashes involving post-1975 vehicles. Total claimants were approximately 77,000, of whom 26,863 were passengers, including 3369 aged 0-14 years.

SBS cases were defined as those car occupants with lumbar spine injuries (ICD 9 codes 805.4, 805.5, 806.4, 806.5 and 952.2) and/or abdominal visceral injuries (ICD 9 codes 863.0 through 866.9 and 868.0 through 869.9) (World Health Organisation, 1975). These rubrics embrace the wider definition of SBS referred to above. The nature of the restraint available could be inferred from the seating position, but whether the restraint was used was unknown. The case frequencies are shown in Table 10.

TABLE 10
SBS IN CAR OCCUPANTS IN CRASHES, JULY 1978 - JUNE 1988, OF POST 1975 CARS

AGE	L FRONT	C FRONT	O/B REAR	C REAR	TOTAL
0-4	1	0	5	2	8
5-9	2	1	11	5	19
10-14					
all children					
>14					
TOTAL	321	5	161	42	529

Source: TAC data

The number of SBS cases among children (14 years or less) for whom a claim was made to TAC in the ten year period was 46. This compares with 32 (estimate derived from 29 in nine years) at the Royal Children's Hospital. The time periods overlap: TAC 1978-1988; RCH 1980-1989. The RCH casualties may be regarded as a subset containing the more severe SBS injuries in Victoria as a whole.

The probability of an injured occupant claiming for a SBS injury, or other selected injury, in a particular seating position, is shown in Table 11. It is not known whether the casualties were restrained or not.

TABLE 11
PROBABILITY (%) OF SBS OR OTHER CASUALTY IN INJURED OCCUPANTS IN VARIOUS SEATING POSITIONS (ALL AGES)

	SEATING POSITION			
INJURY	L F	C F	O/B REAR	C REAR
# LUMBAR SPINE	0.90	0.57	0.94	1.8
ABDOMINAL VISCERA	0.95	1.13	1.26	1.8
CERVICAL SPINE	2.50	2.55	2.57	2.53
FRACT SKULL	0.81	0.57	1.36	1.95
LUMBAR SPINE &/or ABDOMINAL VISCERA (SBS)	1.82	1.42	2.13	3.15

Source: TAC data

The risk of an injured occupant sustaining an SBS injury is higher in the centre rear position than in an outboard rear position, where it is higher than in the left front position. These relative risks will be explored further in 5.3.

5 EXTENT OF THE PROBLEM

5.1 Incidence

Although those SBS cases in children reported in the literature represent only an unknown fraction of those which occur, the rather small number of cases listed in 23 years suggests either that the risk of occurrence is low and/or that the exposure has been low. As noted above, most of the reports are from North America where the use of restraints in the rear seat has been low until recent years. For an example of under-reporting, the spine injuries in Taylor and Eggli's five cases were undiagnosed during hospital stay. They were derived from a retrospective examination of CT studies of 565 children with blunt abdominal trauma, 67 of whom had been passengers in motor vehicle accidents. Some, perhaps many, of these 67 would have had visceral injury.

In addition, the size of the population from which the cases are derived is generally unknown, with some exception in the series of Agran et al.

The TAC data, reported above, permit an estimate in relation to the populations of children and of vehicles in the State of Victoria, as shown in Table 12.

TABLE 12
INCIDENCE OF CHILD SBS CASUALTIES IN VICTORIA

CASES (1978-1988)	46
VEHICLES (1975 and later)	1.5×10^6*
CASES/10,000 VEHICLES p.a.	0.058*
POPULATION 0-14, PERSONS	929×10^3*
CASES/100,000 p.a.	1.10*
ALL CHILD OCCUPANT CASUALTIES #	3369
SBS AS % OF CHILD OCCUPANT CASUALTIES #	1.37%

* 1987. # 1975 and later cars.
See text.

Source: TAC data, ABS Cat 9303.2, and 3201.0

The actual number of child SBS cases 1978 - 1988 was 46. This total is unsuitable for an estimate of the incidence, because children's exposure to risk (by being restrained) increased sharply over the ten year period (1978 and 1988 were half years). Australian Design Rules 4 and 5A required belts in rear seats of cars and station wagons (hereafter referred to as "cars") manufactured after January 1971 - a near approximation is cars first registered after that date. The Victorian belt wearing law of 1976 required children less than eight to be restrained if riding in a front seat. This is likely to have had the effect of moving children to the back seat, where they were not required to be restrained and where, in any case, there were often no belts available.

The belt-wearing law was changed in December 1981 to require all children, wherever seated, to be restrained (if a restraint was available). In the back seat, this change in the law effectively applied to 1971 and later cars. The number of these cars increased almost linearly with calendar year, from about 940,000 in 1978 to 1,850,000 in 1988. This, together with probable increase in compliance, greatly increased the number of child passengers exposed to risk. In effect, the 1981 law required all children to be restrained and the 1971 design rule provided the means of restraint in the back seat. Consequently the number of SBS cases in children also increased.

Because of this increase, instead of the mean annual number of cases, it is more appropriate to consider the expected value from the regression of case frequency on calendar year. For 1987 this is 8.7. This number refers to 1975 and later cars and must be factored up to account for 1971 to 1974 cars. An appropriate factor from the 1988 vehicle census is 1.17, and the expected number of child SBS cases in Victoria in 1987 is 10.2, rounded to 10.

The corresponding number of 1971 and later cars (for 1987) is 1.78 million and of children to age 14 is 928,543.

The SBS and "other" child casualties both refer to 1971 and later cars, so the ratio in Table 12 is an appropriate index.

5.2 Exposure

Information on seating position occupancy by age and restraint use, derived from surveys with matched observation sites on Melbourne arterial roads, and for restraint type usage in 1990 is given in Appendix 2 for centre seats.

The survey observations can be summarised as follows. Centre front seats: low occupancy for all age groups; belt use moderately high (60%) for 0-7, medium (40%) for 8-13, belt use low for adults.

For the centre rear seat: low occupancy but wearing rate improving from 1985 to 1988 for all age groups. The number of active belt wearers in the centre front seat has tended to increase in the period 1985-88, in the centre rear seat it has remained constant.

Child occupants of the centre front seat constitute 2.9% of all child passengers; child occupants of the centre rear seat constitute 18% of all child passengers. Overall, child occupants of the centre seats constitute 4% of all car passengers.

Details of the actual restraint devices available and used by children are given by a survey on Melbourne arterial roads made in 1990. 478 cars were surveyed, so the frequencies are rather small especially for the centre front seat. The relevant survey results are shown in Appendix 2.

5.3 Relative risk of centre seats

The TAC data (Table 10) provide the cases recorded in the 10 year period mid 1978 to mid 1988. Measures of exposure are provided by the survey data. To make use of the survey data it is necessary to assume that the arterial road samples are reasonably representative of Victoria both at the times of observation and for some years earlier.

The second assumption is, from the viewpoint of risk calculations, conservative, since the restraint use rate is likely to have been lower in the years 1978 to 1984. As only "wearers" are used in the estimation of exposure, the estimate of wearers is likely to be inflated and the estimate of relative rates of SBS correspondingly reduced.* The observed frequencies in the various seating positions are used as measures of relative exposure. In addition, in the youngest age groups, some "wearers" (though perhaps not as many as the 35% shown in the 1990 survey) will have been using the restraints such as child seats, generally regarded as safer than lap belts. They have been counted as lap belt wearers, so the estimate of risk is conservative on this count also. The child group 0-13 years in the survey has been adjusted to conform with 0-14 in the TAC data. The risk calculations are shown in Table 13.

TABLE 13
RELATIVE RISKS OF SBS IN VARIOUS SEATING POSITIONS WITH PRESENT RESTRAINTS

A. Children
Centre front vs Left front

	Distribution of exposure to risk of SBS**	SBS Cases fo***	fe***	relative rate of SBS (%)
LF	95.1%	9	10.47	0.696
CF	4.9%	2	0.53	0.8
	100%	11	11	

** based on sample of 1360 wearers

*** fo is the number observed. fe is the number expected from the exposure distribution on the hypothesis of no association between risk of SBS and seating position. fe for the centre front is too small for significance calculation.

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* It may be possible to replicate these risk calculations with later casualty data better matched in time to the surveys.

B. Children
Centre rear vs Outboard rear

	distribution of exposure to risk of SBS*	SBS Cases fo	fe	relative rate of SBS (%)
OBR	79.7%	23	27.9	0.77
CR	20.3%	12	7.1	1.57
	100%	35	35	

* based on sample of 3764 wearers

chi-square = 4.24, 0.02<p<0.05.

C. Children
Left front vs Outboard rear

	distribution of exposure to risk of SBS*	SBS Cases fo	fe	relative rate of SBS (%)
LF	30.1%	9	9.64	0.696
OBR	69.9%	23	22.36	0.767
	100%	32	32	

* based on sample of 19232 wearers

The relative rates are not significantly different.

D. Adults
Centre front vs Left front

	distribution of exposure to risk of SBS*	SBS Cases fo	fe	relative rate of SBS (%)
LF	99.4%	312	313.23	1.63
CF	0.6%	3	1.77	2.78
	100%	315	315	

* based on sample of 3393 wearers
fe for CF is too small for significance calculation

E. Adults
Centre rear vs Outboard rear

	distribution of exposure to risk of SBS*	SBS Cases fo	fe	relative rate of SBS (%)
OBR	93%	138	156.17	4.38
CR	7%	30	11.83	12.56
	100%	168	168	

* based on sample of 22278 wearers

chi-square = 30.02, p<0.001.

F. Adults
Left front vs Outboard rear

	distribution of exposure to risk of SBS*	SBS Cases fo	fe	relative rate of SBS (%)
LF	85.8%	312	386.29	1.63
OBR	14.2%	138	63.71	4.38
	100%	450	450	

chi-square = 100.92!, p<<0.001.

* based on sample of 22278 wearers

G. Children vs Adults (summary)

	relative rate of SBS (%) Child	Adult	chi-square	p
CR	1.57	12.56	52.5	.001
OBR	0.77	4.38	76.5	.001
LF	0.696	1.63	6.85	.001<p<.01

For the front left and front centre seat comparisons, the frequencies are too small for tests of significance. In rear seats, the centre seat is shown to confer a significant increased risk of SBS. The increase is by a factor of two (1.57/0.22) for children and by a factor of almost three for adults (12.56/4.38). The assumptions about exposure referred to above make these estimates conservative, especially for children.

Children appear to be less at risk of SBS than adults in the same seating positions.

Adults in outboard rear seats are at greater risk of SBS, by a factor of 2.7 (Table 13E, 4.38/1.63), than occupants of the left front seat. Th increase in risk for children is small and non significant (Table 13C, 767/.696). Since front seats are well known to be less safe than rear seats (for example, Evans and Frick, 1988), this is an unexpected result. It is, however, explicable in terms of the difficulty in properly positioning the lap belt part of the lap sash restraint in rear seats. This is caused in part by the practice of routing the belts between the seat cushion and backrest. This shortcoming was pointed out as long ago as 1969 by Huelke & Chewning. Leung, Tarriere, Lestrelin, Got, Guillon Patel and Hureau showed in 1982 that rear seat occupants submarined more readily than front ocupants. It is a partial reason for the reversed belt geometry developed by Haberl, Eichinger and Wintershoff (1987). Green, German, Gorski, Nowak and Dance (1987) and Fildes et al (1991) noted the problem of properly positioning these belts.

6 MECHANISMS OF INJURY

Based on accident analysis and substantial cadaver testing, Leung et al (1982) proposed that SBS injuries were caused by one or more of the following mechanisms.

1 The belt remains in contact with the pelvis but (due to very high delta V) the abdominal mass undergoes a deceleration above tolerance. [This is perhaps the basis of the injuries which occur even when the belt is snugly fastened - Macleod and Nicholson (1969) and Dehner (1971)].

2 The belt remains in place on the pelvis and the trunk hyperflexes over the thighs (the head can come in contact with the knees, the seatbase or even the floor). In the case of three point belts, this mechanism is permitted if the shoulder slides under the sash belt. The abdominal injuries are caused by high pressures generated in the viscera.

3 The lap belt is worn incorrectly so that, when the slack is taken up, the belt presses on the abdomen. This mechanism is often associated with static belt systems.

Improper positioning of the belt has been described by Ryan and Baldwin (1972) and many others. Dalmotas, Dance, Gardner, Gutoskie and Smith (1984) found that heavy winter clothing was associated with higher belt injury rates.

There may be other predisposing factors. According to Huelke and Chewning, the rear seat occupant may be more relaxed than the front seat occupants and may sit with the pelvis forward. Because of limited legroom this occupant may sit sideways and limited adequate head room may preclude (adult) occupants from sitting straight up. With this slumped posture, it is impossible to wear the lap belt low on the hips.

4 The lap belt is correctly placed, but, when under tension, rides up over the iliac crests and compresses the abdomen. This is submarining in the strict sense of the term.

In all these cases the spinal injury is mainly due to flexion of the lumbar spine. When there is significant upper body forward motion as in lap belt restraint, the axial tension in the lumbar spine induces the more typical spinal fractures, as described below.

According to Leung et al, the last two mechanisms have the most adverse effects on the abdomen. They noted these features associated with submarining: lower limb fractures, "high violence" crashes ($\Delta V > 50$km/h and acceleration > 10g), seat track damage and rear loading from rear seat passengers (the last also noted by Garrett and Braunstein).

Mechanism 4 in three point belted occupants is equivalent to the process described by Adomeit and Heger in 1975. In adults the pelvis rotates (anti-clockwise viewed from the right), the thorax descends, the lap belt or lap part of the three-point belt slips over the iliac crest on to the abdomen. The bending moment at the lumbar spine produces the mechanism for spine injuries

Kramer (1991) has made a biomechanical analysis of bony pelvic damage and injury to abdominal organs. From sled tests and 2D simulation, he has found a critical value for Adomeit's pelvic rotation. This value is influenced, though not strongly, by impact severity. Though it is not stated, the critical angle implies some standard inclination of the lap belt and seat rake. For pelvic rotation less than 20 degrees, the belt does not slip over the iliac crest and the maximum tolerable pelvic acceleration (for 50% probability of bony injury) is 80g. Above the critical angle, the maximum tolerable acceleration drops abruptly to 13g for 50% probability of abdominal injury.

6.1 Spinal Injury

For lap belt restraint two processes may operate in the lumbar spine. As in the lap-sash case a bending moment may produce fracture. Alternatively or in addition, the inertial force from the trunk, head and upper limbs, now nearly horizontal, may cause failure of the spine in tension, as evidenced by Chance fractures (more or less tranverse fractures of the vertebral body) in the lumbar region (Chance, 1948; and many others).

According to Huelke and Kaufer (1975), not all lumbar spine injuries are to be attributed to belts. **These authors** provided illustrative cases of lumbar spine injuries in unbelted car occupants, citing experiments by Begeman, King and Prasad (1973), to indicate that an axial force can develop along the spine of shoulder-harnessed cadavers subjected to horizontal acceleration. Huelke and Kaufer proposed that it was the fracture-distraction injury (not compression) that should be related to lap belts. The criteria they proposed were: minimal vertebral body compression; longitudinal separation of its neural arch; minimal lateral or antero-posterior displacement, minimal torsional displacement and the presence of a seat belt contusion. (This anticipated the "seat belt type" spinal fracture in Denis's 1983 formulation).

For details of the injury process, reference should be made to Denis, 1983; Gertzbein and Court-Brown, 1988; Holt, 1976; Johnson and Falci, 1990 and Smith and Kaufer, 1969.

6.2 The Abdomen

Using intrusion and pressure monitors in the abdominal area of a three-year-old child dummy subjected to a 30mph impact, Melvin & Weber (1986) showed that misplaced lap belts generated high intra-abdominal pressures (54 psi) compared with a correctly placed lap belt (5-10 psi) and lower pressures with a booster and tethered harness (1.9 psi) or booster and lap sash belt (0.2 psi). The last two configurations also yielded the lowest head excursions (19.2 in). They noted that extreme body bending alone did not cause restraint system intrusion into the abdomen.

Miller (1989), who carried out experimental acceleration tests with pigs, showed that damage to solid organs, e.g the liver,is rate-dependant (according to the Viscous Criterion of Lau and Viano, 1988). The gastro-intestinal organs, however, react to belt loading in a quasi-static manner (i.e. it is a crushing-type injury).

Specific mechanisms of injury to the various abdominal organs have been proposed by Backwinkel, 1968; Sube, Ziperman and McIver, 1967; Williams and Sargent, 1963 and Williams and Kirkpatrick, 1971.

6.3 Anthropometric Considerations.

In 1969, Burdi, Huelke, Snyder and Lowrey reviewed the anthropometry of children relevant to the design of devices for their protection in cars. They pointed out that a child cannot be considered a miniature adult. There are important differences between adult and child - the bony structure, centre of gravity, head mass in relation to neck and general body proportions, relative lack of body protection for body organs and biomechanical properties of tissues. For example, young children tend to have substantial subcutaneous fat.

Proper positioning of restraints on children one to three years old may be difficult to maintain. Sitting height represents about 70% of total height at birth but falls to 57% at 3 years, and 50% later. At birth the head is one quarter of the total body length, whereas in the adult it is one seventh. The centre of gravity cannot be located precisely in groups of children of the same age, but it is located vertically on the torso well above lap belt level. In a lap belt the greater body mass above the belt may cause the child to "whip forward" more than an adult.

The child's head is vulnerable not only because of its relatively large size and greater fragility but because the neck supporting structure is relatively weaker. Burdi et al cite other authors to show that children in car accidents have a higher proportion of head injuries than adults.

Regarding the pelvis, the anterior superior iliac spines (ASIS) are undeveloped up to age 10 and the distance of the ASIS to the front of the thigh is small, so there may not be adequate space for the lap belt, which may then ride up on to the lower abdominal wall. (For a description of pelvic development, see Chumlea, 1983).

Reviewing the subject in relation to belts in 1975, Snyder and O'Neill pointed out that, at that time, with very few exceptions, experimental dynamic studies of child restraint systems used dummies. Child dummy development had lagged behind dummies for adults in part because of the very limited availability of "volunteers" or child cadavers. Snyder and O'Neill concluded, however, that on the very limited actual crash data available (then 18 cases) lap belts appeared to give protection even for children less than five.

The unstated implication of the described (and frequently quoted) anatomical differences between adults and children is that the latter are more prone to injury. Examination of actual injury data, however, shows that - apart from head injury - children are less likely to be injured than adults in comparable impacts (Ashton, MacKay and Gloyns, 1974; Dejeammes, Tarriere, Thomas and Kallieris, 1984; Dejeammes, Tingvall and Nygren, 1986 and Lowne, Roberts, Roy, Hill and Jones, 1984)

6.4 Submarining.

Submarining or its absence has become an important criterion in the evaluation of child restraint systems. Bacon (1985) describes acceleration tests of adult belts with and without tethered booster cushions, using two body shells and actual vehicle seats. TNO child dummies were used, corresponding to ages three, six and ten years. These were tested with and without boosters when restrained by automatic inertia reel belts, three point static belts and two point static belts. Submarining of various degrees was noted on all dummies when restrained by an adult belt only. The use of a hard cushion reduced the severity of submarining in all cases with the "auto" belt and to zero in some. A soft cushion had little beneficial effect.

The stiffness of the seat cushion installed in the car was also important, a stiff cushion being desirable. (The ECE 44 seat was criticised by implication by Bacon and also by Bastiaanse, Maltha and Tak (1982) and Czernakowski (1984).

The booster cushion has two benefits: it improves the lie of the diagonal sash across the child's chest (the sash may otherwise lie across the neck or even the face, with no booster) and it makes the angle of the lap belt (viewed laterally) steeper. The steeper the angle, the less likely (in a given crash) that Kramer's critical pelvic angle will be exceeded. (For a discussion of belt geometry, see Fildes et al, 1991).

Bacon also found that the two point (lap) belt was less conducive to submarining because the dummy torso folded forward, hit the seat in front or perhaps its own legs or the seat base.

Bacon's conclusion was that the best combination was a firm, tethered booster with a three point automatic belt. This combination was, in his view, acceptable in the age range from three to ten years.

Because boosters are frequently misused, Klanner and Czernakowski (1986) examined the performance of boosters and three point belts in a series of sled tests with TNO P3, P6 and P10 dummies at 50 km/h impact speeds and sled decelerations of 23 g. Problems were experienced with shoulder strap location on P3 dummies. The critical items were chest loading for the P3 and horizontal head excursion for the P6 dummy. They concluded that an "impact shield" should be added to the booster cushion for children between three and six years.

7 DISCUSSION

It appears that lap belts were initially accepted uncritically by those concerned with crash protection: more recently they have been perhaps unreasonably condemned.

In large samples of crashes lap belts have been shown to confer substantial protection, though less than that provided by three point assemblies. High tolerance, with only temporary discomfort, to loads imposed by lap belts has been demonstrated in healthy adult males - to 14 g by Ruff in 1941 and 26 g by Lewis and Stapp in 1958.

The limitations of the lap belt are, first, it provides insufficient protection, by failing to prevent the head and upper body from contact with unyielding surfaces. Second, it may cause injuries to the abdomen and lumbar spine by direct loading combined with the body motion that the belt induces under impact.

The standard Emergency Locking Retractor (ELR) three point lap and sash combination also shares these shortcomings but to a much smaller degree. For both restraint systems, part of the injury mechanism is due to design deficiencies in the lap belt geometry and to some extent in the seat.

Despite much case description, it has been difficult to estimate the numerical size of the SBS problem. The collections of Agran and associates and series based on accidents suggest that the incidence has been low. The increased child case frequencies noted in recent years in Australia can be related to increased restraint use in child passengers as post 1971 cars have penetrated the car fleet. The fatality rate in casualties with SBS derived from published papers is 14.5%, but this is perhaps unduly weighted by the five fatalities from the NTSB's series of severe accidents. If these are excluded, the rate is 8.3%. The casualties may have had other serious injuries, as they did in the Royal Children's Hospital series but in which there were no deaths.

SBS is a serious condition, usually requiring emergency surgery **and carrying the risk of missed early diagnosis. The** characteristic visceral injury is to the gastro-intestinal tract, especially to the small and large intestines.

When there is a lumbar spine fracture, there is risk of spinal cord damage and paraplegia. **The percentage of paraplegia was** as high as 28% of casualties with SBS in the literature collection. It was 3.5% in the Royal Children's Hospital series. A particular type of lumbar spine fracture, the Chance fracture, is especially associated with lap belts.

The substantial case literature indicates a preponderance of lap belt restraint, though the association is confounded with rear seat position in many reports. This association of lap belts with SBS is confirmed in the Royal Children's Hospital series and in the Monash crashed vehicle series.

From the Victorian mass data the relative risk of incurring SBS from a lap belt is now estimated, for adults, as three times that from a three point belt in the rear seat. For children the relative risk is twice that from a rear-seat three point belt. In addition, rear seat three point installations have, themselves, nearly threefold the risk compared with front seat passenger three point belts.

A deficiency in the published information, is any clear estimate of the incidence of SBS. The mass data analyzed above indicate a case rate of about ten child cases per annum (for 1987) in the State of Victoria (less confidently, about 14 for 1991). Not all these children were using lap belts: in fact, twice as many children sustained SBS when using adult three point belts, because, despite the greater risk in lap belts, more children are seated in outboard than in centre seats.

Although the focus of this investigation is on children, there are many times more SBS passsenger casualties in adults than children. In addition there were about 485 SBS cases in drivers in the years surveyed. Some of the drivers' visceral injuries may come from steering wheel contacts (few, according to Leung et al), but the lumbar spine injuries must be related to the belt. Adult car occupants with SBS amount to 159 (the expected number for 1987 in 1975 and later cars), eighteen times the number of child cases. This approximates to 186 adult cases for all cars for 1987.

Overall there is a case frequency for all car occupants, in Victoria, of about 196 per annum for the year 1987.

It is to be noted that these totals may contain an uncertain number of occupants who were not wearing belts. They cannot be eliminated from the data because the TAC file does not contain information on belt wearing and because it has been necessary, as stated earlier in section 4, to use a broad definition of the injuries contributing to the Seat Belt Syndrome.

7.1 Countermeasures

A substantial gain may be made by providing upper body restraint in the centre seat positions. More than four fifths of centre-seated occupants are in the rear (87% of children, 77% of adults). Most recent cars do not provide a centre front seat.

The rear centre seat can be provided with a tethered harness for children of appropriate body size. For adults and larger children a lap-sash belt is needed. For new cars, this could become standard practice - a few sedan car models already have lap sashes in the centre rear seat.

For existing cars a retrofit may be feasible. For rear seats of vehicles such as hatchbacks, there are already devices in the after-market for supporting tether anchorages. It may be possible to adapt these for sash attachment points.

Replacing the lap belt with a lap-sash belt could be expected to eliminate about two thirds of the SBS cases in occupants of the centre rear seat.

Reducing SBS in all seats already required to be fitted with lap-sash belts requires attention to the shortcomings of existing installations. This objective is discussed by Fildes et al (1991), but, in brief, the needed improvements are in making the lap belt angle steeper, better access to the buckle in outboard rear seats and vertically adjustable D rings. Belt tensioners would be useful additions, to minimise belt slack.

For smaller children, for whom adult belts with or without a booster are unsuitable, there is the available child seat, or, best for children up to 9 kg, a backward facing seat or capsule (Turbell, 1990; Lutter, Kramer and Appel, 1991). At present in Australia there appears to be no commercially available backward facing seat for children from 9 to 18 kg, though seats to this mass limit are provided for in Australian Standard 1754 (1991).

7.2 Possible Disbenefits

A lap-sash installation in the centre seat differs from those in the outboard seats only in that there is no restraint by the car's interior side wall to lateral body motion in the event of a side collision on the side on which the D ring is located. In this case the body would be restrained laterally only by the sash contacting the neck.

The reversed geometry for outboard rear seats developed by Haberl et al as an aid to easy fastening and correct belt positioning (and now fitted to some production car models) has the same loading configuration in side impacts.

This loading case has been investigated by Kallieris and Schmidt (1990) using adult cadavers and a US Side Impact Dummy in far side impacts at 50 km/h. The cadavers' head and neck bending reached a mean maximum angular velocity of 16 rad/s and acceleration of 374 rad/s^2. Neck injuries to the cadavers did not exceed AIS 1 (abrasion, haemorrhage in neck muscles and intervertebral discs). The velocities and accelerations were less than those experienced by a near side front occupant in a three-point belt and are lower, according to the authors, than proposed tolerance values. (In any event there are solutions available to reduce this side loading: a side impact break away sash mount has been developed by Renault).

8 CONCLUSIONS

1. Lap belts provide substantial protection to occupants, both adult and child, of both front and rear seats. Lap belts should always be used if no better restraint is available.

2. Both lap belts and lap sash belts have a disbenefit, being liable to cause a particular type of injury, the seat belt syndrome (SBS) consisting of abdominal visceral injury and/or lumbar spine injury. Lap belts appear to have about three times the propensity to cause this injury as lap sash belts. Children may be less at risk than adults.

3. SBS can result from improper placement of belts, or even thick clothing, but the mechanism depends mainly on:

- for lap sash belts, the geometry of the restraint as at present installed and the properties of the seat.

- for lap belts, additionally, on the absence of upper body restraint.

4. Of occupants restrained by lap-sash belts, rear occupants have a greater liability to SBS than left front passengers. This is an unexpected finding which may be explained by the geometric shortcomings of rear seatbelt installations.

5. Lap and lap-sash belts, as a group, cause about ten cases of SBS in children and 186 cases in adults in Victoria per annum (1987 expected totals).

6. Two thirds of the SBS cases in lap belt wearers in the centre rear seat could be expected to be eliminated by replacing the lap belts with lap sash belts, or, for children, adding a tethered harness. For children of appropriate sizes, a tethered booster with adult lap-sash belt, a tethered booster with lap belt and harness, or child seat are the preferred restraints. For infants and small children backward facing devices are the restraints of choice.

7. Reduction of SBS in general (three quarters of all passenger cases occur in lap-sash wearers) requires improved seat and belt design: improved belt geometry and a stiffer, ramped seat cushion.

8. A design study is suggested to investigate and, if practicable, develop a means of retrofitting lap-sash assemblies in the centre rear seat of current cars.

9. Development and manufacture of backward facing seats for children of weight 9 to 18 kg should be encouraged.

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AUTHOR	SOURCE	DATE	'N' IN REPORT	CASE NO.	AGE	SEX	RESTRAINT TYPE	SEATING POSITION	KIND OF IMPACT	VISCERAL INJURY	SPINAL INJURY	CORD INJURY	OUTCOME	INJURY LEVEL
Anderson et al. 1991	Hospital	Jul-85 Dec-88	5 of 20	1	5	M	2pt belt	R. Pass.		Present	Present	Present	disability	L3/4
				2	13	F	2pt belt	R. Pass.		Present	Present		disability	L2/3
				3	13	F	2pt belt	R. Pass.		Present	Present		disability	L2/3
				4	11	M	2pt belt	R. Pass.		Present	Present			
				5	7	M	2pt belt	R. Pass.		Present	Present			L1/2
Asbun et al. 1990	Hospital	Jun-86 Oct-88	1 of 8	6	14	M	2pt belt	R. Pass.		Present			recovery	
Blasier & Lamond 1985	Hospital		1 of 1	7	6	F	2pt belt	C/R. pass.	head on	Present	Present			L4
Braun & Dion 1973	Hospital		1 of 1	8	4	F	2pt belt	R. Pass.	side	Present			recovery	
Bull et al. 1988	Hospital	1988	1 of 1	9	3m	F	child seat *	R. Pass.		Present			fatal	
Burke 1971	Hospital	Apr-68 Jul-69	1 of 7	10	10	F	2 pt belt	R. Pass.			Present	Present	disability	L2/L3
Czyrko et al. 1990	Hospital		3 of 6	11	6	F		Pass.		Present			recovery	
				12	9	F		Pass.		Present			recovery	
				13	13	M		Pass.		Present	Present		recovery	L3
Gallagher & Heinrich 1990	Hospital		1 of 1	14	4	F	2pt belt	Pass.	frontal	Present	Present		recovery	L1
Gloyns & Rattenbury 1988			1 of 1	15	6	F	3pt belt lap part	L/R. Pass.	frontal	Present				

AUTHOR	SOURCE	DATE	'N' IN REPORT	CASE NO.	AGE	SEX	RESTRAINT TYPE	SEATING POSITION	KIND OF IMPACT	VISCERAL INJURY	SPINAL INJURY	CORD INJURY	OUTCOME	INJURY LEVEL
Gumley et al. 1982	Hospital	1973 1981	2 of 20	16	12	M	2pt belt	Pass.		Present	Present		recovery	L3
				17	11	M	2pt belt	R. Pass.		Present	Present		recovery	L3
Hardacre et al. 1990	Hospital	1990	2 of 2	18	8	F	2pt belt	R. Pass.	head on	Present	Present		recovery	L4
				19	8	M	2pt belt	F. Pass.		Present			recovery	
Hope & Houghton 1986	Hospital	1986	1 of 1	20	9m	F	shoulder part of 3 pt belt	F. Pass.	head on	Present	Present		disability	L2/L3
Hubbard 1974	Hospital	Jan-55 Jan-71	2 of 42	21	9	M	2pt belt?				Present		recovery	L2/3
				22	12	M	2pt belt?				Present		recovery	L3
Huelke & Chewning 1969	Hospital		2 of 18	23	12	F	2pt belt	L/R. Pass.	frontal	Present	Present		fatal	
				24	13	F	2pt belt	R/R. Pass.	frontal	Present			recovery	
Huelke & Kaufer 1975	Hospital		1 of 11	25	13	F	2pt belt	F. Pass.	frontal		Present			L2/3
Huelke et al. 1987	Hospital	1980 1984	4 of 6	26	13	F	2pt belt	L/R. Pass.	frontal				recovery	
				27	7		2pt belt	L/R. Pass.	head on				recovery	
				28	6		2pt belt	R/R. Pass.	head on				recovery	
				29	14	M	2pt belt	L/R. Pass.	head on	Present	Present		recovery	
Johnson & Falci 1990	Trauma Service	1985 1988	2 of 3	30	4	F	2pt belt	R. Pass.	head on	Present	Present		disability	L2/L3

AUTHOR	SOURCE	DATE	'N' IN REPORT	CASE NO.	AGE	SEX	RESTRAINT TYPE	SEATING POSITION	KIND OF IMPACT	VISCERAL INJURY	SPINAL INJURY	CORD INJURY	OUTCOME	INJURY LEVEL
Johnson & Falci 1990	Trauma Service	1985 1988	2 of 3	31	7	F	2pt belt	R/R. Pass.	head on	Present	Present		disability	L1, L2, L3
LeGay et al. 1990	Hospital	1981 1988	1 of 18	32	14	F	2pt belt	L/R. Pass.		Present	Present			L4
Lowne et al. 1987	Accident series	1979	1 of 18	33	4		3pt belt	F. Pass.	frontal	Present			fatal	
Moskowitz 1989	Hospital	Jun-85	1 of 1	34	8	F	2pt belt	R. Pass.	head on	Present	Present		recovery	L2/L3
Mure et al. 1990	Trauma Surgery		1 of 1	35	7	F	2pt belt	R. Pass.		Present		Present	fatal	
National Transp. Safety Board 1986	Hospital	1984 1986	10 of 139	36	13	M	2pt belt	L/R. Pass.	frontal	Present			fatal	
				37	13	M	2pt belt	R/R. Pass.	frontal	Present			fatal	
				38	5	F	2pt belt	R/R. Pass.	head on	Present	Present	Present	disability	L4
				39	6	F	2pt belt	L/R. Pass.	frontal	Present			recovery	
				40	6	F	2pt belt	L/R. Pass.	frontal	Present	Present	Present	fatal	
				41	14	M	2pt belt	L/R. Pass.	frontal	Present			fatal	
				42	11	M	2pt belt	R/R. Pass.	frontal	Present	Present	Present	disability	L3
				43	6	F	2pt belt	R/R. Pass.	frontal	Present		Present	fatal	
				44	12	M	2pt belt	R/R. Pass.	frontal	Present				
Newman et al. 1990	Trauma Centre	Jan-85 Aug-88	9 of 10	45	9	M	2pt belt	C/R. Pass.	head on		Present			L3/L4

AUTHOR	SOURCE	DATE	'N' IN REPORT	CASE NO.	AGE	SEX	RESTRAINT TYPE	SEATING POSITION	KIND OF IMPACT	VISCERAL INJUR	SPINAL INJURY	CORD INJURY	OUTCOME	INJURY LEVEL
Newman et al. 1990	Trauma Centre	Jan-85 Aug-88	9 of 10	46	6	M	2pt belt	R. Pass.	head on		Present			L3/L4
				47	3	F	2pt belt	R. Pass.	head on	Present	Present	Present		L2/L3
				48	6	F	2pt belt	R. Pass.	head on	Present	Present	Present		L2
				49	12	M	2pt belt	R. Pass.	head on		Present			L3/L4
				50	5	F	2pt belt	R. Pass.	head on		Present	Present		L3/L4
				51	5	F	2pt belt	R. Pass.	rear end	Present				
				52	14	F	3pt belt	F. Pass.	head on	Present	Present		recovery	L1
				53	3	M	2pt belt	F. Pass.	sideswipe		Present		recovery	L2/3
Reid et al. 1990	Hospital	1978 1988	3 of 7	54	7	F	2pt belt	R. Pass.	head on	Present	Present		disability	L2
				55	13	F	2pt belt				Present			L3
				56	9	M	3pt belt	F. Pass.	head on	Present	Present		recovery	L3
Ritchie et al. 1970	Hospital	Apr-69	2 of 4	57	11	F	2pt belt	R. Pass.	head on	Present	Present		recovery	L3/L4
				58	7	F	2pt belt	R. Pass.	head on		Present		recovery	L3
Rogers 1971	Hospital	1971	2 of 5	59	14	M		R. Pass.		Present	Present	Present	disability	L2
				60	10	M		R. Pass.		Present	Present	Present	disability	L3

AUTHOR	SOURCE	DATE	'N' IN REPORT	CASE NO.	AGE	SEX	RESTRAINT TYPE	SEATING POSITION	KIND OF IMPACT	VISCERAL INJURY	SPINAL INJURY	CORD INJURY	OUTCOME	INJURY LEVEL
Ryan et al. 1988	Hospital	1988	1 of 8	61	6	F	2pt belt	C/R. Pass	head on	Present	Present	Present	disability	L2/L3
Smith & Kaufer 1969	Hospital		1 of 24	62	9	F	2pt belt	F. Pass.	frontal	Present	Present		recovery	L2
Sripathi & King 1991	Hospital		1 of 1	63	7	F	2pt belt	C/R. Pass	frontal	Present	Present		recovery	L2/L3
Taylor & Eggli 1988	Hospital	1983 1987	5 of 5	64	9	M	2pt belt			Present	Present			L3/L4
				65	6	M	2pt belt			Present	Present			L3/L4
				66	12	M	2pt belt			Present	Present			L3/L4
				67	5	F	2pt belt			Present	Present			L3/L4
				68	14	F	2pt belt			Present	Present			L2, L3, L5
Upadhyay 1989	Hospital			69	14	M	3pt belt	F. Pass.		Present				recovery
Vandersluis 1987	Hospital		2 of 2	70	9	F	2pt belt	R. Pass.	head on	Present	Present		recovery	L2
				71	7	M	2pt belt	F. Pass.	head on	Present	Present		recovery	L3
Wheatley & Cass 1975	Hospital	Jan-82 Aug-87	1 of 11	72	2	M	3pt belt	F. Pass.		Present			fatal	

* Child restrained incorrectl in child car seat.

APPENDIX 1: Individual child SBS cases reported in literature. Outcome: recovery, disability or fatal. Injury level refers to lumbar vertabrae. Source: Authors cited.

APPENDIX 2

RESTRAINT USAGE, MELBOURNE ARTERIAL ROADS, 1985, 1986, 1988.

	Centre Front Seat				
	1985	1986	1988	all	
cars	22646	22488	19044	64178	
all passengers	13908	12763	10679	37350	
0-7 years					
belt worn	5	13	25	43	31%
not worn	55	33			
not known	3	3	4	98	
sub-total	63	49	29	141	100%
8-13 years					
belt worn	6	3	11	20	37%
not worn	13	8			
not known	2	8	3	34	
sub-total	21	19	14	54	100%
0-13 years					
belt worn				63	32%
sub-total				195	100%
14-17 years					
belt worn	4	3	6	13	50%
not worn	7	4			
not known	1	1			
sub-total	12	8	6	26	100%
all others					
belt worn	24	41	33	98	42%
not worn	68	47	1		
not known	3	7	7		
sub-total	95	95	41	231	100%
all					
belt worn	39	60	75	174	39%
not worn	143	92	1		
not known	9	19	14		
total	191	171	90	452	100%

Source: VicRoads

APPENDIX 2
RESTRAINT USAGE, MELBOURNE ARTERIAL ROADS, 1985, 1986, 1988

Centre Rear Seat

	1985	1986	1988	all	
cars	22646	22488	19044	64178	
all passengers	13908	12763	10679	37350	
0-7 years					
belt worn	214	207	209	630	63%
not worn	139	116	75		
not known	9	9	17	365	
sub-total	362	332	301	995	100%
8-13 years					
belt worn	53	28	40	121	38%
not worn	70	61	40		
not known	7	5	13	196	
sub-total	130	94	93	317	100%
0-13 years					
belt worn				751	57%
sub-total				1312	100%
14-17 years					
belt worn	22	16	16	54	29%
not worn	56	26	16		
not known	3	5	12	135	
sub-total	81	47	61	189	100%
all others					
belt worn	55	73	70	198	25%
not worn	220	159	126		
not known	25	19	34	583	
sub-total	300	251	230	781	100%
all					
belt worn	344	324	335	1003	44%
not worn	485	362	274		
not known	44	38	76		
total	873	724	685	2282	100%

Source: VicRoads

APPENDIX 2
RESTRAINT TYPE USAGE, MELBOURNE ARTERIAL ROADS, 1990

AGE		CENTRE FRONT SEAT 0-7	8-13	0-13
RESTRAINT USED				
	LAP BELT	7	5	12
	HARNESS	0	0	0
	CHILD SEAT	2	0	2
	OTHER	0	0	0
NOT USED				
	LAP BELT	1	1	2
	OTHER	0	1	1
	UNSURE	4	1	5
		5	3	8

AGE		CENTRE REAR SEAT 0-7	8-13	0-13
RESTRAINT USED				
	LAP BELT	38	28	66
	+ BOOSTER	127	1	18
	HARNESS	13	1	14
	CHILD SEAT	57	2	59
	BABY R'NT	7	0	7
	OTHER	0	1	1
	NOT SURE	2	1	3
		134	34	168
NOT USED				
	LAPBELT	23	11	34
	+ BOOSTER	2	0	2
	CHILDSEAT	1	0	1
	OTHER	0	1	1
	NOT SURE	6	4	10
		32	16	48
		166	50	216
	USE RATE	80%	68%	78%

Source: VicRoads