The value of safety belts: a review

Summary: The literature is reviewed to ascertain the values and dangers of safety belts. They are said to reduce the risk of major or fatal injury in impacts by nearly 60%. An incidence of abdominal trauma of the order of 0.5% is ascribed to the safety belt, and in addition there is a low incidence of a specific type of spinal fracture. The safety belt has not been shown to make injuries worse, and in causing injuries of its own has prevented more serious ones. The design of the safety belt is discussed; the three-point (lap-and-diagonal) belt is probably the best type for automobiles currently available. Recent research suggests that more sophisticated restraint systems may make survival possible in very severe impacts.

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The value of safety belts

Safety belts have been the subject of controversy since they were first installed in aircraft over 50 years ago. They were thought to cause ruptures of the abdominal viscera, or even transection of the body. Flexion around the belt was held to cause fractures of the spine, and belts fell into disrepute. Teare,[1] writing a report of a Comet aircraft crash, claimed that many of the injuries could be attributed to the wearing of seat-belts, and this drew a strong reply from DuBois[2] entitled "Safety-belts Are Not Dangerous". In order to discover the facts of the matter, the Automotive Crash Injury Research (ACIR) department of Cornell University began to study the problem, which had two facets: did seat-belts reduce fatalities and serious injuries, and did they themselves produce injury? The ACIR studied both light aircraft and automobile crashes, the latter mainly in rural California. At the same time similar surveys were carried out in Britain (by the Road Research Laboratory) and in Scandinavia.

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Effectiveness of the seat-belt

Early reports of the effectiveness of seat-belts in aircraft were encouraging.[3,4] There was a 69% reduction in major and fatal injuries in aircraft personnel equipped with seat-belts. The first report of their efficacy in automobiles came from Campbell,[5] who asserted that they had been responsible for reduction in injuries sustained in 19 car crashes that he had studied.

The first report of the ACIR's study of road accidents was published in 1960.[6] After studying injuries to 933 front-seat occupants with seat-belts and 8784 without, Tourin and Garrett concluded that seat-belt users sustained 35% fewer major or fatal injuries than did non-users, although the overall number of injuries was comparable in the two groups. The seat-belts seemed to be most effective in rollover accidents, and this was probably owing to the prevention of ejection, which had been shown to be a major cause of death in road accidents.[7-9]

In England, Moreland[10] noted a 55% reduction in injuries in people wearing seat-belts. Basing his assessments on a damage index/car weight ratio, he concluded that injuries were greater in (a) those ejected, (b) the passenger rather than in the driver and (c) those not wearing belts. Lister and Milsom,[11] again in England, showed that seat-belts reduced the risk of serious injury by 67%. In Sweden[12,13] seat-belts were judged to have given good or slight protection in 365 out of 382 accidents, and Bäckström[9] reported that they reduced the overall frequency of serious injury by at least 50%. In Australia the estimated reduction in injury was 80%,[14] and in Michigan, Gikas and Huelke[15] claimed that lap-belts reduced the risk of fatality by 34%, and that the addition of a shoulder strap lowered the risk by a further 11%.

The most detailed statistical analysis was carried out by Kihlberg and Robinson[16] using the ACIR computer. From 50,000 tabulated accidents they matched 651 pairs for car make and year, direction of impact and severity of crash. They concluded that the relative risk taken by an occupant without a seat-belt was 70% higher than that for a belted occupant.

In summary, there is a large body of evidence to show that the risk of major or fatal injury is considerably reduced by the wearing of a seat-belt, the average reduction in risk quoted in the literature being nearly 60%. The figures are summarized in Table I.

Injuries caused by seat-belts

Despite the series of reports stressing the protection afforded by the seat-

TABLE I
Reduction in major and fatal injuries by the use of seat-belts

Authors	*No. of injuries studied*	*Percentage reduction*
Tourin and Garrett[6]	9717	35
Bäckström[9]	712	50
Moreland[10]	121	55
Lister and Milsom[11]	893	67
Lindgren and Warg[13]	382	69
Herbert[14]	not stated	80
Gikas and Huelke[15]	79	45
Kihlberg and Robinson[16]	1302	59

belt there has been an increasing volume of literature suggesting that at the same time the seat-belts may produce injury. This has been reported mainly from the U.S.A., where lap-belts are the type almost universally used, and the injuries reported have been confined chiefly to the abdomen and lumbar spine.

Abdominal injuries

Kulowski and Rost[17] described an adhesion between the mesentery of the ileum and the pelvic brim causing partial small bowel obstruction, and claimed that this was produced by pressure from a seat-belt in a car accident three months earlier. In Sweden, diagonal seat-belts were implicated in the production of upper abdominal injuries, such as ruptured spleen, liver and kidney.[18,19]

This problem was investigated by Garrett and Braunstein[20] of the ACIR, who studied 2778 cars with 3673 occupants, at least one of whom in each car was wearing a seat-belt. They found seven cases of "internal injury". Unfortunately, no statistical comparison was made with similar injuries in non-users of seat-belts. All of the serious injuries were produced in high-speed crashes, and the authors felt that the belts prevented more injuries than they caused.

Since the publication of that report there have been numerous papers describing abdominal injuries attributable to seat-belts. These include rupture of the stomach,[21] small and large bowel and omentum,[22-32] spleen[33,34] and the pregnant uterus[35] and production of a ventral hernia.[36]

The statistical analyses of Kihlberg and Robinson[16] tend to confirm that these injuries are indeed caused by seat-belts, rather than being coincidental, as the incidence of abdominal trauma was consistently higher in belted than in unbelted occupants, although other injuries were reduced. Of the 651 belted occupants, 30 had abdominal injuries which could be ascribed to seat-belts, but 27 of these were minor (bruises, abrasions), so that the incidence of severe trauma caused by seat-belts is 0.5%, which can favourably be set against an overall reduction of 59% in serious and fatal injuries. From a practical point of view, it was noted that seat-belt injuries were more common in front-seat passengers and in frontal impacts.

It can therefore be assumed that seat-belts can be held responsible for a variety of intra-abdominal injuries, but that these injuries are considerably less common and less serious that those which the seat-belt prevents.

Mechanism of abdominal injury

Williams and Sargent[37] attempted to demonstrate how these intestinal injuries could be brought about, by using anesthetized dogs with pressure catheters inserted into the viscera and the peritoneal cavity. When a weight was dropped onto the abdomen they found that the intraperitoneal pressure always exceeded that of the lumen of the bowel, unless there was a closed loop, and hence they considered that rupture of the bowel was due to shearing forces rather than to increased pressure. A functionally closed loop could, however, be produced by tethering of the bowel or by peristaltic waves.[30]

Some have suggested that the blow-out takes place when the segment of bowel is trapped between the seat-belt and the vertebral column,[22,31,32] while others believe that the injuries are due to the bowel being carried forward by momentum and tearing of the mesentery.[29]

From a practical point of view, it is apparent from the literature that many seat-belt injuries are produced in occupants who are wearing the belts too loosely or too high. For maximal protection with minimal hazard the belt should fit snugly across the lap, and be held against the anterior superior iliac spines.

Of interest to the clinician is the observation, noted in numerous reports, that seat-belt injuries to the bowel will often not reveal themselves for some days, so that the patient may be discharged from the emergency department while continuing to have minimal abdominal discomfort. Careful watch should therefore be kept on people involved in motor vehicle accidents when there is any question of a seat-belt injury, particularly if a band of bruising across the abdomen bears witness to improper placement of the belt.

Spinal injuries

Garrett and Braunstein[20] included some spinal injuries in their study of the 'seat-belt syndrome', but it is not clear whether or not these injuries were caused directly by the belt. In most of the other cases reported the fractures were of the compression type, and were thought to have been caused by hyperflexion over the belt.[29,31,32,38] In some cases there were fractures of the pelvis,[21,31] the articular processes of the vertebrae[26] and the transverse processes.[21]

Many of these fractures can have a cause other than the seat-belt. However, a unique pattern of fracture has been reported by Smith and Kaufer[39,40] which they describe as follows: (1) disruption of the posterior elements of the lumbar spine—osseous, ligamentous or both; (2) longitudinal separation of the disrupted elements; (3) no (or minimal) compression of the vertebral body; (4) no (or minimal) forward displacement of the superior vertebra or fragment; (5) no (or minimal) lateral displacement; (6) usually located between L1 and L3, and (7) a seat-belt contusion is usually visible.

A particularly interesting variant of this fracture is one first described by Chance,[41] in which there is a horizontal fracture of the vertebral body, spine and transverse processes. This has now been described again in seat-belt injuries by Smith and Kaufer, and also by Fletcher and Brogdon.[42]

Mechanism of spinal injury

Smith and Kaufer[39,40] have ascribed these fractures to the following mechanism. Flexion and extension of the lumbar spine usually occur around an axis which runs through the nucleus pulposus. Hence, on anteflexion, there is a compressive force on the anterior border of the vertebra and a distractive force posteriorly. As the distance from the anterior spinal margin to the axis is one-quarter that of the distance from the axis to the tip of the vertebral spine, the pressure on the anterior border is four times the distraction force on the spines. Therefore anterior compression rather than posterior disruption can be expected. When a seat-belt is worn, it provides a new axis of flexion lying in front of the anterior border of the vertebral body, thus eliminating the anterior compressive forces. The leverage on the posterior elements is greater than that on the anterior vertebral border and hence the characteristic type of injury takes place. It seems reasonable to argue that this type of injury is more specifically attributed to the seat-belt than the abdominal injury, which reflects the general effects of blunt trauma.

Design of seat-belts

Considerable experimental work is being carried out to determine the safest type of seat-belt for use in aircraft and cars. Many authors have argued that the lap-belt is inadequate, and that some type of shoulder restraint is also necessary.[22,43-46] The diagonal belt alone is often adequate in anteroposterior impacts, but it is unable to prevent considerable movement of the wearer or partial ejection in more complex impacts. It may lead to major or fatal thoracic and cervical trauma.[13,42,47]

It is possible to approach this problem in three ways. Early experimenters used human volunteers[48] and found that a young healthy male could tolerate 26 G. at 850 G. per sec. for .002 second using a 3″ lap-belt, and sustain only thoracic soreness and whiplash. Obviously this approach is limited, as serious and fatal injuries cannot be investigated. Other workers have used instrumented dummies to ascertain the loads sustained by the belts, and the efficiency of the common restraint systems.[49] They found that the lap-belt did not protect the upper torso, and that the diagonal belt alone allowed the dummy to slip out from beneath it. The three-point (lap-and-diagonal) belt gave good support to the body, and the anchoring of the diagonal belt to the door post rather than to the floor halved the forward movement of the head and upper torso.

However, dummies cannot fully simulate effects on the human body, and a compromise has been reached by Snyder and his co-workers,[50] who have used Savannah baboons with a variety of harnesses and seating positions on a Daisy decelerator. First the effects of the lap-belt alone in forward, rearward and lateral impacts were noted. It was found that rearward impacts could be survived at 44 G., frontal ones at 35 G., and lateral ones at 20 G. The second series of experiments was more comprehensive[51] and tested six different types of harness (Fig. 1) in the three impact positions. Apart from the four systems currently available, they also used an inverted-Y chest restrainer with inertia reel, and an air-bag restraint system. The latter comprised a lap-belt together with an airbag which was carried in front of the animal and inflated immediately before impact. Their results are summarized in Table II. It is evident from these figures that the two experimental systems used were less dangerous than those in current use.

Of those restraints available to the car-owner, the least effective and most dangerous is the diagonal belt alone. Next, in order of effectiveness, is the lap-belt. Full harness is the best system, but the three-point (lap-and-diagonal) belt is probably the most satisfactory compromise[49,52] and should be fitted to all automobiles.

Conclusions

Lap seat-belts reduce the risk of major or fatal injury by nearly 60%. Nevertheless they may be responsible for visceral injury including intestinal perforation, and can be associated with a specific type ("chance") of spinal fracture. They have never been shown to worsen injury, and while themselves producing injuries, they have prevented more serious ones. The addition of a shoulder restraint (diagonal belt) confers appreciably greater accident protection. More sophisticated restraint systems may enable victims of severe accidents to survive.

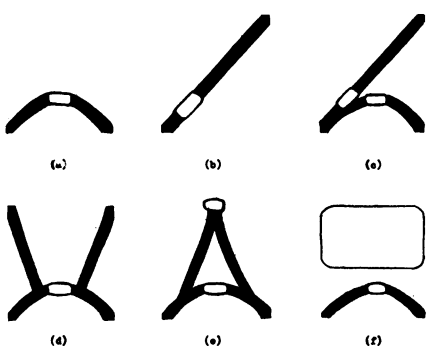

FIG. 1 – Restraint systems: (a) lap belt; (b) diagonal; (c) three-point (lap-and-diagonal); (d) full harness; (e) inverted-Y with inertia reel; (f) air-bag restraint.

TABLE II
Survivability of G. forces with varying impact directions and restraint systems[51]

Restraint	*Direction*	*Max. survivable gravitational force (G.)*
Lap-belt only	Rearward	40-45
	Lateral	15-20
	Forward	25-35
Diagonal only	Forward	30 fatal
Three-point	Rearward	40
	Forward	30 non-fatal
	Lateral	22
Full harness	Forward	20 no trauma
Inverted Y	Forward	43
	Lateral	32
Air bag	Forward	57+

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