

THE EVOLUTION OF THE THREE POINT SEAT BELT FROM YESTERDAY TO TOMORROW

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ABSTRACT

The three point seat belt (the safety belt) has been in use in cars for almost fifty years. In 1959 Volvo, as the first car producer in the world, started to install three point safety belts (of the static type) for front seat occupants as standard equipment. A few years later it was obvious from car accident studies that safety belts were of considerable benefit. No other safety product has saved so many lives of car occupants as the seat belt. Other products as frontal and side airbags have been successfully implemented to further enhance car occupant protection. However, these new restraint systems complement the three point seat belt - they do not replace it.

Several improvements to the seat belt have taken place over the years. The first was the inertia reel (the belt retractor) during the 1960s, followed by the retractor pretensioner and the buckle pretensioner during 1980s. The largest improvement made so far was probably the shoulder belt force limiter introduced in 1995. The first, and an important step into active and integrated safety was taken by Mercedes-Benz in 2002 with the belt pre-pretensioner (PRE-SAFE).

Possible future improvements such as various ways to prevent car occupants' upper torso from sliding out of the shoulder belt in rollovers and in far-side impacts are discussed, as well as steps to take elderly even more into account by a further reduction of the risk of sustaining serious chest injuries in frontal crashes. More also needs to be done to prevent violent head-to-upper torso motions to reduce the risk of sustaining disabling neck injuries with long term consequences.

The three point seat belt will probably remain the primary car occupant restraint system for many more years. Its protection capabilities combined with other restraint systems can be developed further, as well as improvements to its ease of use.

Keywords: Safety belts, three point belt, occupant, protection, restraint systems

USE OF SAFETY BELTS has been a habit for me since I was a young teenager, when in 1959 my family bought its first car. This was and still is a very good habit. The car was a two year old Opel Rekord equipped with two diagonal front seat belts. This type of belt was very convenient to put on and easy to adjust. The safety belt was therefore always used. The belts were installed in Sweden. They were probably manufactured by either Autoliv or Klippan as both these Swedish companies started to produce safety belts for cars already by the mid 1950s.

1959 is also an important year in the history of the three point seat belt. During that year Volvo was the first car producer in the world to start installing three point safety belts (of the static type) as standard equipment for front seat occupants in their cars (Volvo, 2006). Other car makers followed soon afterwards.

A few years later it was obvious from car accident studies that safety belts were of considerable benefit. In Sweden Bäckström (1963) studied over 400 car crashes with 712 front seat occupants in which 79 % of these were wearing diagonal belts. Analysis of data showed a 54 % reduction in the probability of death and injury. A larger study of more than 28,000 crashes of Volvo cars was reported by Bohlin (1967). The average injury reducing effect of the three point belt ranged from 40 to 90 % depending on the crash speed and type of injury. Many other studies have later demonstrated the great benefit of using seat belts (Norin et al., 1984; Evans, 1990).

Shortly after I started to work for Autoliv in January 1984 I met Bertil Aldman for the first time. This was the beginning of a long and very stimulating cooperation with him and his department at Chalmers University. Some years after our first meeting I got a copy of Bertil Aldman's doctoral thesis entitled "Biodynamic Studies on Impact Protection" (Aldman, 1962). I have recently read his thesis again. It is fascinating to see how early many of the important features of the three point safety belt, as we know it today, were considered. In the introduction of his thesis Bertil Aldman writes "...the method of protection of occupants of automotive vehicles must be as simple as possible and yet effective" and "...without impact the occupant must be decelerated in an upright posture. This requires the use of an upper restraint in combination with the lap restraint. But the construction of the upper-torso is different from that of the pelvis and there are reasons for believing that critical velocity of the upper-torso is much lower than for the pelvis."

In the thesis you will find tests performed by Bertil Aldman with different safety belt systems. The three point belt was found to be superior to all others. Three of the restraints tested can be found in figures 1 – 3.

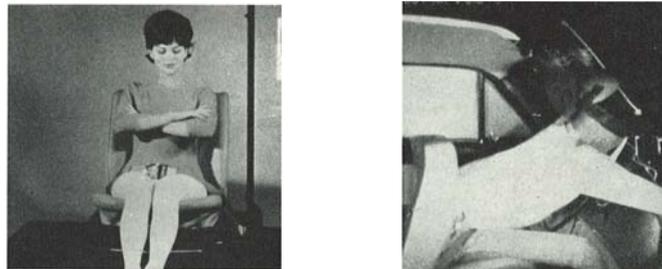


Figure 1. Single lap belt on a live subject and during dynamic testing (40 km/h) 100 ms after impact.

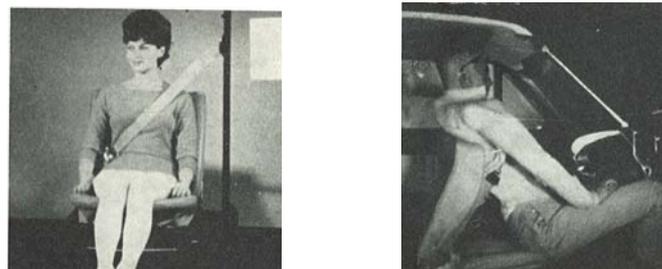


Figure 2. Single diagonal belt on a live subject and during dynamic testing (40 km/h) 25 ms after impact.

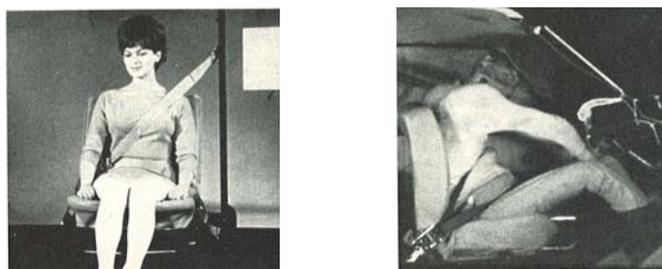


Figure 3. Combined lap and chest restraint with two anchoring points on the floor and one in the door post (the three point belt). Restraint on a live subject and during dynamic testing (40 km/h) 100 ms after impact.

High stretch belts (25 % elongation at 1,500 kp (15 000 N) static load) to give a lower onset rate of the force on the torso was studied and found suitable. More than 30 year later a very important improvement of the three point belt was introduced - the so called shoulder belt force limiter.

Bertil Aldman also found in his early studies that the geometry of the belt in the area of the junction of the lap and chest restraints was very important to avoid the lap belt cutting deeply into the soft abdominal part of the dummy (or occupant). The potential problem of what we often call "submarining" was thus recognized at a very early stage.

Finally, further on in his thesis you can read “..if the rate of application of the force has to be kept low on the upper torso it is also important that the upper-torso restraint should be well adjusted to the wearer.” By the end of 1960s (Volvo, 2006) the three point safety belt was supplemented with the inertia-reel (the retractor), and in the 1980s by the pretensioner (see below).

THE EVOLUTION OF THE THREE POINT BELT FROM YESTERDAY TO TODAY

THE SEAT BELT RETRACTOR. The first generation of the three point safety belt, the static belt, was a very good restraint provided it was well adjusted with only a small amount of slack present. However in practice that was often not the case. One major reason for this was probably that people wanted a loose belt for good comfort. Another common reason was that for example the husband and his wife used the same car. The belt was often adjusted for one of them, but it was inconvenient for the other to readjust, when using the same belt.

Therefore, during the 1960s the first improvement of the three point belt was the inertia-reel, today normally called the retractor (figure 4). It was installed in the lower part of the B-pillar of the car. The fixed upper anchorage point was replaced by the so called D-ring or the pillar loop. The shoulder belt was routed down from this loop to the retractor. The main function of the retractor is to pull in excessive webbing and thereby eliminate the worst of the slack in the belt. However, the rewinding spring force has to be rather weak otherwise the belt will be too uncomfortable to wear. The rewinding capacity of the retractor has to be sufficient to “clean up” the belt, when you un-buckle.

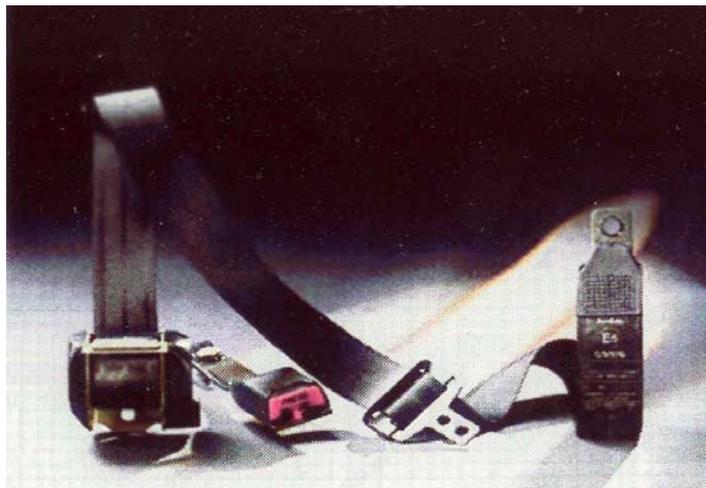


Figure 4. A three point safety belt with retractor (inertia-reel).

A critical function of the retractor was the locking mechanism. It had to lock very early in a crash, or even before, if there was a hard braking. Bertil Aldman told me that the low threshold for the vehicle deceleration required to lock the retractor, 0.45 g according to regulation ECE R 16, was established very early based upon braking tests with cars and unrestrained occupants. The car driver can resist a motion forward relative to the car during a hard braking because he/she is holding on to the steering wheel. Passengers normally can not resist this motion forward. Similar results have been found much later in a student’s graduate work (Svedlund, 1994).

In order to get people to trust the function of the seat belt it was necessary to introduce an additional locking mechanism in the retractor. It was a locking based upon the acceleration of the webbing itself, by the so called webbing sensor. This also locks very early in a crash, as does the vehicle sensor/mechanism. However, when a car occupant pulls the webbing somewhat faster than

normally, the locking mechanism with the webbing sensor also works. This gives the user confidence in using the seat belt.

Installation of three point safety belts with retractors as standard equipment in cars increased rapidly during the first half of the 1970s.

THE RETRACTOR PRETENSIONER. The restraining function of the static seat belt was very good provided it was very well adjusted/tightened. A three point belt with a retractor has to sacrifice some restraining ability in the early phase of a frontal crash to get the belt comfortable in the daily usage.

The retractor pretensioner, which was first installed in Mercedes-Benz cars in 1983, eliminated this weakness (Mitzkus and Eyrainer, 1984). A small pyrotechnic charge generates gas very quickly with a high pressure which then acts upon a pulling mechanism to rewind the retractor spool. Depending on the amount of slack present, up to 150-200 mm of webbing can be pulled in. The retractor pretensioner is fired by an electronic control unit sensing the vehicle crash pulse. The belt is tightened up significantly before the occupant has moved more than a few centimetres forward relative to the car during a frontal crash. This very early coupling of the occupant to the car in a crash reduces the maximum loading to the upper-torso (figure 5).

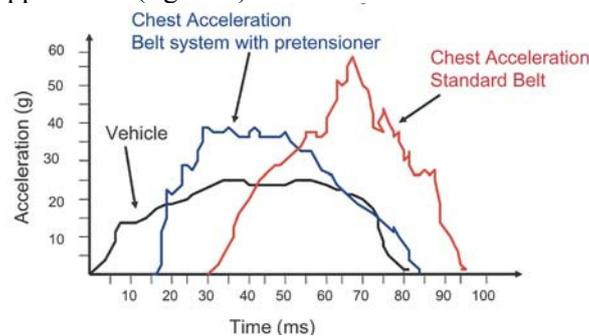


Figure 5. Chest acceleration of a three point belt restrained Hy III dummy in a frontal crash test with and without retractor pretensioner.

THE BUCKLE PRETENSIONER. The potential problem of the lap belt penetrating into the abdomen was mentioned by Bertil Aldman in his thesis. The geometry of the lap, and the location of the anchorage points, are both very important to reduce this risk according to a study by Adomeit (1979).

However, if people wear a lot of clothing, a considerable amount of slack can be present in the belt system and especially in the lap belt, and this can increase the risk of submarining. In order to further improve the pre-tensioning of the lap belt, the buckle pretensioner was developed by Autoliv. The first generation design was fully mechanical with a strong and fast acting spring (about 1500 N) and was able to be used in cars without an electronic sensor system (Håland and Spångberg, 1989) as the sensor also was a mechanical device. The buckle is pulled down within 10 ms by up to 70-80 mm - exactly how much depends upon the amount of belt slack present (figure 6). Buckle pretensioners were installed as standard equipment in a Volvo car from 1989.

Today with airbags commonly mounted into cars, the actuators of the buckle pretensioners are pyrotechnically driven. There are also pretensioners in use today that act on the outer lower end-bracket of the lap belt.



Figure 6. The function of a buckle pretensioner.

Håland and Nilsson (1991) developed a new criterion to evaluate the risk of submarining. Using this criterion they showed in a series of sled tests and by mathematical simulations that pre-tensioning of the lap belt was very effective in preventing submarining not only for belted front seat occupants but even more so for belted rear seat occupants. The reason found for this was that the closer the occupant's feet are placed to the seat the more likely submarining is to occur due to a more unfavourable angle between the lap belt and the frontal part of the pelvis. The risk of submarining was also found to increase with the amount of belt slack.

SHOULDER BELT FORCE LIMITATION. The probably most important improvement of the three point seat belt so far is the limitation of the shoulder belt force. It is well known that the risk of thoracic injury increases by age and that the chest deflection tolerance decreases (Foret-Bruno et al., 1998, Kent et al., 2003).

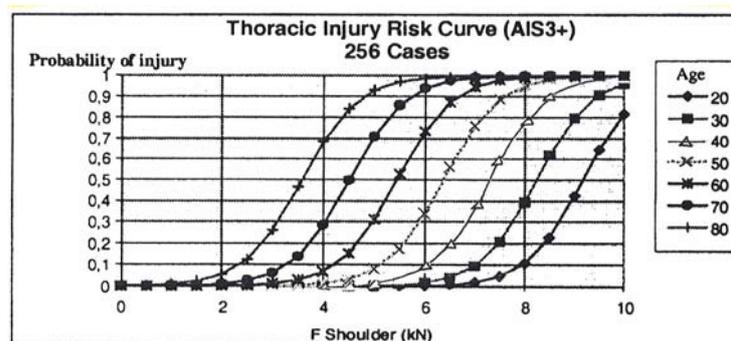


Figure 7. From Foret-Bruno et al. (1998). Probabilities of thoracic AIS 3+ injury risk according to age and shoulder belt force for 256 cases.

In 1995 Renault equipped its cars with a load limiter located at the retractor attachment to the car structure at the B-pillar. The new load limiter was designed to limit the shoulder belt force to 6 kN. In 1998 in a second step an airbag especially designed to provide optimum force distribution over the thorax and to prevent higher head excursions was introduced. The threshold of the force limiter was then reduced to 4 kN (Foret-Bruno et al., 2001). The principle of the operation of the load limiter was no longer tearing of a steel part but torsion of the axis of the retractor (figure 8).

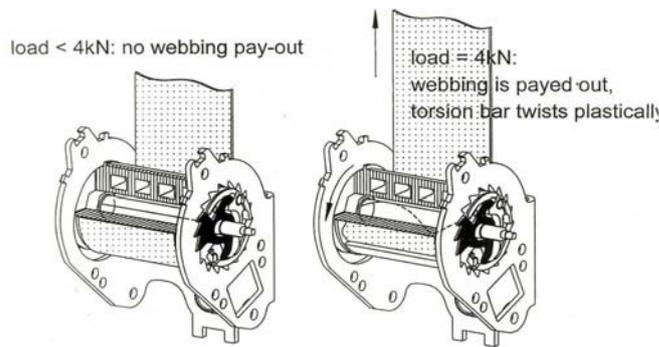


Figure 8. Retractor with force limiting function.

In a study of real car accidents Foret-Bruno et al. (2001) reported that the 4 kN load limitation of the shoulder belt force resulted in a very important reduction of thoracic injury risk for all AIS levels compared to other samples. A 50 to 60 % reduction of AIS 2+ injuries were observed, as well as 75 to 85 % for AIS 3+ injuries. The complete absence of AIS 4+ injuries with a 4 kN load limiter was also highlighted. For 6 kN load limiters, the thoracic injury risk reduction was low (10 to 20 %) compared to non-limiter cases.

Since the tolerance for chest deflection decreases by age, it should be an advantage to adjust the load limiting level according to the age of the occupant. An attempt to find a sensor to measure the bone strength of car occupants was reported by Hardy et al. (2005). Another way to proceed is to make the car occupant restraint systems even more tolerant of severe crash loads for all car occupants regardless of their age. The load distribution between the seat belt and the airbag in frontal crashes can probably also be further developed.

THE PRE-PRETENSIONER. The first step into integration of passive and active safety was taken by Mercedes-Benz in 2002, when the PRE-SAFE system was introduced for the S-Class car. For the first time the activation of protective systems can take place before a possible accident. By use of reversible belt pretensioners the driver and the front seat passenger can be firmly pressed into their seats. The occupants are thereby better coupled to the vehicle and hence prepared for a possible collision. The vehicle systems react to various critical driving conditions that may lead to an accident. These conditions are identified by the electronic stability program (ESP) sensors and by those of the brake assist (BAS) system (Schöneburg et al., 2003). An electrical motor is coupled to the belt retractor via a coupling and can tighten the belt to a maximum force of 140 N within 120 ms (Bogenrieder et al., 2002). If the possibly dangerous situation disappears then the tensioning force is reduced in steps over a number of seconds. The PRE-SAFE system also includes a function to raise the seat back of the passenger. If an accident does take place, the normal pretensioners are triggered as well.

A reduction in chest forward displacement of 10 cm and of the head by about 15 cm, due to the activation of PRE-SAFE, has been reported by Mercedes-Benz (Schöneburg and Breitling, 2005). Thick clothing and large amounts of belt slack were not used on the test subjects. Compared with conventionally equipped vehicles, the study revealed great potential for reducing the loads experienced by the occupants. Particularly in the head area the loads could be reduced by 30-50 %, depending on the criterion used, compared with a front passenger not protected by PRE-SAFE. With a reduction in load of 20-40 %, the neck region was also subjected to less stress.

The next generation of the PRE-SAFE system was introduced by Mercedes-Benz in the new S-Class model in 2005. The adaptive cruise control system (Distronic) includes not only a long-distance (77 GHz) radar but also a short range (24 GHz) radar (Schöneburg and Breitling, 2005). In cases where the driver brakes, but has incorrectly assessed the distances in a traffic situation, the system can operate automatically up to the maximum possible braking deceleration. In parallel to partial braking, at the start of the deceleration, preventive measures such as belt tightening, and the adjustment of the front passenger seat are also activated. Similar systems have now also been introduced by Toyota, Honda and Nissan.

SOME POTENTIAL EVOLUTIONS IN THE FUTURE OF THE THREE POINT BELT

PREVENTION OF SLIDING OUT OF THE SHOULDER BELT. In a rollover, the lap belt part of the three point belt restrains the occupant's lower torso and prevents him/her from being fully ejected from the vehicle. However, the upper torso of the far side occupant may slip out of the shoulder belt. Influenced by the lateral deceleration of the vehicle in the early tripping phase of a rollover, the torso tries to move towards the opposite side of the occupant compartment. The upper torso then can slide out of the shoulder belt (Boström and Håland, 2003). A considerable amount of belt slack is then created. Later on during the rollover event - typically when the vehicle's roof hits the ground - the occupant is then less restrained and he/she may impact quite violently (for example) the inner roof structure.

The benefits of an extra seat integrated two point belt in addition to the standard three point belt were investigated by Boström and Håland (2003) by means of mechanical simulations of rollover crashes. The additional two point belt efficiently prevented the upper torso from sliding out of the shoulder belt part of the three point belt. In order to reduce the risk of possible injurious belt-to-neck loads caused by the two point belt, an inflatable side support was also used (figure 9). This bag is small in volume, unventilated and inflated to a pressure of about 2 bar. Due to its attachment to the frame of the seatback it can give a quite considerable support to the upper torso. The inflation time for this small bag can be as long as 30-40 ms, which is a good prerequisite for benign out-of-position performance.



Figure 9. An extra seat integrated two point belt to supplement the three point belt and an inflatable torso side support on the inboard side.

However, the need to buckle up an extra belt was unfortunately found to be a hurdle in selling this 2+3 point belt system. Therefore, Boström and Håland (2005) proposed and evaluated a simplified belt system with the same good restraining capability in rollovers, namely a seat integrated three point belt with reversed geometry and an inboard torso side support side airbag (the same as for the 2+3 point belt system). See figure 10.



Figure 10. Seat integrated three point belt with reversed geometry and an inboard torso side support airbag.

This seat integrated belt system with reversed geometry was evaluated by Boström and Håland (2005) with a new sled test method simulating a full-scale tripped rollover, both during the initial phase of tripping, the airborne phase and the first ground impact. A standard Hy III 50th percentile dummy modified with a 3D-flexible lumbar spine ("spring spine") was used. Whilst the head of the non-leading (far) side dummy impacted the inner roof in the standard three point belt configuration,

the seat integrated belt with reversed geometry and buckle pretensioner showed an ability to restrain the torso from moving inboards and towards the roof (figure 11).

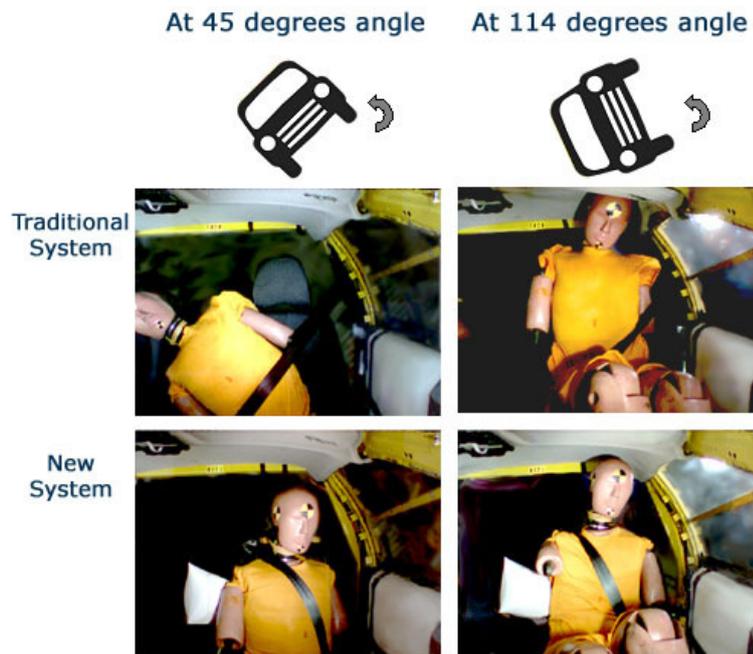


Figure 11. “Occupant” on non-leading (far) side during rollover tests with standard belt geometry and with reversed belt geometry.

To obtain a low belt-to-neck load an inboard side support airbag of the type mentioned before was included in the reversed belt geometry configuration to reduce the belt loading. Also, the upper belt guide aligned the belt vertically in order to promote a flat belt contact with the neck. Whilst there are no currently accepted load limits for evaluating the direct interaction of the shoulder belt with the soft tissues of the neck, the direct belt loading to the neck caused by the reversed belt geometry measured by the lower neck load cell was considered by Boström and Håland to be low (less than 1 kN).

This torso side support airbag has shown its ability in earlier far side impact tests to keep an occupant with a standard geometry three point belt within the seat for a lateral acceleration of 10g, both in 90 degree as well as in 60 degree tests.

So far one type of inboard torso side support has been evaluated. There are probably other possible and suitable solutions to supplement the reversed geometry three point seat belt system.

ONE HAND OPERATION TO BUCKLE UP. With the first generation of the three point safety belt, the static belt, it was possible to buckle up by using only one hand. This was, according to Bertil Aldman, an important feature of the safety belt to get people to buckle up. With the introduction of the inertia reel (the retractor) the worst belt slack disappeared, but unfortunately the easiness to buckle up by using only one hand also disappeared. To buckle up a standard three point belt it is normally a multi-step operation requiring both hands (figure 12).



Figure 12. A typical way to buckle up a standard three point belt.

However, there is a rather easy way to come back to the one hand operation. The solution is to use a dual retractor belt system - to have one retractor for the lap belt and another for the shoulder belt. The two belt parts are each attached to the buckle tongue. With this arrangement the movement of webbing through a slot in the tongue is not possible. It is not needed either. Figure 13 shows the ease by which the belt can be buckled up by a one handed operation. Due to the use of two retractors the lengths of the lap belt and of the shoulder belt are automatically adapted to the shape/size of the occupant. With a single retractor standard three point belt the adjustment of the two belt parts are accomplished by movement of the webbing through the slot in the buckle tongue, which its associated friction. To overcome this friction it normally requires the operation to be undertaken using both hands.

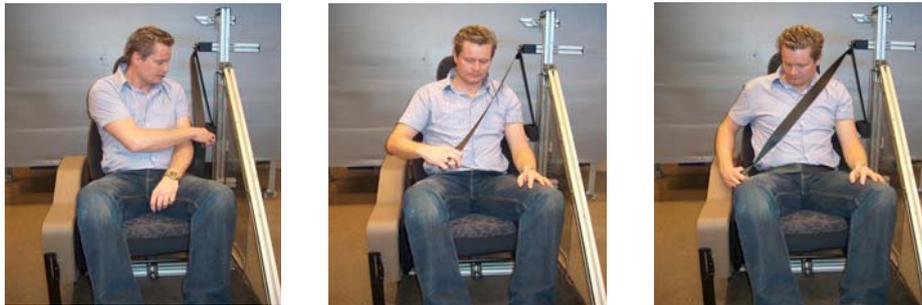


Figure 13. Buckling up of a dual retractor three point seat belt with one hand.

There are a few car models on the market with dual retractor belt system like some Cadillac models and the Volkswagen Phaeton car, but no high volume cars use the system.

FURTHER REDUCTION OF SHOULDER BELT LOADS. Further account must be taken of the growing elderly population in many countries when developing car occupant protection systems. The shoulder belt load limiter mentioned previously was an important improvement, which was made possible by the introduction of frontal airbags. Can more be done to reduce the risk of serious thoracic injuries of elderly car occupants?

Mertz et al. (1997) have shown that the risk of AIS 3+ thoracic injury is considerably higher for a certain deflection of the sternum (measured with the Hybrid III dummy) due to a concentrated shoulder belt loading compared to a distributed loading (as from an airbag). Kent et al. (2003) ran a number of cadaver tests, where the same subject was loaded by different conditions to levels approaching rib fracture threshold. The different loading conditions were a distributed load (over an area of 730 cm²), a double diagonal belt (460 cm²), a single diagonal belt (250 cm²) and a steering wheel hub (250 cm²). The effective stiffness of the thorax was found to increase with the loaded surface area. However, the relationship was not continuous indicating that the specific anatomical structures that are engaged by the restraint system play a large role.

The 2+3 point belt system mentioned earlier was also evaluated in frontal impact conditions by Boström and Håland (2003) using the THOR dummy. Compared with a standard three point belt system with a load limiter, the double diagonal belt system, (also with load limiters), loaded the chest of the dummy in a more even way and the maximum chest deflection was significantly reduced. However, the THOR dummy is more sensitive to the addition of a second belt than the human is according to a study by Forman et al. (2005).

In an on-going study at Autoliv Research (Pipkorn, 2006) using the human body model THUMS (version 2.21-040407) developed by Toyota, a three point belt system with 50 mm wide webbing was compared with the same belt system but with 100 mm wide shoulder belt webbing in a 30 km/h frontal impact condition with an average crash pulse of 15g. The belt systems did not have any load limiters, and no any airbag was used. The configuration with the 100 mm shoulder belt can be found in figure 14. Different widths of the lap and shoulder belts respectively can be incorporated if a dual retractor

belt system is used. The wider part of the shoulder belt can be limited to a certain length from the buckle tongue so as to just cover the rib cage of an adult male occupant. A normal D-ring for 50 mm webbing can then be used.



Figure 14. Belt configuration with 100 mm wide shoulder belt using the human body model THUMS. Frontal impact at 30 km/h. 15g crash pulse.

At maximum loading of the ribcage (at 100 – 110 ms) the two belt configurations show differences in rib deflections. It is obvious by studying figure 15 that the 50 mm webbing is creating a deeper and narrower deformation on the right hand side of the rib cage (figure 15 left) compared to that produced by the 100 mm wide webbing (figure 15 right). What this means in terms of any difference in the risk of sustaining serious chest injury, especially for elderly, and if so to what degree is indeterminate at this stage. However, the author considers the results to be interesting enough to justify further work. For rear seat occupants especially, who are not protected by frontal airbags, a wider shoulder belt could be considered.

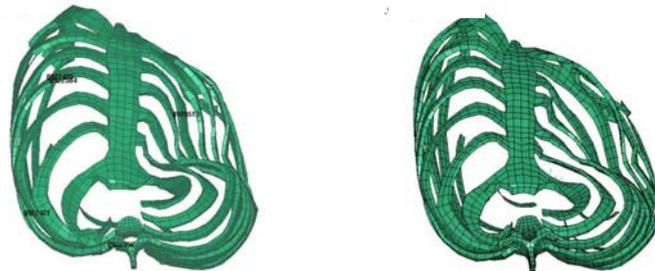


Figure 15. Maximum chest deflection by 50 mm and 100 mm wide shoulder belts. (30km/h and 15 g frontal impact condition, and the human body model THUMS). View of the rib cage from above.

PREVENTION OF VIOLENT HEAD TO UPPER TORSO MOTIONS. The seat belt primarily restrains the torso. The head, however, is only indirectly restrained by the belt by forces and moments transmitted via the occupant's vulnerable neck. Injuries to the head/brain are normally well prevented by airbags, paddings, and other soft impact surfaces. The neck, however, must be protected in a different manner.

To prevent the neck from injuries, which often have life-long consequences, it is obviously not possible to have for example a supporting neck collar. Other measures are needed. The main principle is to try to minimize the relative head-to-torso motion for different crash conditions (frontal, side, rear). It is probably even more important to try to minimize the violence of this relative motion. This can be compared to what has been developed to protect the neck in rear-end collisions. Here the aim is to either get a very early head to headrest contact (figure 16 right) or to reduce the early head-to-torso motion by means of a force controlled yielding of the seatback (figure 16 left) and/or a combination of both. The latter principle is used in the WHIPS (WHiplash Injury Protection System) developed by Volvo and Autoliv and introduced in Volvo cars from 1998 (Lundell et al., 1998).

Reduce the pushing force forward

Early head-to-headrest contact

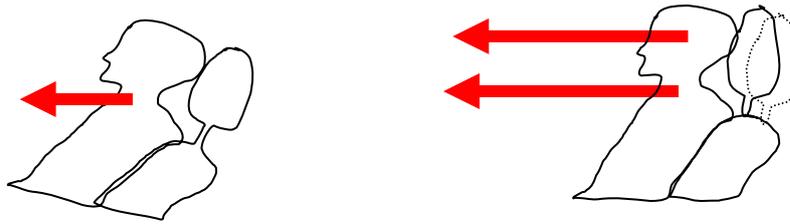


Figure 16. Two basic principles to reduce the violence of the relative motion between the lower and upper part of the neck

In near side impacts the head curtain type of airbag (the Inflatable Curtain), an Autoliv innovation introduced in cars by both Mercedes-Benz and Volvo in 1998 (Brambilla, 1998; Bohman, Håland and Aldman, 1998), is probably also of benefit in reducing the risk of sustaining neck injuries. The lateral head-to-torso motion is stopped very early in the crash event (figure 17).



Figure 17. The Inflatable Curtain for side impact and rollover protection

The AIS1 neck injury is the most frequent type of disabling injury in frontal impacts. Protecting the head and the torso does not guarantee that disabling neck injuries are avoided (Krafft, 1998). In a study by Bohman et al. (2000) the influence of the restraint system on the neck loads in frontal impacts were investigated by using mechanical as well as mathematical (MADYMO) models of the Hy III 50th percentile dummy. The mathematical simulations were based on 168 frontal crash pulses collected from crash recorders installed in passenger cars in Sweden. The neck loads were evaluated by a new injury criterion, NIC protraction, the upper neck flexion moment and the Nij criterion to take into consideration all the phases of neck motion from the initial protraction phase to the later flexion phase. New long term neck Injury Assessment Reference Values (IARVs) found by Boström et al. (2000) were used. It was found in the study by Bohman et al. (2000) that a pretensioner, a load limiter or an airbag have the potential to reduce the neck loads below the suggested long term neck IARVs. Moreover, the interaction between the pretensioner, the load limiter and the airbag was found to be of great importance in order to minimize the neck loads. However, this work has just started and much more research is needed.

SUMMARY AND CONCLUSIONS

The three point seat belt (the safety belt) has been in use in cars for almost fifty years – and no other safety product has saved so many lives of car occupants as the seat belt. It is indeed a lifeline, a low cost life insurance. Other products as frontal and side airbags have been successfully implemented to further enhance car occupant protection. However, these new restraint systems complement the three point seat belt - they do not replace it.

Several improvements of the seat belt have taken place over the years. The first was the inertia reel (the belt retractor) during the 1960s followed by the retractor pretensioner and the buckle pretensioner

during the 1980s. The largest improvement so far was probably the shoulder belt force limiter introduced in 1995. The first, and an important step into active and integrated safety was taken by Mercedes-Benz in 2002 with the belt pre-tensioner (PRE-SAFE).

Possible future improvements to prevent car occupants' upper torso from sliding out of the shoulder belt in rollovers and in far-side impacts have been discussed, as well as the need to take the elderly even more into account by a further reduction of the risk of sustaining serious chest injuries in frontal crashes. More needs to be done to prevent violent head-to-upper torso motions to reduce the risk of sustaining disabling neck injuries with long term consequences. The list can and will be longer in the future.

Finally, it is my believe that the three point seat belt will remain as the primary car occupant restraint system for many more years. Its protection capabilities together with other restraint systems can be developed further as well as the convenience to use it.

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ACKNOWLEDGEMENTS

I wish to acknowledge my colleagues in Autoliv and especially those within Autoliv Research for many years of stimulating, pioneering and successful work. I also wish to acknowledge colleagues at Chalmers University. The cooperation started already in 1984 with Professor Bertil Aldman and has continued with Professor Per Lövsund and his staff.

A special acknowledgement is given to Dr. Bengt Pipkorn for his mathematical simulations of the effect of a wider shoulder belt during the preparation of this lecture.