EFFECTIVENESS OF A MECHANICAL PRETENSIONER ON THE PERFORMANCE OF SEAT BELTS

Franco Zuppichini

Emergency Surgery Dept. of the Verona University Medical School (Dir. Prof. Claudio Cordiano)
Piazzale A. Stefani, 1 I - 37126 Verona (Italy)

ABSTRACT

A pretensioner is a device that actively withdraws a portion of belt (about 10–15 cm) during the impact, in order to keep the car occupant adherent to his seat and prevent contacts with the steering wheel, or with dashboard components. In its general form, a pretensioner is composed by a front-installed sensor (with an intervention threshold among 8–15 g) and by an effector connected to the belt system itself.

A research has been performed on a mechanical pretensioner, on a pyrotechnical pretensioner and on standard automatic seat belts, with and without slack. Each device has been tested by simulation in a frontal impact at 35 mph with a GM Hybrid II dummy.

The laboratory results show a significant reduction in HIC vs standard belts, especially when poor wearing conditions are present (slack). The reduction in forward displacement of head is particularly important for the interaction with the steering wheel (or dashboard components for the passenger) in small car interiors, in order to offer a better protection to occupants of economical, large diffusion cars.

One can individuate some differences in the functioning of the pyrotechnical and the mechanical system, mainly in the direction of the retraction force, that is door-oriented in the first on, inside-oriented in the other one.

Other characteristics of the pretensioner, not evaluable in this study, can present relevant effects in preventing dangerous side effects of seat belt action. It will be very interesting to investigate the performance of pretensioners -both pyrotechnical and mechanical- in real car accidents.

PRETENSIONING AND DECELERATION PATTERN

In a frontal impact, deceleration is already demonstrable during braking phase, if present; however, it can become dangerous for a restrained occupant only after the contact with foreign structures.

An ideal safe vehicle is composed by a rigid core, designed as a shell to protect its occupants, and by progressively deformable periferic structures, projected to absorb the whole amount of the inertial force, or a fraction as higher as possible. Its interiors are out of contact (or fully padded), and the occupant is perfectly adherent to his seat.

In a such conceived motorvehicle, the only limiting factor to the effectiveness of restraint system is the conservation of the structural geometry of the car interior ("survival space").

In the actual car, this dampening effect is always partial and disomogeneous, due to lack of structure and/or to the presence of not deformable mechanical devices (e.g., engine or steering components); each model of car has its own deceleration pattern, characterized by a sequence of spikes that can reach dangerous levels. Car interiors are traumatic if impacted, and moreover the occupants are allowed a certain degree of movements by the restraint system.

In a lateral crash, there is no way to reduce the deceleration force before the involvement of the passengercompartement; on the opposite side, the dissipation of deceleration forces is easier in rollover and multiple crashes [6,17].

Both laboratory and epidemiological researchhave conclusively proved the effectiveness of seat belts in preventing or ameliorating the lesions caused by car accidents [9,10]; nevertheless, it is well known how in some frontal impacts the face of the driver can hit some parts of the steering wheel. The so produced face lesions play an important role in the described "redistribution of lesions" [10,11] following seat belts use.

Furthermore, if the belt system is malpositioned, the driver can move forward against the belt itself, or slip under the belt (submarining) [2]. This action can produce lesions of various kind ("seat belt syndrome"), generally located at the abdomen, thorax or side of neck [4,7,8,18].

Abdominal lesions regard usually the peritoneum and the small bowel, with pathogenetic mechanisms involving pressure from the belt, compression of gas-filled ansæ, or sudden deceleration alone[3,7,16]. Thoracic lesions usually consist in fractures of sternum and/or ribs or clavicula, while neck lesions involve vascular structures like the jugular vein or the carotid artery [18].

The elimination, as far as possible, of these side effects is a must for oncoming generations of seat belts, whose performance can be improved by the following means:

- Reducing the cinetic energy to dissipate (intervention outside car structure: e.g., speed limit or deformable barriers);
- Optimizing the dissipation pattern of deceleration (intervention on car structure);
- Raising the compliance of the restraint system.

The last objective can be pursued with belt pretensioning.

During the impact, a portion of the belt is extracted from the system, due to delay from the first contact and the locking of the retractor, to the narrowing of spires around the retractor ("film spool effect"), and then to the stretching of the belt under the pressure of the body. The sum of these effects is referred to as "web pay-out".

The "ignition" of a restraint system starts with a defined retard from the initial impact; this histeresis, that is characteristic of each single car model, is around 25–35 msec for three-point automatic belts.

The *web-clamp* systems [1] are simple devices that can passively prevent most of the spool effect, but not other components of web pay-out.

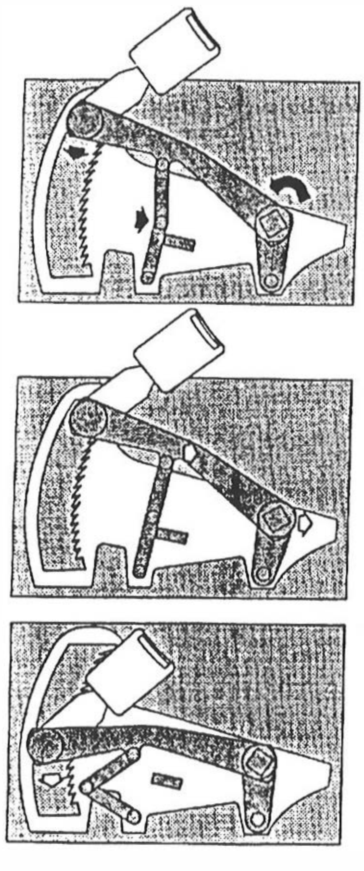
In its general form, a pretensioner is composed by a crash sensor, a power source and an effector connected to the belt retractor.

The *pyrotechnical pretensioner* has a small explosive charge, that is ignited by an electronic control system when an impact is detected. The electromechanic sensor is based on an inertial mass (usually a sphere), that for decelerations over a given threshold switches an electric contact and modifies the logical status of a microprocessor. A central check control, always active to relieve eventual failure of the circuitation, sees this changed signal and drives the explosion of the charge, connected with the retractor by means of a steel wire. Pyrotechnical pretensioners are installed on some Mercedes cars.

The *mechanical pretensioner* is powered by a preloaded torsional spring bar, which can be mounted transversally under the seat [5]. Since the torsional bar is hinged as a pendulum, the bar itself is the crash sensor; during the impact, one end of the bar will move forward and an overbent knee-joint mechanism will collapse (Picture 1). This device too has already been adopted and installed on some upper-class European cars.

Both kinds of pretensioners are activated in frontal impacts, with collision angles no wider than ±30°.

Another type of mechanical pretensioner, named *procon/ten* (programmed construction tension), is installed as optional on the Audi 80 sedan. This interesting device is powered by the displacement of the engine during the impact; a steel wire provides both pretensioning of seat belts and retraction of the steering wheel [13].



Picture 1: *Design and operating system of the mechanical belt pretensioner.*

A pretensioner device must have an intervention time no longer than 20–25 msec; otherwise, the occupant body inertia would rise to values so high to vanish the pretensioning effect. The threshold for the activation is triggered usually at 8 g, depending on the specific standards of the car manifacturer.

Adding active components to traditional seat belt systems can be adjusted on the peculiar deceleration pattern of the assigned car model, so to smooth its spikes and furtherly prevent head trauma.

Materials and method

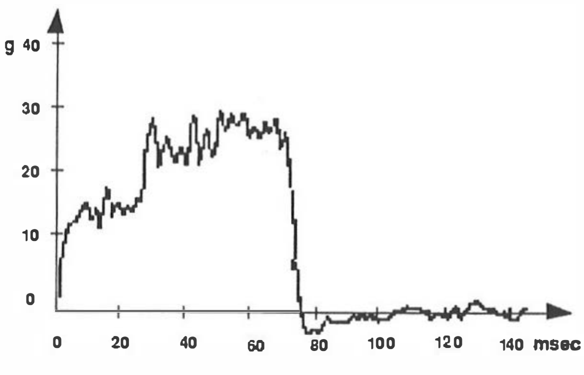
The experimental study is aimed to evaluate the performance of a mechanical pretensioner in a simulated car impact, in relation to the performance of a pyrotechnical pretensioner and of standard three-point automatic seat belts.

All the tests were performed at the Autoliv Development laboratories in Vårgårda (Sweden), during 1988.

It was not used a standard car crash pulse as foreseen by the ECE 16 regulation, but the characteristic car crash pulse (Picture 2) of a currently marketed and recently projected European upper-class car.

The instrumentation was set as following:

- Acceleration sled, in conformity to vigent rules;
- Soft seat, currently producted, belonging to the same car model which the car crash pulse is referred to;
- Dummy General Motors Hybrid II, equipped with decelerometers;
- High speed film recorder (1000 photograms/sec).



Picture 2: *Car crash pulse as choosen in the described research.*

The seat and the restraint system were fitted to the sled with adherence to the geometry of the specific car model.

In each series of tests, one of the following three items was installed on the sled:

- Standard three-point automatic belt, currently producted by Autoliv-Klippan in conformity to ECE rules;
- Three-point automatic belt, with a mechanical pretensioner currently producted by Autoliv-Klippan in conformity to vigent rules;
- Three-point automatic belt, with a pyrotechnical pretensioner developed by Autoliv-Klippan in conformity to vigent rules.

The following data were looked for:

- Head Injury Criterion (HIC);
- Chest acceleration of the dummy in simulated impact;
- Head forward displacement during the restraint action;
- Histeresis time between impact and belt locking;
- Webbing pay-out of the system.

In particular, HIC and acceleration of chest were reported from the decelerometers, while the delay in locking time and the forward displacement of the Hybrid II head were measured by a single-photogram review of the high-speed film taken during the test.

Webbing pay-out was measured by drawing a sign, before the launch, at the origin of the belt from the retractor.

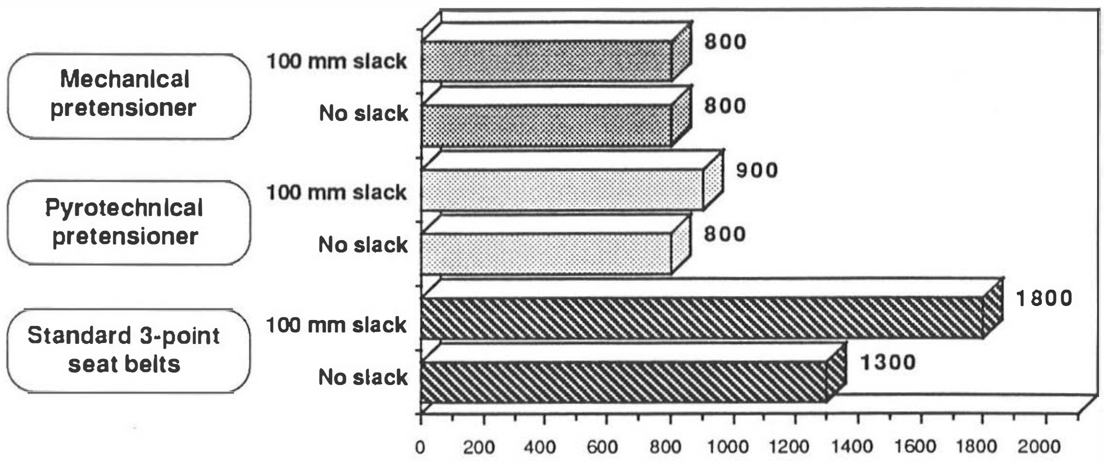
The test conditions were performed both with a perfectly worn belt, and with 100 mm slack.

Results

Values for *Head Injury Criterion* (HIC) were over 1000 with standard three-point belts, both in optimal wearing conditions and with 100 mm slack. With pretensioners, it was firm at values of 800-900, depending on the presence of slack; the mechanical pretensioner behaved similarly even with bad wearing (Picture 3).

Chest acceleration is significantly smaller (–20%)with pretensioners: both kinds of pretensioners grant 40 g at 35 mph, or 45 g with slack (Picture 4).

Head forward movement better value was obtained by the pyrotechnical device, with 49 cm; this device was sensitive to slack (52 cm), while the mechanical one was constant with 51 cm with and without slack (Picture 5).



Picture 3: *HIC values for the tested devices, with and without belt slack.*

The *web pay-out* measured with standard seat belts was 7 cm, while with 100 mm slack it reached a value of 8 cm (Picture 6).

With the mechanical pretensioner, without slack, we measured a mean web pay-out of 5 cm, with an active retraction of –8 cm; the respective values for the pyrotechnical are 4 cm and –5 cm. Net belt extraction is therefore a negative value: –3 cm for the mechanical and –1 cm for the pyrotechnical.

With slack, the retraction was sharper: –13 cm for the mechanical and–8 cm for the pyrotechnical, with net extraction values of –8 and –4 cm respectively. The mechanical device retracted 5 cm more with slack than in optimal conditions, while the pyrotechnical one retracted 3 cm of belt more than in optimal wearing conditions.

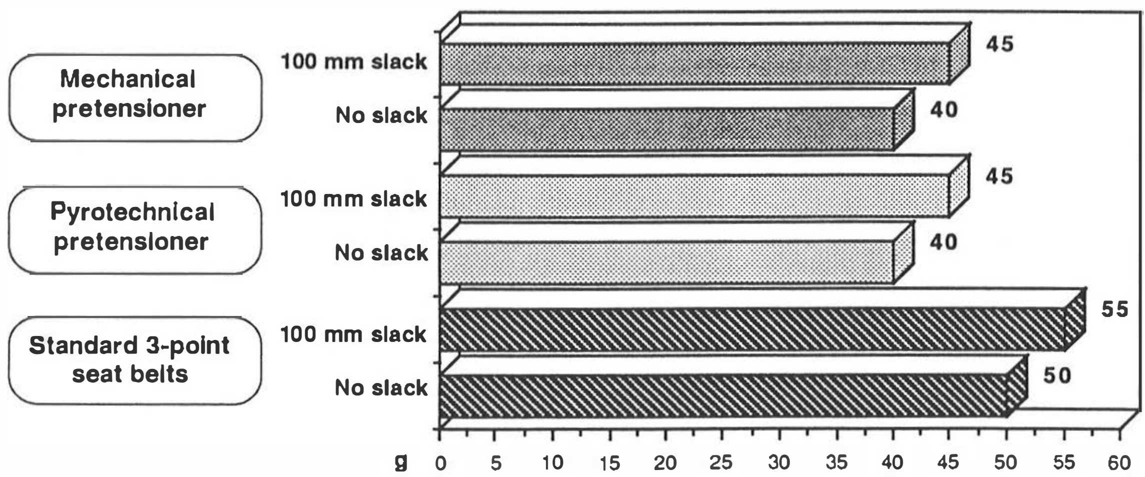
Both the pretensioners had an activation time in the range of 10–15 msec.

While the possible buckle retraction of the mechanical pretensioner is around 90 mm, in real crash it did not exceed 2/3 of this length.

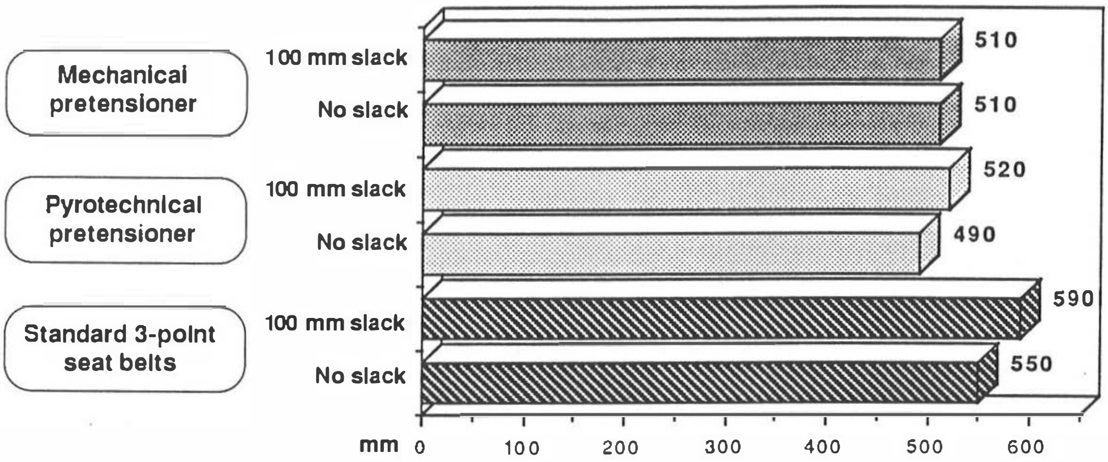
Discussion

The analysis of the data yields encouraging informations about the effectiveness of the mechanical pretensioner.

Both reduction in HIC and in thoracic charge are statistically significant ($p < 0{,}01$) and constitute a good predicting factor for the effectiveness of pretensioners in reducing injuries to impact-exposed car occupants. The forward excursion of head is limited, but is difficult to evaluate in absence of data regarding every single situation with position of dashboard, glasses and steering wheel.



Picture 4: *Chest acceleration values for the tested devices, with and without belt slack.*



Picture 5: *Head forward movement values for the tested devices, with and without belt slack.*

The pretensioners proved to be effective in minimizing the effect of belt malposition, reducing slack by 50%; web pay-out is better contrasted by the mechanical pretensioner.

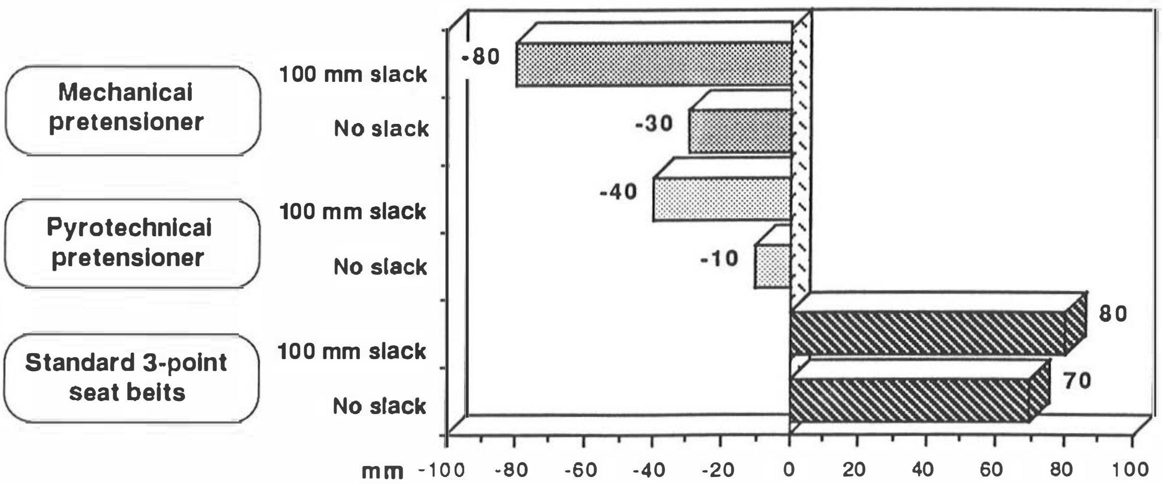
The retraction force of the mechanical device is directed towards the inner of the car, not towards the B-pillar; this feature could prevent dangerous contacts with side glasses and/or rigid components of car structure. Moreover, the retraction is directly performed also on the abdominal tract of the belt, furtherly preventing submarining.

The mechanical pretensioner overcomes any trouble caused by electric wires and connections, and the possible, even if rare, "decapitation" of the system by cutting away of the battery during a violent crash. The absence of explosive eliminates the caution measures that are necessary while repairing or destroying a pyrotechnical-equipped car.

The mechanical pretensioner has a cost about 1/4 of the pyrotechnical; it is feasible that this characteristic could offer pretensioning choice also to lower-class cars. In small-sized cars, it could be possible to install only one mechanical retractor in the middle of the seat to assist two belts, in order to save space and cut the cost of the device.

Data on performance of pretensioners with child seats and with rear seat belts are not available, although they can be of great interest. Pretensioning even in non-frontal impacts could be obtained by providing a supplementary sensor to the device.

Since people drive not in laboratories, but in every-day roads, we look with particular interest



Picture 6: *Net extraction of the belts in the tested devices, with and without slack.*
For the standard 3-point belt only, it is equal to web pay-out.

at the good results of pretensioners in bad belt wearing conditions.

The performance of pretensioners even in presence of slack can offer great advantages in the prevention of lesions caused by loose seat belts, that are a major contributor to the seat belt syndrome [3,7,8].

A theoretical side effect of pretensioners -of any kind- could be a more violent whiplash injury, due to the constriction of the torso to the seat while the head is free to move forward. The same mechanism, coupled with the about 10cm friction of the retracted belt, could give a more severe seat belt sign (abrasions and contusions along the way of the belt).

There is suggestion that some pathologic conditions are related to risk from the use of seat belts: severe cervical arthropaties, implant of pacemaker or vascular prostheses, pregnancy [12,15]. Particularly in the last case, the recall of the belt in the abdominal region can be dangerous to the fetus, and could suggest not to wear seat belts if mechanically preloaded.

Pretensioning could aggravate the consequences of some patterns of voluntary malposition: e.g., underarm wearing of seat belts [14].

After a simulated impact, the dummy has not to unbuckle its seat belts, of course; but in emergency situation, we wonder if any driver or passenger is able to find and correctly operate a buckle that has been retracted some centimeters lower than usual, and energycally pulled down. We think that all seat belts, but particularly the preloaded ones, need a luminescent release buckle and possibly a general unlocking command to be operated with grossly movements (fist or elbow), from the dashboard or the door panel.

Obviously, the absence of data on real accidents makes these arguments only speculative matter: it will be very interesting to investigate the performance of this "buckle" mechanical pretensioner in real car accidents.

References

1. ADOMEIT D, BALSER W: Items of an engineering program on an advanced web-clamp device. Paper SAE 870328, 119–128, 1987.
2. BIARD R, CESARI D, DERRIEN Y: Advisability and reliability of submarining detection. Paper SAE 870484, 27–38, 1987.
3. CHRISTOPHI C, McDERMOTT FT, McVEY I, HUGHES ESR: Seat belt induced trauma to the small bowel. World J Surg, 9:794-797, 1985.
4. GARRETT JW, BRAUNSTEIN PW: The seat belt syndrome. J Trauma, 1962, 2:220-237.
5. HÅLAND Y, SKÅNBERG T: A mechanical buckle pretensioner to improve a three-point seat belt. 12th ESV Conference, Göteborg, Paper 89-5B-0-001, 1989.
6. MACKAY GM: The prevention of injury in road accidents. In: Tubbs N, London P (Editors), Topical reviews in accident surgery, pag.1–22, Wright & Sons Limited, Bristol, 1982.
7. MEURISSE M, LEJEUNE G: Traumatisme et ceinture de sécurité. Acta Chir Belg, 1984, 84:186-191.
8. NEWMAN RJ: Chest wall injuries and the seat belt syndrome. Injury, 1984, 16(2):110-113.
9. NILSSON G, SPOLANDER K: Seat belts and road safety: some conclusions. Swedish Road and Traffic Research Institute, Paper, Stoccolma 1984.
10. NYGREN Å: Injuries to car occupants - Some aspects on the interior safety of cars. Acta Oto-Laryngol (Suppl.), 395-1:164, 1984.
11. OTTE D, SÜDKAMP N, APPEL H: Variations of injury patterns of seat-belt users. Paper SAE 870226, 61–71, 1987.
12. PEPPERELL RJ, RUBINSTEIN E, McISAAC IA: Motor-car accidents during pregnancy. Med J Aust, 1977, 1:203-205.
13. SEIFFERT U: Occupant protection in motor-vehicle accidents. Paper SAE 870490, 97–109, 1987.
14. STATES JD, HUELKE DF, DANCE M, GREEN RN: Fatal injuries caused by underarm use of shoulder belts. J Trauma, 27(7):740-745, 1987.
15. STROBEL E, ARENZ R: Intrauteriner Fruchttod nach Verkehrsunfall. Geburtsh u Frauenheilk, 1980, 40:462-465.
16. TSCHERNE H, OTTE D: Invited commentary. World J Surg, 1985, 9:797.
17. WALZ FH: Unfalluntersuchung Autoinsassen. Eidgenössisches Justiz- und Polizeidepartement, Bern, 1982.
18. ZUPPICHINI F: Le cinture di sicurezza nei traumi stradali. Morelli Ed., Verona, 1987.