SHOULDER-BELT-FORCES AND THORAX INJURIES

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Frontal collisions of automobiles at relatively low velocities often result in serious if not lethal thorax injuries of not safety-belt protected front-seat passengers when crashing against the steering-wheel or dash-board.

The wearing of safety-belts may help to prevent the crashing of the upper part of the body against one of these interior instruments and is therefore suited to eliminate injuries caused by these instruments. At the same time, however, the belt becomes now the bearing-surface area of the thorax and can therefore be a cause for thorax injuries itself. But the expected injury risk should, by all means, be smaller due to the special cushioning characteristics of the belt. When wearing a safety-belt the upper part of the body is included in the deceleration of the vehicle.

Because of the steadily increasing number of people wearing safety-belts in road traffic it has become important to investigate in series the tolerance limit of the thorax when crashing against the safety belt during frontal collisions.

The tests were carried through with 1 to 5-day old cadavers who have been preserved in a cold-storage chamber at a temperature of 3°C. At the time of the tests the body temperature of the cadavers ranged from 10°C to 20°C. X-ray photographs of the thorax had been made before the tests. If rigor mortis still existed the cadavers were treated in such a manner in order to bring them in a seating position (Kallieris and Schmidt 1974). The testing material consisted of 22 natural and 29 unnatural causes of death. The most frequent natural death was the heart death with 11 cases (21.6%), the largest group of the unnatural causes of death amounted to 17 poisonings (35.3%). A further splitting can be seen at figure 1.

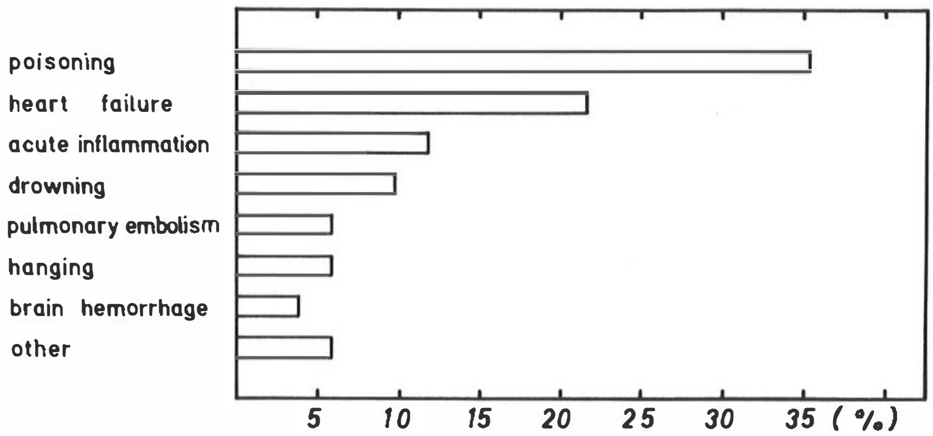

Figure 1 - Causes of death - relative frequency.

Male and female cadavers in the age range 12 to 82 years have been tested; figure 2 shows a percentual spreading of the age. The weights of the tested cadavers varied from 44 kg up to 91 kg.

The following restraint systems (Fa. REPA) were used when simulating frontal crashes of a belt-protected occupant (without using a dash-board) on an acceleration track operated through a falling weight (Kallieris 1974).

1. 3-point-belt*, automatic retractor (with and without force limitor (torsion bar), and preloading device).

2. Diagonal-shoulder-belt , automatic retractor (with and without a force limitor and preloading device) combined with a kneebar (Schmidt et al 1974).

3. Diagonal-shoulder-belt, knee-belt, automatic retractor,

belt-force limitor, preloading device (two experiments).

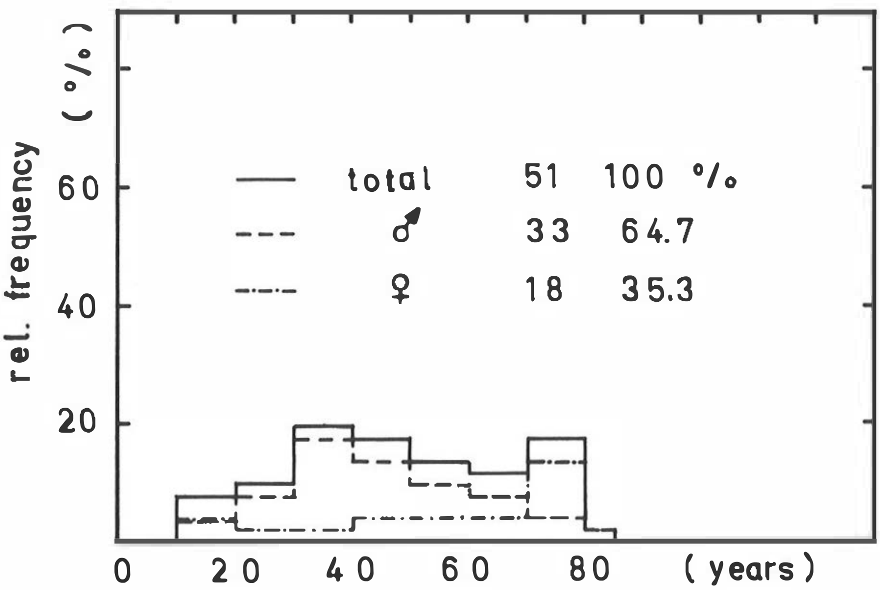

Figure 2 - Age dispersion of the tested cadavers.

* In most cases a 50 mm broad belt with an expansion of 18% respectively 6% had been used. One test was made with a 3-point-belt and 2 tests were made with diagonal-shoulder-belts/kneebar while using a 100 mm broad belt. During 4 tests, a 10 cm broad leatherpiece, padded with hard rubber, had been put underneath the belt for a length of 45 cm. During 4 more tests, a 15 cm broad aluminium sheet, padded with felt, was also put underneath the belt for a length of 45 cm.

Fourty-four tests were conducted with crash velocities of 50km/h; 6 tests with crash velocities of 64km/h; and one test with a crash velocity of 80km/h. The calculated sled deceleration ranged from 18.5g to 31.4g; the measured shoulder-belt-forces lie between 340kp and 1080kp.

According to physical considerations it can be expected that the shoulder-belt-forces on one hand essentially depend upon the crash velocity and deceleration of the sled, on the other hand of the weights of the tested cadavers.

This dependability was confirmed to a great extent with the tests made. At a permanent sled velocity of 50km/h the shoulder-belt-forces increased nearly linear according to the weight - a common dispersion experienced with biological testing material (figure 3).

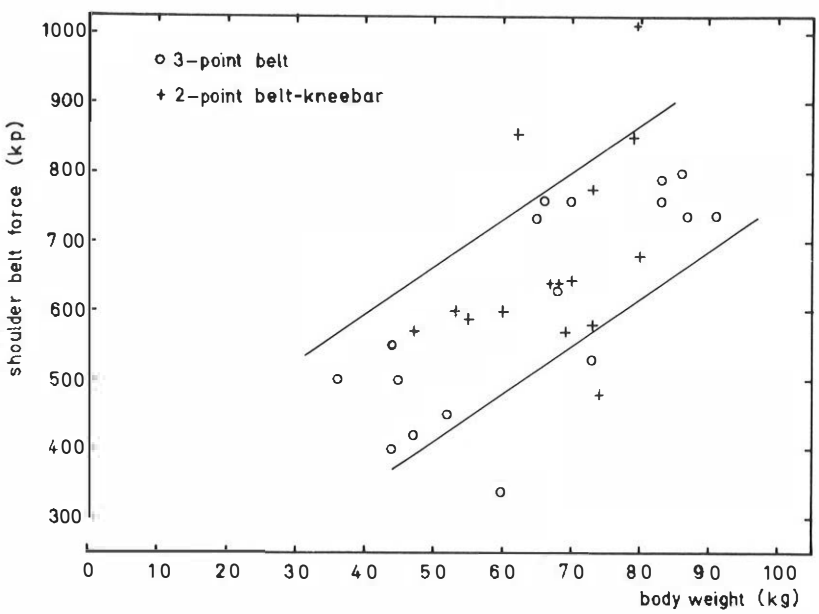

Figure 3 - Shoulder-belt-force in dependence to the weight of 32 impact tests: 17 tests were accomplished with 3-point-belt and 15 tests with 2-point-belt-kneebar. (Crash velocity: 50km/h, 50mm broad belt).

There was only one exception (a 17-year-old man, 60kg/169cm) in our test series, where an influence of the torsion bars reducing the shoulder-belt-forces could not be proved.

Just as little was it possible to determine a distinct difference in regard to the efficiency of the used 3-point-belt system and the 2-point-kneebar system.

With six impact tests at a velocity of 64 km/h (the restraint systems used were equipped with a force limitor and preloading device) the shoulder-belt-forces in relation to the weight in the case of the 3-point-belt system were at the upper limit of the 5okm/h tests; whereas the measured shoulder-belt-forces of the 2-point-kneebar system considerably exceeded this limit (table 1).

Table 1 - Shoulder-belt-force in dependence of the weight during an impact velocity of 64km/h (belt-systems with force limitor and preloading device).

Belt System	Weight (kg)	Shoulder-belt-force (kp)
3-point-belt	81	840
3-point-belt	67	820
3-point-belt	69	780
2-point-belt-kneebar	66	1040
2-point-belt-kneebar	77	1080
2-point-belt-kneebar	63	1080

If the shoulder-belt's bearing-surface area of the thorax was enlarged by aluminium sheets respectively leather plates, then, as expected, the shoulder-belt-forces remained in the same range as common belt widths (table 2). The shoulder-belt-forces of the 3 tests accomplished with a 100 mm broad belt were not measured.

Table 2 - Shoulder-belt-forces in dependence of the weight at an impact velocity of 5okm/h by using a leatherplate respectively an aluminium sheet.

Belt System	Weight (kg)	Shoulder-Belt-Force (kp)
3-point-belt (leatherplate)	52	640
"	56	700
"	62	700
"	67	660
3-point-belt (aluminium sheet)	60	580
"	64	630
"	75	680
2-point-belt-kneebar (aluminium sheet)	57	750

The results obtained when measuring the shoulder-belt-forces of the diagonal-shoulder-belt/kneebelt system are considered to be within the same ranges as experienced with the 3-point-belt-system and the diagonal-shoulder-belt-kneebar system.

The tested cadavers suffered deformations of the thorax caused by the belt-forces of the diagonal-shoulder-belt. The occurrence of bone fractures depends, to a great extent, upon the elasticity of the sternum-rib-spine-system and the existing bone strength. When considering the experiences made by traumatology and the biological strength-doctrine, it can be expected that, under the same conditions, there will be a frequency of rib fractures by advancing years. This could be confirmed by our tests (figure 4).

With the same crash velocity of 50km/h an increased dispersion of the part-results can be determined by advancing years. A possible explanation regarding this observation could be a variable proceeding of the old age osteoporosis. The frequencies of rib fractures of the seventeen 3-point-belt tests seem to be somewhat higher than those of the fifteen 2-point-kneebar tests.

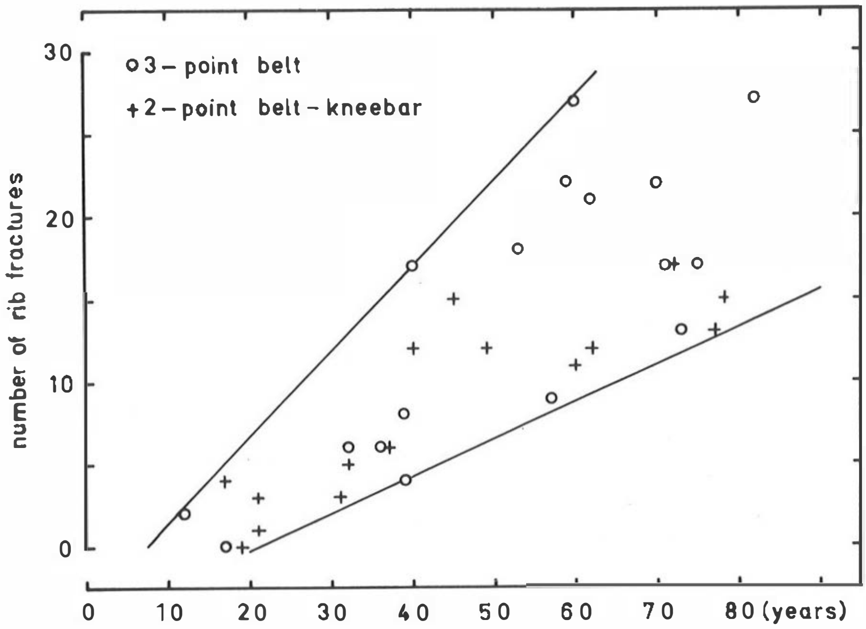

Figure 4 - Number of rib fractures in dependence of the age at 32 crash tests: 17 tests accomplished with 3-point-belt and 15 tests with 2-point-belt-kneebar (crash velocity 50km/h, 50mm broad belt).

Figure 5 indicates the influence, affected by the enlargement of the bearing-surface area of the shoulder-belt through aluminium sheets respectively leather plates, and during 3 tests through a 100 mm broad belt, in regard to the number of rib fractures. When comparing these results with tests made using common bearing-surface areas, a reduction of injury hazards can be considered and consequently proves the effectiveness of the principle regarding the enlargement of bearing-surface areas. There is only limited reliability concerning this statement because of the small number of tests made. The results of the tests carried out at a velocity of 64km/h are more intense dispersed (fig.6). Indeed, this test series is still at the beginning.

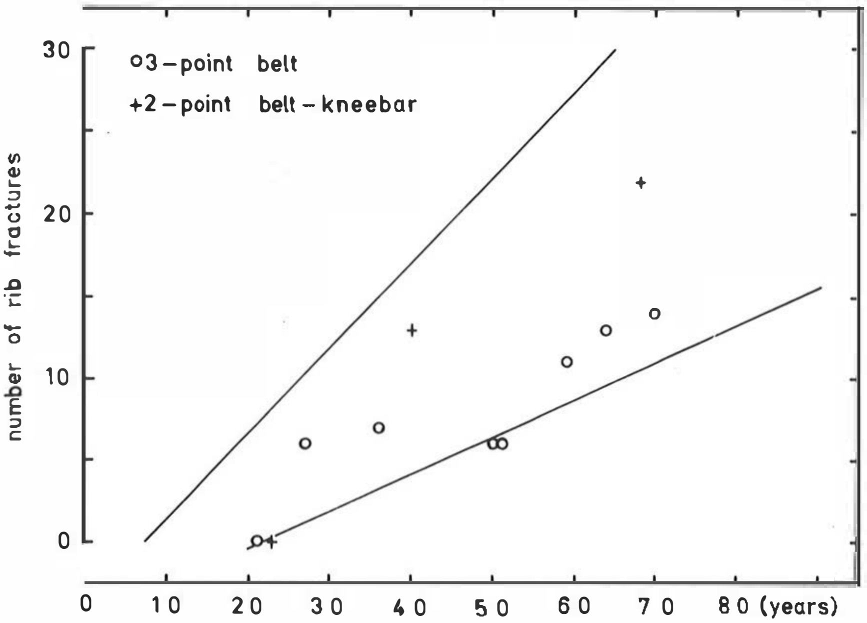

Figure 5 - Number of rib fractures in dependence of age at 11 crash tests: 3 tests accomplished with a 100 mm broad belt, and 4 tests each with aluminium respectively leather plates (crash velocity 50km/h).

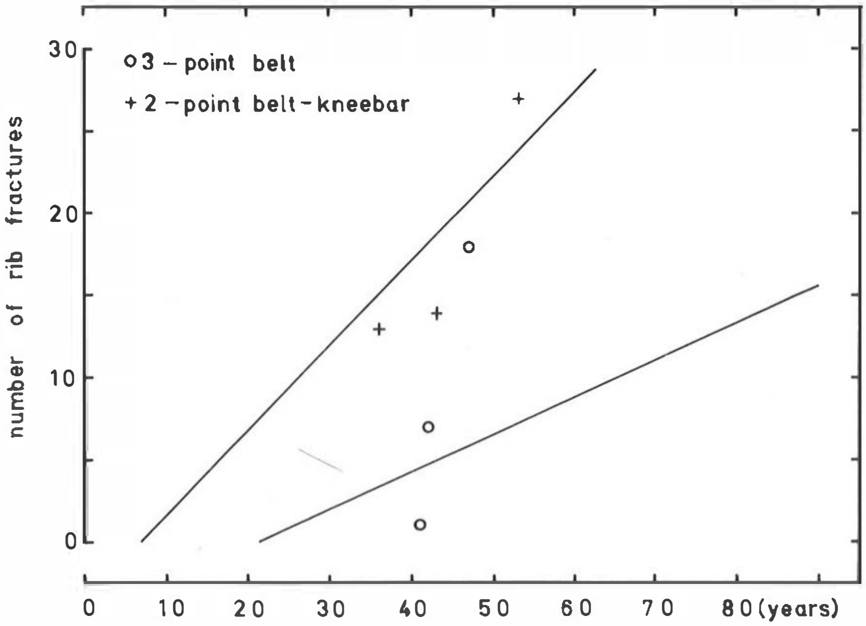

Figure 6 - Number of rib fractures in dependence of age (crash velocity 64 km/h, 50 mm broad belt, force limitor, preloading device).

According to the arrangement of the diagonal-shoulder-belt from the right shoulder to the left side (passenger position) a differential strain has been noticed of the right and left thorax (figure 7).

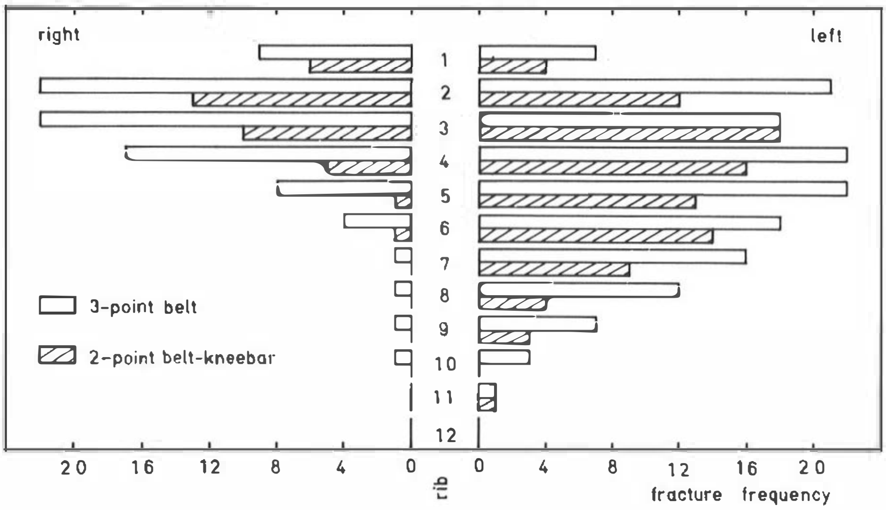

Figure 7 - Localisation and frequency dispersion of rib fractures at 32 crash tests: 17 tests accomplished with 3-point-belt and 13 tests with 2-point-belt-kneebar (crash velocity 50 km/h, 50 mm broad belt).

On the right side, fractures of the upper six ribs dominate, whereas on the left side a concentration of more frequent rib fractures in the middle thorax area was experienced. When applying plates to enlarge the bearing-surface area the injury model of the rib fractures did not change (figure 8). It is also noticeable that the special shape of sternum fractures respectively sternum diagonal fractures, from right above to left below, corresponds with the belt direction.

Most rib fractures are regarded to be shear fractures and are directly caused by the influence of the expanded belt; in the cases of older people, the width of the belt was often indicated by the width of the fracture fragments, if rib-piece-fractures did occur.

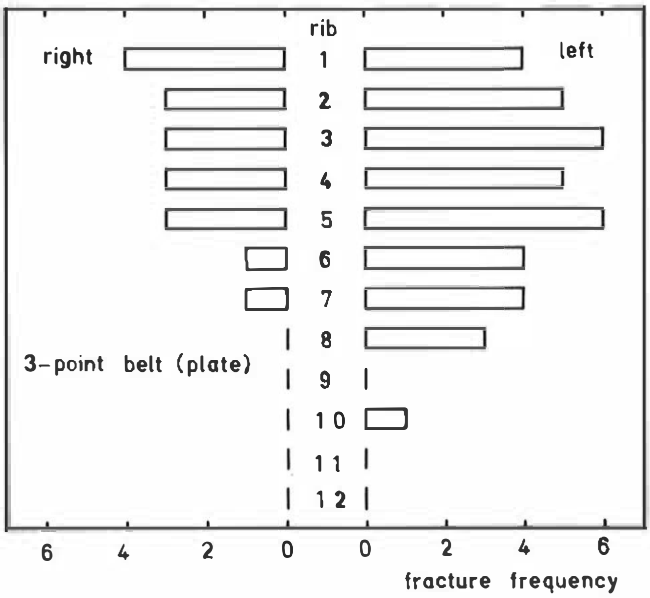

Figure 8 - Localisation and frequency dispersion of rib fractures at 7 crash tests with 3-point-belt using leather-plates respectively aluminium sheets (crash velocity 50km/h).

Outside the bearing-surface area of the belt, bending fractures were noticed but they mainly pertained to the right below and left upper thorax half; in rare cases also the paravertebral region was covered.

In seven out of 51 tests, the thoracic spine was broken, whereby in one case a twofold fracture was noticed, when using a 100mm broad belt. Eight times there were fractures of the right clavicle, which mostly occurred as splintered fractures and were combined with extensive pocket-formations and tissue ruptures of the shoulder region. In some cases the right plexus brachialis was injured because of splintered bones (table 3).

Table 3 - Frequency of soft tissue thoracic spine-sternum-and clavicle injuries.

Plexus Brachialis right	4
Carotid Artery right	1
Pocket Formation right	10
Rupture of the right Lung Root	4
Rupture of the Pericardium	2
Rupture of the Cardiac Outer Skin	4
Rupture of the below Hollow Vein	2
Mediastinal Hemorrhage	1
Rupture of the Aorta	1
Liver Rupture	7
Spleen Rupture	6
Mesentary Rupture	2
Thoracic Spine Fracture	7
Clavicle Fracture right	8
Transfixing of the Pleura	7

The more often the thorax skeleton was instabilized through fractures, the more frequent injuries of the internal organs were observed (table 3). Table 3 shows a synopsis of the frequency of the internal injuries. Liver and spleen ruptures have been included because of their protected location underneath the thorax skeleton, they too, to a special extent, are affected by the instablization of the thorax skeleton, as is the rest of the internal organs of the thorax.

When evaluating the injuries of the internal organs inflicted upon and observed at the cadavers, it has to be taken into consideration, that, in any case, because of the low organ-turgor and the lacking of blood pressure in the blood vessels, only minor injuries occurred in regard to the acting forces. A much stronger trauma diagnosis would be the result if the same influence of violence would have been applied while intravital. In particular, the dependability in regard to the time of survival or effective therapeutical operations, the extent of flowing hematomas or tissue hematomas would take a decisive influence on the pattern of the injuries. These considerations should be regarded when establishing degrees of injuries in relation to the thorax (table 4).

Table 4 - Definition of the injuries' degree for thorax injuries.

0	=	No injuries.
1	=	Single rib fractures (up to 6) with or without sternum fracture, without inner injuries, without transfixing.
2	=	Rib series fractures (up to 16) with or without sternum fracture, with or without transfixing, without inner injuries, Group 1 and light injuries.
3	=	Rib series fractures and rib-piece fractures (up to 20), with sternum fracture, with or without transfixing, light organ injuries.
4	=	Rib series fractures and rib-piece fractures (over 20). Group 2 and 3 with serious injuries. Group 3 with spine fracture.

Beside the resulting danger caused by organ injuries as circulatory disturbance, disturbance of metabolism and bleeding to death, the respiratory insufficiency is of decisive significance because of rib series fractures, rib-piece fractures, and sternum fractures as well as pulmonary and pleuropulmonary causes.

Figure 9 shows an increase of the injury degrees when advancing in years. Additionally, it should be taken into consideration when estimating the chance of survival that the occurrence of complications, which are independent in regard to the accident, and are determined by age, constitution and physical condition, can significantly influence the thorough healing of the trauma.

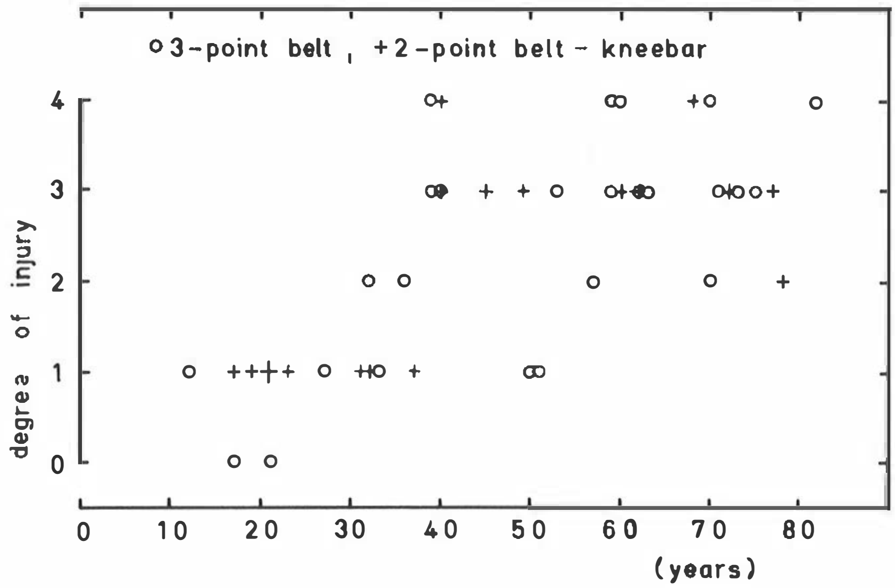

Figure 9 - Injury degree in dependence of the age at 43 crash tests: 25 tests accomplished with 3-point-belt (5omm broad belt, leatherplate respectively aluminium sheet) and 18 tests accomplished with 2-point-kneebar, (50mm broad belt, 1 test with aluminium sheet, 2 tests each with a 100 mm broad belt), crash velocity 50km/h.

According to the results of our investigations, it can be said that the wearing of safety-belts can protect younger occupants (up to 30 years) of having thorax injuries, when crashing against a rigid wall by a crash velocity of 50km/h or at least keeps the injury risk relatively small. In regard to their constitution, middle-aged occupants would suffer slight to most serious injuries and old-aged occupants would suffer serious to most serious injuries. In all cases of serious injuries, the existence of accident conditions (such as physical conditions, constitution, age, time of survival, and kind of therapeutical operations, etc.) can be of decisive significance in regard to a prognosis.

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