Response and Vulnerability of the Human Body at Different Impact Velocities in Simulated Three-Point Belted Cadaver Tests

D. Kallieris, Gg. Schmidt, J. Barz, R. Mattern and F. Schulz
University of Heidelberg

INTRODUCTION

At present, the three-point safety belts represent the most important group of restraint systems. While the use of static belts slowly decreases, the application of three-point automatic belts increases more and more. In many countries is it already mandatory to wear safety belts, and in some countries this is planned (SCHMIDT et al 1975).

In frontal collisions mainly is the high safety effect of the three-point safety belt unquestioned (SCHMIDT et al 1975, HARTEMANN et al 1977, Proceedings of the VIth International Conference of the IAATM 1977).

According to a new study of the HUK-association (1977) in 30 to 40 percent of all accidents injuries are avoided when using a safety belt; considerable injuries are reduced by 50 to 70 percent.

In 1976, when the wearing of safety belts was mandatory the same number of fatally injured belt wearers has been dissected in our Institute as in 1975, namely three.

NIEDERER et al (1977) reported on accident studies involving 304 cars with 410 persons. The passengers used three-point static belts (55 percent of the cases); three-point automatic belts (29 percent of the cases) and shoulder belts (16 percent of the cases). 153 persons of these passengers were fatally injured (37,3 percent), and 257 persons were seriously injured (62,7 percents) (OAIS 2).

The accident analyses of belt wearers mostly deal with combined strains either caused by the belt influence or by impact against vehicle interiors.

Beside the real accident investigation also accident simulations with human cadavers is for the investigation of the seat belt syndrome of great importance as well as to determine the actual injuries caused by the belt.

By means of sled devices tests can be conducted under reproducable conditions. By using transducers and high speed cameras evidence can be gained about the load and the injury mechanism of the human body.

In this paper we report about the influence of the impact velocity in regard to the load, the injury seriousness and the injury mechanism of assorted cases of our testing material.

METHOD

The tests were conducted on the deceleration sled at the Institute for Legal Medicine of the University Heidelberg (KALLIERIS 1974) at impact velocities of 30 km/h, 40 km/h, and 50 km/h. The deceleration pulse form corresponds to a trapezium (SCHMIDT et al 1975), the medium sled deceleration amounted 19,0 to 21,4 g. VW-standard seats as well as three-point automatic belts (FA. REPA) had been used. The anchorage points of the belts did not correspond to a certain type of car but lay within the variation range of European cars.

The impact velocity, the sled deceleration, the belt forces (in the belt) and in most cases the acceleration were measured in each case at the right and left side of the head in x- and z- direction (SCHMIDT et al., 1978).

The phase of impact was laterally (1000 p/s) and frontally 500 p/s) documented with high-speed cameras.

An especially developed dissection technique was applied to make the diagnosis (SCHMIDT et al., 1978). The injuries were recorded in standardized injury sheets and evaluated according to the Abbreviated Injury Scale (AIS).

TEST SUBJECTS

Up to now a total of 127 tests have been conducted in higher deceleration ranges of 17 to 25 g. In order to better compare the tests in regard to the influence of the collision velocity only those cases were selected which were within a close deceleration range of 2,4g (19-21,4g).

Impact velocity 30km/h	19 tests
Impact velocity 40km/h	21 tests
Impact velocity 50km/h	21 tests
n =	61 tests

The cadavers showed no injuries; the time between death and test amounted 12 to 120 hours. Body temperatures in the rectum of 6° to 25°C were measured. The age of the test subjects was between 13 and 74 years.

RESULTS AND DISCUSSION

Figure 1 shows the age dispersion of the 61 test subjects.

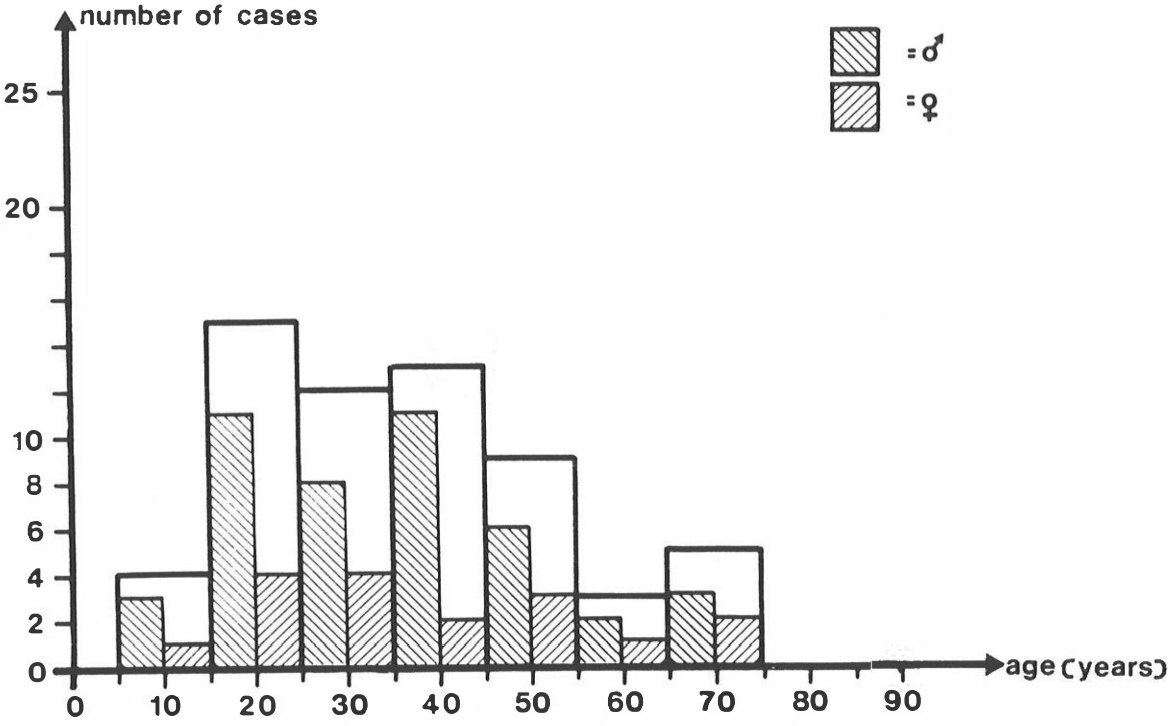
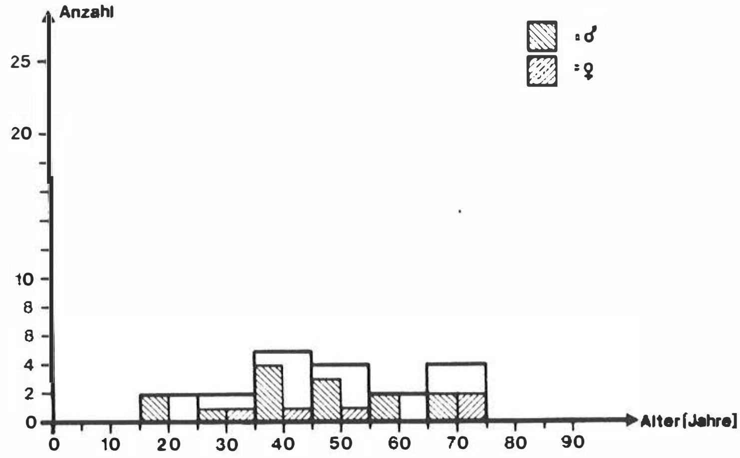


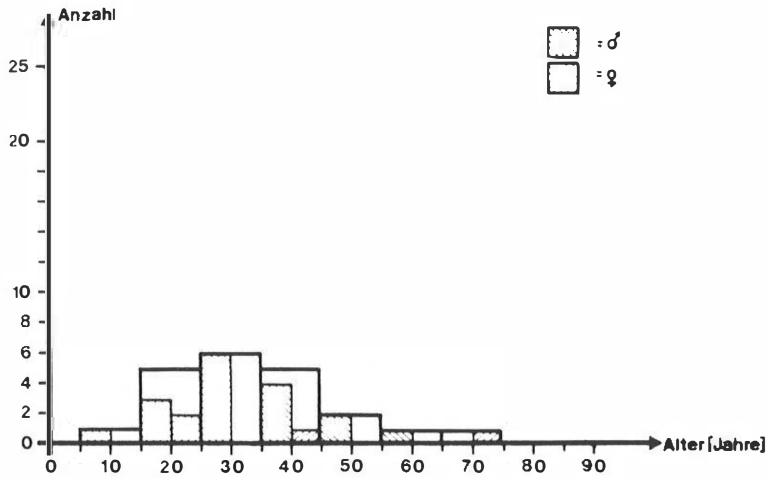
Fig. 1: Age dispersion of all test subjects (61 cases)

About 65 percent of all cases are in the age range between 15 and 45 years. The following figure 2 shows the age dispersion in each for the impact velocities of 30km/h, 40km/h and 50km/h. In the range 15 to 45 years are 47 percent in the 30 km/h, 76 percent in the 40km/h and 71 percent in the 50km/h group.

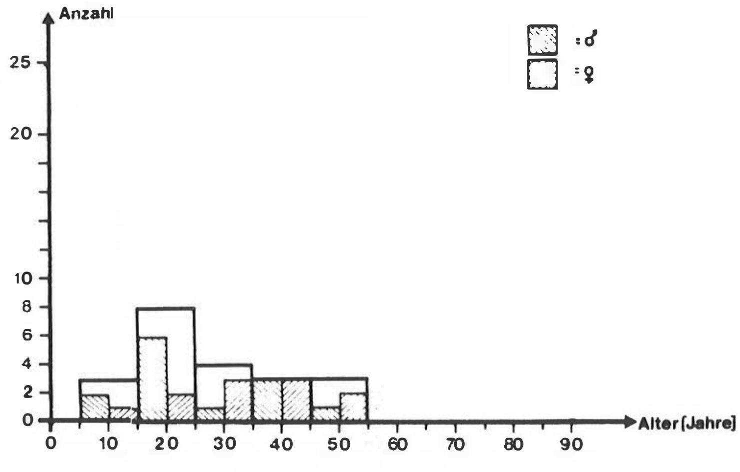
The older test subjects are over-represented in the 30km/h group compared to the 50km/h group and are also lesser in the 40km/h group.



a. 30km/h
(19 cases)



b. 40km/h
(21 cases)



c. 50km/h
(21 cases)

Fig. 2: Age dispersion of test subjects
sorted by collision velocity

HEAD ACCELERATION MEASUREMENTS, HIC-VALUES, HEAD INJURIES

Without the use of a steering wheel or a dashboard there is no direct head contact when conducting tests with belted cadavers in driver or passenger position. The measured head accelerations are indirectly caused by the effect of the safety belt.

Table 1 shows the variation range, averages and standard deviations of the measured accelerations in x- (averages measured at the right and left side of the head) and z-direction (also determined as in x-direction) as well as the computed resultant acceleration of both directions and the HIC. All magnitudes increase with increasing collision velocity. The computed HIC-values lie between 61 and 1008 and therefore insignificantly exceed the permitted HIC-value of 1000 according to the US-standard 208 only in one case (HIC-value 1008).

Imp. Vel. km/h	HIC				Head res. accel. (g's)				Head accel. x (g's)				Head accel. z (g's)			
	Min.	Max.	Mean	Std.Dev.	Min.	Max.	Mean	Std.Dev.	Min.	Max.	Mean	Std.Dev.	Min.	Max.	Mean	Std.Dev.
30	61	269	153	59	18	64	32	10	11	47	20	9	17	46	28	8
40	150	904	409	231	33	71	52	12	14	53	33	13	31	66	49	12
50	406	1008	659	173	54	85	70	10	17	61	41	11	47	82	64	11

Table 1: Head acceleration values and HIC values at collision velocities of 30km/h, 40km/h and 50km/h.

Morphological provable brain injuries were not macroscopically observed.

In one case it was observed that the parietal and occipital bridging veins were torn off at the right and left side when joining the sinus sagitalis superior. The frontal bridging veins, however, have been preserved. In other cases there was an occassional suspicion of artificial damages caused by the dissection technique could not be excluded with the required security.

RELATION OF THE SHOULDER BELT FORCE TO THE BODY MASS

The relation between the maximum of the shoulder belt force and the body mass at the three collision velocities is shown in Figure 3. The shoulder belt force maximum in each case is reached when the sled has already come to a stop. The regression straight line and the standard error of estimation is stated for the respective velocity. As already mentioned in former papers (KALLIERIS and MATTERN 1974, SCHMIDT et al 1975) increases the shoulder belt force with the body mass.

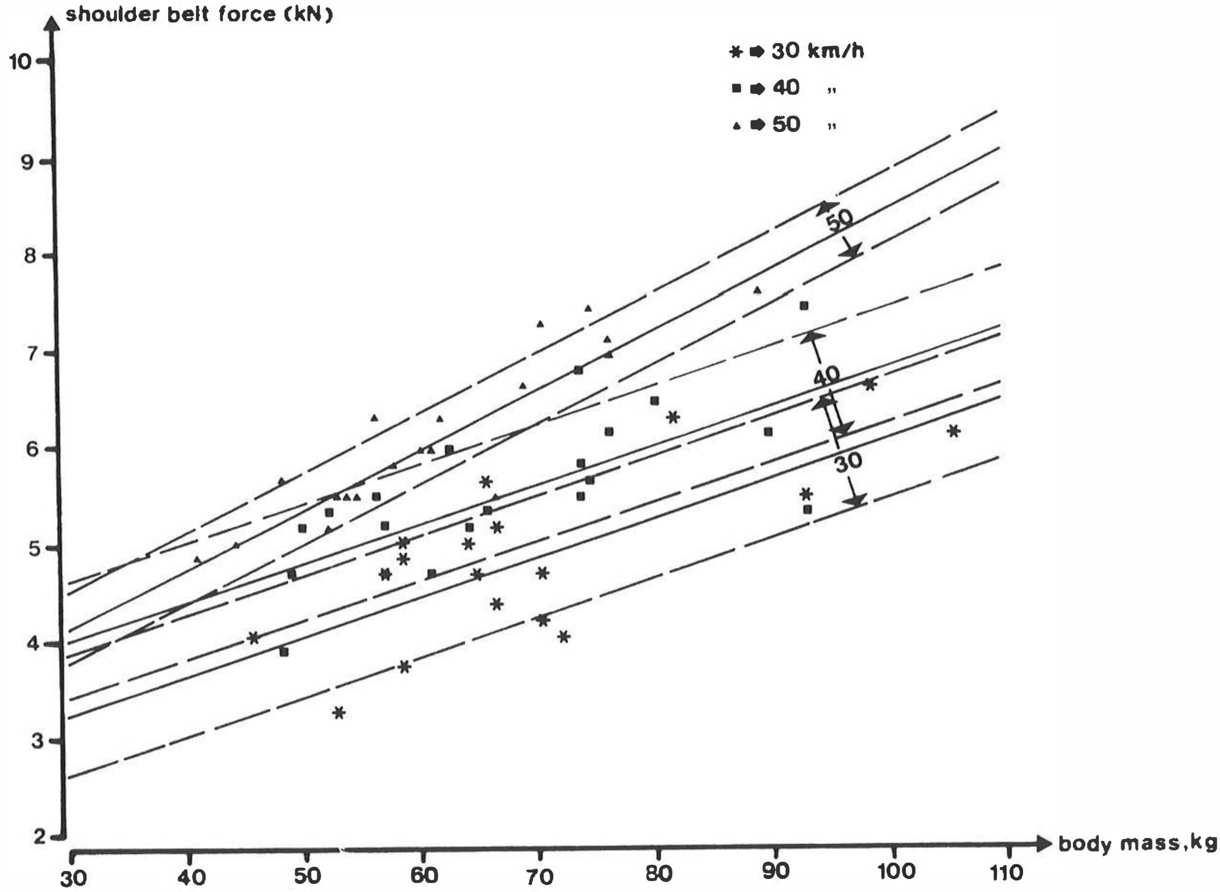


Fig. 3: Relation of shoulder belt force with the body mass for the collision velocities 30 km/h, 40km/h and 50km/h, deceleration range 19-21,4g

We physically expect that with similar body masses also similar shoulder belt forces will be measured at a constant sled deceleration (here 19,0 to 21,4g) independent of the collision velocity (Newton's Basic Law of Mechanics F=m•a). According to this presentation however, the regression straight lines of the 30km/h and 40km/h collisions run about parallel, whereby the level of the 40km/h straight line lies at about 770N higher than the one of the 30 km/h group. On the contrary, the regression straight line of the 50km/h group has a steeper course, whereby in higher body masses essentially higher shoulder belt forces are reached, while in lower body masses the standard errors of estimation overlap in all three regression straight lines.

When discussing the question how such a surprising result is reached one has to realize that the height of the shoulder belt force is determined by a deceleration which is not only composed of the sled deceleration (here 19 to 21,4g), but is also influenced by the extensibility of the belt and the thorax flexibility. If the sled decelerations and the extension characteristics of the belt could be regarded to be constant, one has to prove if the elastical reactions of the thorax are changing, if therefore the thorax will be stiffer with increasing collision velocity. If this is the case, the increase of the shoulder-belt-force-time-curve should increase with increasing collision velocity. Therefore we have examined the course of the force-time-curve from this point of view.

In all three collision velocities the ascending time was determined in the range of 10 to 90 percent of the maximum height of the shoulder belt force. With increasing collision velocity also an increase of the ascending time was observed, similar the total impression period of the force. On the other hand, the average force slope was similar at all three velocities. This could mean, when increasing the collision velocity from 30km/h to 50km/h there is no stiffer reaction of the thorax.

Only from this consideration no different elasticity behavior of the thorax can be derived from the various collision velocities.

Despite of it shows the medical evaluation a different reaction of the thorax: in dependence to the collision velocities different rib fracture frequencies were found, which will be discussed as follows.

The occurrence of a certain number of rib fractures in connection with a sternum fracture results in a break-down of the original elasticity behavior. After this incident, the dorsal skeleton parts of the thorax as well as the thorax- and upper abdominal organs must be of significance for the further force-time-course.

RELATION BETWEEN NUMBER OF RIB FRACTURES AND THE AGE

Rib fractures are the most serious kind of injuries occurring at all three velocities in the above mentioned deceleration range. Most rib fractures are directly caused by the influence of the belt underneath the bearing surface area or additionally indirectly away of it as incomplete bending fractures or real bending fractures. In older persons the belt width is indicated by the width of the fracture fragments (KALLIERIS and MATTERN 1974). As already mentioned in former publications (SCHMIDT et al 1974, 1975) increased the number of rib fractures according to the age. Figure 4 showed the relation between the number of rib fractures to the age at three different collision velocities but the same sled deceleration range. While the regression straight lines of the 40km/h and 50 km/h groups are close together, the one of the 30 km/h lies significantly below.

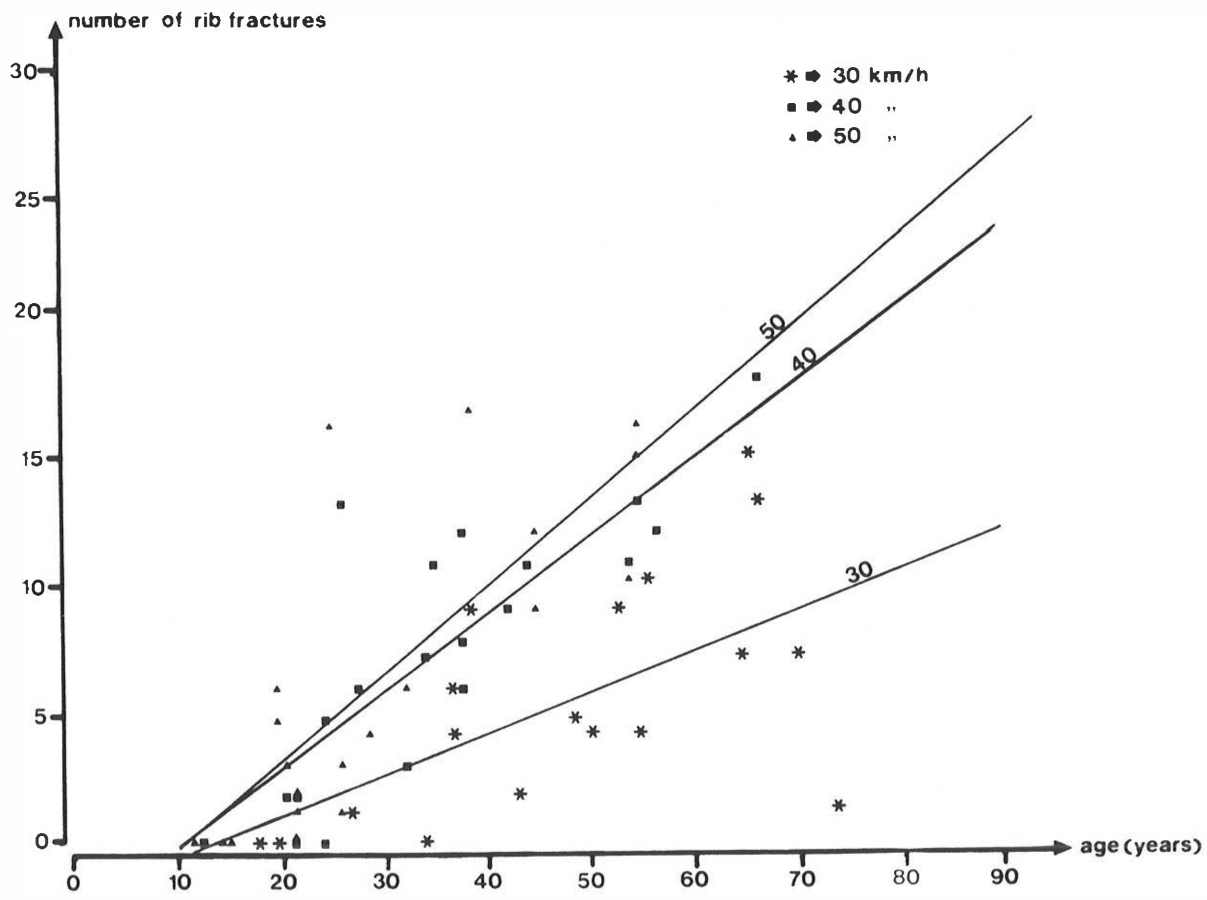


Fig. 4: Relation of number of rib fractures with the age at collision velocities of 30km/h, 40km/h and 50km/h, deceleration range 19-21,4g

This is particularly relevant because the 30km/h showed the already mentioned over-representation of older test subjects. From the considerable distance of the 30km/h group's regression straight line to the ones of the 40km/h and 50 km/h group it can be derived that between the collision velocity 30km/h and 40km/h the thorax is exposed to such a strain that its elastical structure breaks down. This caused an erratic increase of rib fractures; however, with further increasing collision velocities no proportional increase of the number of rib fractures took place.

LOCALISATION AND FREQUENCY OF RIB FRACTURES

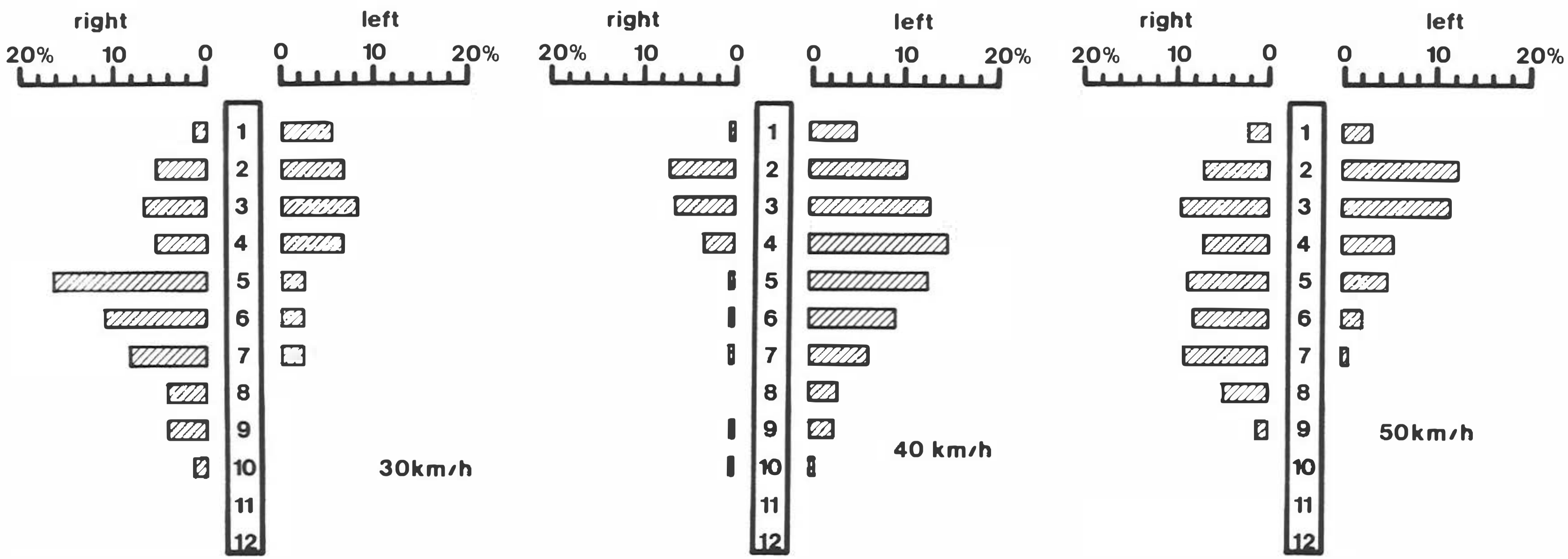
According to the use of the shoulder belt in driver or passenger position the thorax halves are differently strained and so determines the localisation of rib fractures.

The localisation and frequency of rib fractures in the 30km/h, 40km/h and 50km/h groups are expressed in percentage in Figure 5.

The 30km/h group contained 10 tests in driver position (the remainder was in passenger position and therefore not considered in the figure). Of the 10 tests there were 3 cases without rib fractures. The 40km/h group comprised 21 tests in passenger position only and three subjects had no rib fractures. The 50 km/h also included 21 tests in driver position having four cases without rib fractures.

In the 30km/h group fractures of the second and the third rib of the left thorax half were registered in 5 and 6 percent of the cases respectively; corresponding to 15 and 14 percent in the 50km/h group. In passenger position the same ribs at the right thorax half are represented by 10 and 9 percent. In the 30km/h and 50km/h group the right thorax half in driver position showed an irregular picture of fractured ribs. While the 50km/h group indicated a similar picture between the second and seventh rib at the right side (fracture frequency of the respective rib 9-12 percent). The 30km/h group reached a maximum at the fifth rib with 12 percent, while the others (2nd to 7th rib) lie between 4 and 8 percent.

In the 40km/h group (passenger position) most rib fractures occurred in the left middle thorax region. In the 30km/h and 40km/h tests the localisation of rib fractures essentially followed the belt path. The uncharacteristical fracture dispersion in the 50km/h tests can be explaned by the occurrence, indirect rib fractures outside of the belt path.



a. 30km/h (10 cases)

b. 40km/h (21 cases)

c. 50km/h (21 cases)

Fig. 5: Localisation and frequency dispersion of rib fractures

SOFT TISSUE AND ORGAN INJURIES

Table 2 shows the dependence of the injury frequency from the collision velocities. Nearly in all injuries mentioned an increase is determined in regard to their frequency with the collision velocity. More serious injuries are seldom. In this connection one can refer to transfixings of the pleura, which naturally also include the danger of lung puncture. These injuries, which are only caused through rib fractures were first seen in the 40km/h and 50 km/h groups if the thorax structure is destroyed and a more frequent displacement of fracture ends occurred.

	impact velocity (km/h)		
	30	40	50
Shoulder skin	69	72	95
Supraclavicular region	15	38	50
Pleura	-	24	15
Lung puncture	-	5	5
Lung root	-	-	5
Heart auricle	-	5	-
Abdominal skin	79	86	75
Liver	-	10	10
Spleen	-	5	-
Pancreas	-	5	-
Kidney	-	5	5
Interstine	-	10	10
Mesentary	-	5	25
Abdominal vessels	-	-	10
Urinary bladder	-	-	5
	n = 19	n = 21	n =21

Table 2: Dispersion of soft tissue and organ injuries in percentage at collision velocities of 30km/h, 40km/h and 50km/h

Very often are also mesentary contusions in the 50km/h group, caused by the influence of the lap belt to the abdomen during submarining. Nearly regular findings are abrasions and contusions of the shoulder skin at the upper anchorage point side, as well as mostly symmetrical pelvis skin abrasions. The intensity of injuries of the extra-thoracic soft tissues in the lateral neck triangle below the bearing surface area of the belt significantly increases with the velocity; contusions of the lateral muscular system of the neck and the plexus brachialis, in 50km/h also lacerations of the blood vessels are the result, especially if the clavicle is broken.

SPINAL COLUMN INJURIES

The spinal columns were examined by a special dissection technique (HEESS 1977, SCHMIDT et al. 1978). Spinal column injuries seem to belong to the regular findings, whereby two injury main points could be defined. One is the transition of the cervical vertebra column to the thoracic vertebra column, the other is the region of the thoracic lumbar transition. In the 30km/h group the frequency of the test subjects in driver- and passenger position was about equal so the question of a side-typical injury pattern of the spinal column could be examined. In both seating positions a throughout similar injury pattern could be observed; which is obviously caused through the ventral flexion. According to the belt position the resultant torsion of the test body right or left around the spinal column axis only plays a secondary part in regard to the injury dispersion.

Characteristical spinal column findings caused by the belt strain are lacerations of the ligamenta flava, dorsal lacerations of intervertebral discs and ventral compression fractures of the vertebral bodies. They are the expression of the ventral flexion as already mentioned, the kinematic of it has been documented in high speed films. Between torso and spinal column bending angles of 62-125 degrees were measured.

If one compares the frequency of the injuries indicated as typical in the three velocity groups an increase of injuries in the cervical-thoracic transition between the 30km/h and 40km/h group can be proved (Tab. 3). Opposite to it the 50km/h group shows in all single injuries a significantly smaller frequency. The reasons for this behavior contrary to expectations are not quite solved yet. Without doubt also here the lesser age average in the 50km/h group plays an important part; because of the big difference in the injury frequencies one can suppose that other factors of the kinematic and dynamic additionally influence this behavior. Additional analyses are in work for final clarification.

Also no gradual increase of the injury frequency in the thoracic lumbar transition (Tab. 3) with the collision velocity can be

Imp. Veloc. km/h	Muscles	Ligamenta flava	Intervert. discs	Corpus vertebrae	
30	37	32	39	35	cervic.-thor. transition
40	42	50	33	45	
50	21	18	28	20	
30	42	0	39	27	thor.-lumb. transition
40	28	60	39	46	
50	30	40	22	27	

Table 3: Dispersion of selected spinal column injuries in percentage

recognized. Less distinct than in the cervical-thoracic transition also here in the 50km/h group a comparable smaller injury degree was observed.

OAIS-COLLISION VELOCITY

None of the 61 cadavers remained uninjured; one can derive from Table 4 that a significantly smaller total injury grade

		OAIS						
Imp. vel.		0	1	2	3	4	5	6
30 km/h	100 %	0	0	10	74	16	0	0
40 km/h	100 %	0	0	9	48	33	10	0
50 km/h	100 %	0	5	15	45	15	20	0

Table 4: Dispersion of the OAIS in percentage at collision velocities of 30km/h, 40km/h and 50km/h

occurred in the 30km/h group than in the 40km/h and 50km/h groups. Especially in this group in no case injuries of OAIS 5 were found, however, injuries of this highest injury grade in our cadaver tests were observed by 10 percent in the 40km/h group and by 20 percent in the 50km/h group. In lower injury grades the dependency of the velocity to the injury frequency is not clear in each case in the 30km/h and 40km/h groups. The lesser frequency of injuries in OAIS 2, 3 and 4 in the 50 km/h group can be probably explained with the special age composition: this group as already mentioned had the lowest age average with 30 years.

SUMMARY

In this paper we report about the results of frontal collision tests with belted cadavers simulated on a deceleration sled at collision velocities of 30km/h, 40km/h and 50km/h. In order to better compare the various collision velocities 61 tests in the deceleration range of 19-21,4g were selected out of 127 tests in higher deceleration ranges (17-25 g). About 65 percent of the cases were in the age range of 15 to 45 years. The HIC-values amounted 61 to 1008 and increased with increasing collision velocity. Morphological provable brain injuries were not observed. The shoulder belt forces increased according to the body mass, and there is an increase of the number of rib fractures by increasing age. In nearly all soft tissue and organ injuries an increase of the frequency according to the collision velocity was noted. The spinal solumn injuries showed two main points, one at the cervical-thoracic transition and the other at the thoracic-lumbar transition. An increase of injuries of the 30km/h group to the 40 km/h group could be observed; however none in the 50km/h group. The total injury degrees were between 1 and 5 of the AIS. Significantly smaller total injury degrees occurred in the 30km/h group than in the 40km/h and 50km/h groups.

ACKNOWLEDGEMENTS

Our work is sponsored in part by FAT (Forschungsvereinigung Automobiltechnik e.V., Frankfurt, West Germany) and CCMC (Commitee of Common Market Automobile Constructors), with technical assistance by the Volkswagenwerk AG, for which we are grateful.

REFERENCES

Fakten zu Unfallgeschehen und Fahrzeugsicherheit HUK-Verband 1977.

HARTEMANN, F., THOMAS C., HENRY C., FORET-BRUNO, I-Y., FAVERJON G., TARRIÈRE C., GOT C. and PATEL A.: "Belted or Not Belted: The Only Difference Between Two Matched Samples of 200Car Occupants" Proceed. of the 21 th Stapp Car Crash Conf. 1977

HEESS G.: "Wirbelsäulenverletzungen menschlicher Leichen bei simulierten Frontalaufprallen" med. Diss. Heidelberg 1977.

KALLIERIS D.: "Eine Fallgewichtsbeschleunigungsanlage zur Simulation von Aufprallunfällen, Prinzip und Arbeitsweise" Z. Rechtsmedizin. 25, 1974.

KALLIERIS D. and MATTERN, R.: "Shoulder-Belt-Forces and Thorax Injuries" Proceed. of the IRCOBI Conf. Lyon 1974.

NIEDERER P., WALZ F., and ZOLLINGER U.: "Adverse Effects of Seat Belts and Causes of Belt Failures in Severe Car Accidents in Switzerland During 1976" Proceed. of the 21th Stapp Car Crash Conf. 1977.

Proceedings of the sixth International Conference of the International Association for Accident and Traffic Medicine Melbourne 1977.

SCHMIDT Gg., KALLIERIS D., BARZ J. and MATTERN, R.: Results of 49 Cadaver Tests Simulating Frontal Collision of Front Seat Passengers" Proceed. of the 18th Stapp Car Crash Conf. 1974.

SCHMIDT, Gg., KALLIERIS D., BARZ J., MATTERN R. and KLAIBER J.: "Neck and Thorax Tolerance Levels of Belt-Protected Occupants in Head-On Collisions" Proceed. of the 19th Stapp Car Crash Conf. 1975.

SCHMIDT Gg., KALLIERIS D., BARZ J., MATTERN R. und SCHULZ F.: "Belastbarkeitsgrenze und Verletzungsmechanik des angegurteten Fahrzeuginsassen" FAT Schriftenreihe Nr. 6 1978