THORAX ACCELERATION MEASURED AT THE 6TH THORACIC VERTEBRA IN CONNECTION TO THORAX AND SPINAL COLUMN INJURY DEGREE

by

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Introduction

Spinal Column and thorax injuries are relatively frequent in belted car passengers injured in road accidents. The order of precedence concerning localisation and injury seriousness is differently stated in literature. According to HAVEMANN and SCHRÖDER (1979), the thorax was found to be the most frequent injury location when investigating 64 belted, severely injured car passengers. Spinal column injuries were noticed in the second place.

Investigations with belted cadavers have shown that thoracic skeleton- and spinal column injuries essentially influence the injury severity. Therefore, the connection of spinal column acceleration in regard to thorax- and spinal column injury degree shall be investigated in this paper.

Method

Frontal collisions at velocities of 40 km/h and 60 km/h were conducted by a deceleration sled (KALLIERIS 1974). The deceleration pulse form corresponds to a trapezium, the medium sled deceleration amounted for the 40 km/h tests 10 g, and the 60 km/h tests 10 g and 15 g. VW-Golf seats and three-point automatic belts (Fa. Repa) were used.

The collision velocity, the sled deceleration, the belt forces, the acceleration of the right and left side of the head in x- and z-direction and the acceleration at the 6th thoracic vertebra (SCHMIDT et al 1979) were measured. The collision phase was frontally and laterally documented by high-speed cameras. The accelerometers for the spinal column acceleration were installed to a special mounting which was screwed to an alu-plate (Fig. 1). By previous x-ray identification of the 6th thoracic vertebra the alu-plate was mounted to the skin above the processus spinosus. In order to fix the basis plate at the left and right side of the processus spinosus, two screws were turned into the vertebral bodies, similar as LEVINE et al (1979).

In order to record the injury findings, a special dissection technique has been developed (SCHMIDT et al 1978), which allows a

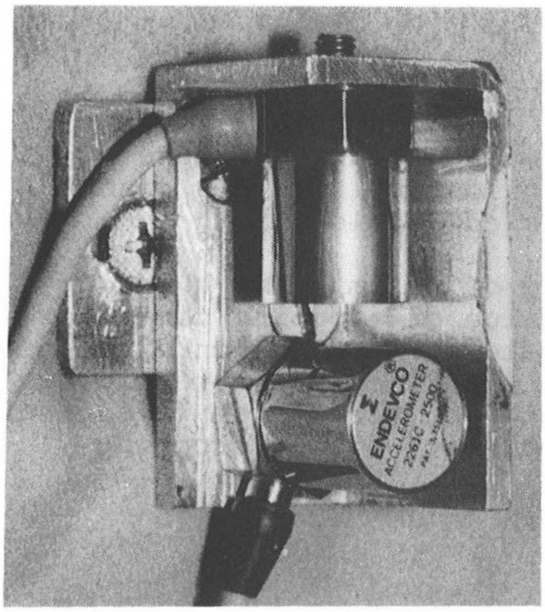

Fig. 1:Mounting plate with Accelerometer at 6th Thoracic Vertebra

thorough examination of the thorax. The spinal column was submitted to a detailed preparation: after taking out the whole spinal column, also including the occiput, the muscular system was removed in layers until a bony ligament preparation was present. This was frozen when sawed with a band-saw in the medium sagittal plane through the processus spinosus, as well as right and left in sagittal planes through the vertebral joints and the foramina intervertebralia. In this way, it was possible to safely diagnose the findings in the intervertebral discs, the vertebral bodies and the ligaments, if for example, they could not be proved by x-ray (MATTERN et al 1977).

The injuries were recorded according to a standardized injury blank form and evaluated to AIS.

In order to check out connections between several variables the multiple regression (linear model) has been employed (NOLLAU 1975, REIDELBACH and SCHMID 1976, SCHMIDT et al 1979).

Test Subjects

35 fresh (unembalmed) human cadavers of both sex in the age range between 18 and 69 years were at our disposal.

The number of cases is listed according the collision velocity and sled deceleration as follows:

Impact velocity 40 km/h, sled deceleration 10 g, 11 tests
Impact velocity 60 km/h, sled deceleration 10 g, 12 tests
Impact velocity 60 km/h, sled deceleration 15 g, 12 tests

Results and Discussion

Acceleration and Belt Force Time Histories

The comparison of the measured acceleration courses at the 6th thoracic vertebra and those of the shoulder belt forces cannot be conducted without considering the sled deceleration.

In the group with a collision velocity of 40 km/h and a medium sled deceleration of 10 g (computed value of stopping distance and collision velocity), the sled deceleration duration disperses between 120 and 150 ms (Fig. 2). This variation can be explained by the differences of the kinetic energy of the system (sled and test subject) as well as by the inhomogenity of the stopping sheet.

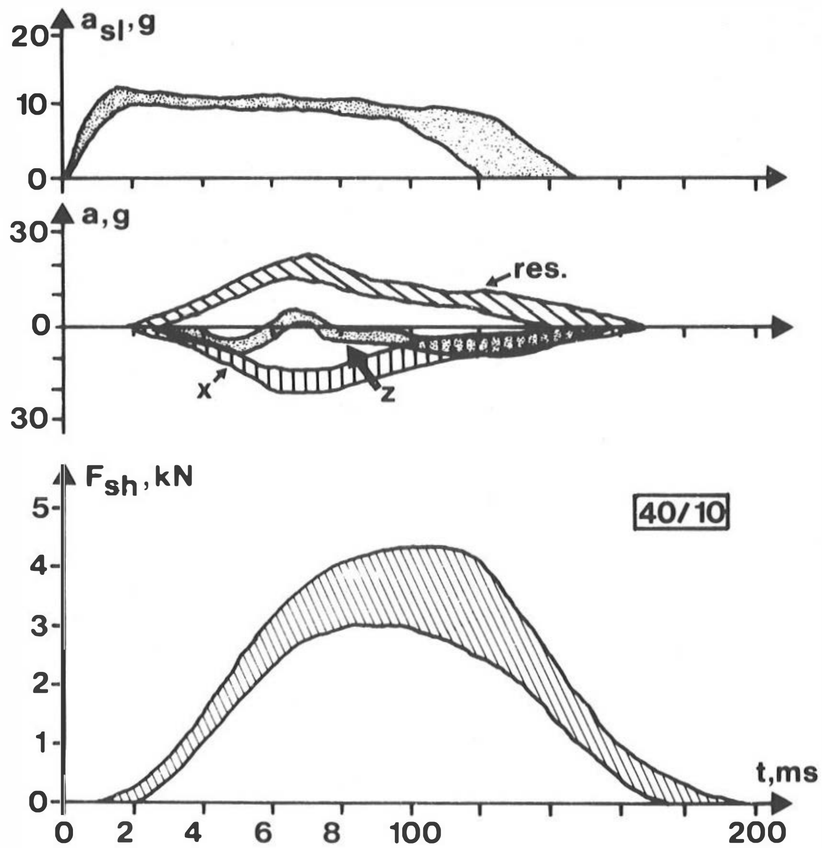

Fig. 2: Time Histories of Accelerations and Belt Force (40 km/h, 10 g)

The acceleration measured at the 6th thoracic vertebra has a duration of 100 to 150 ms. It starts about 20 ms after the impact, at a time at which the sled deceleration has already reached its plateau.

The maximum values of the spinal column acceleration in x-direction and those of the resultant are reached at the same time with the shoulder belt maximum 65 ms after the begin of impact and are always positive.

The acceleration in z-direction changes its direction (sign) and shows positive maxima at the shoulder belt force increase and in the range of the shoulder belt maximum; as well as a negative maximum simultaneously with the positive maximum of the x-direction. This causes in the beginning phase a load- and tension strain of the spinal column in its longitudinal axis. The z-component is essentially influenced in its beginning phase by the conduct of the seat. In the second half of the collision phase, the z-direction takes over acceleration parts being effective in the sled x-direction because of an increasing bending of the test subject.

The duration of the shoulder belt force lays at about 130 and 180 ms and shows different maxima. These maxima can be explained by the different kinetic energy of the test subject (body mass), as well as by thorax deformation and belt extension (KALLIERIS and MATTERN 1974, SCHMIDT et al 1974, SCHMIDT et al 1978); they will be reached in the second half of the sled deceleration duration.

The acceleration- and shoulder belt force courses of the 60 km/h-10 g group are similar to the ones of the 40 km/h-10 g group. Caused by the higher collision velocity of 60 km/h, the duration of the sled deceleration is almost twice as long as in the 40 km/h group (210-250 ms) (Fig. 3).

Correspondent to it, the acceleration measured at the 6th thoracic vertebra as well as the shoulder belt force have a much greater effect. The test subject takes longer part in the sled deceleration. Against the 40 km/h group two maxima ranges occur during the x- and resultant acceleration at the 6th thoracic vertebra.

The duration of all three courses of the test group with 60 km/h-15 g in Fig. 4 can be compared with those of the 40 km/h-10 g group (Fig. 2). The occurrance of two oppositely directed maximum ranges of the spinal column acceleration in z-direction in the 60 km/h-15 g group is much more distinct than in the 60 km/h-10 g group (Fig. 3).

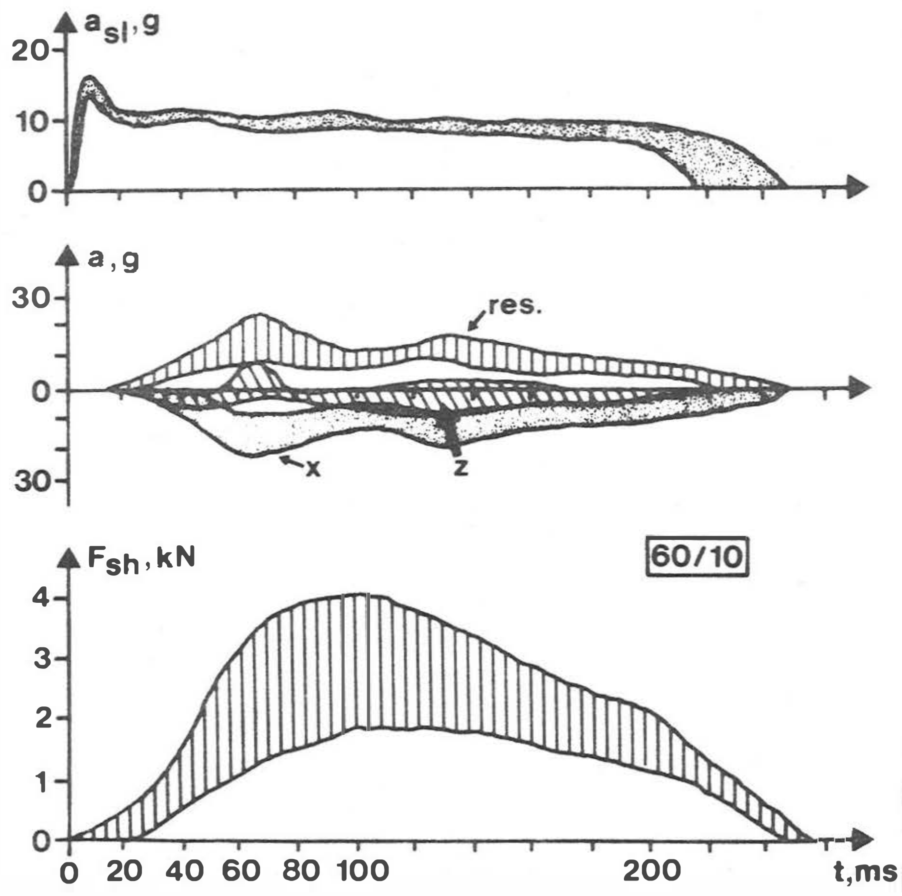

Fig. 3: Time Histories of Accelerations and Belt Force (60 km/h, 10 g)

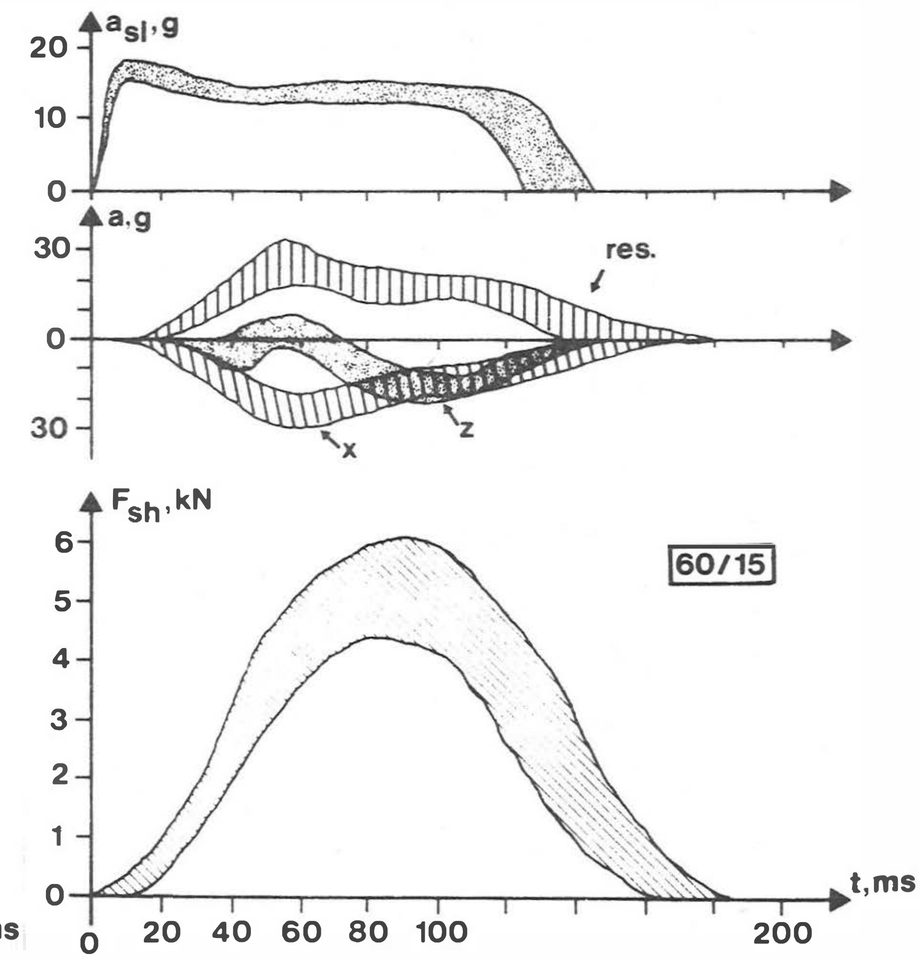

Fig. 4: Time Histories of Accelerations and Belt Force (60 km/h, 15 g)

Frequency of Determined Injuries

The following Table 1 lists the frequency of all occurring single injuries of thorax and spine $\geq$ AIS 1. One can see that with a constant sled deceleration of 10 g and an increasing of the velocity from 40 to 60 km/h the frequency of most single injuries increases. In both test groups, injuries of the spinal column muscular system and rib fractures occur at the most, followed by injuries of the ligamentus system and the intervertebral discs.

Injuries	all 35 / 100%	40 km/h 10 g 11 / 100%	60 km/h 10 g 12 / 100%	60 km/h 15 g 12 / 100%
Vertebral muscles	32 / 91%	10 / 91%	12 / 100%	10 / 83%
Ribs	27 / 77%	8 / 73%	9 / 75%	10 / 83%
Sternum	21 / 60%	7 / 64%	5 / 42%	9 / 75%
Interv. discs	20 / 57%	6 / 55%	10 / 83%	4 / 33%
Vertebral ligam.	19 / 54%	7 / 64%	8 / 67%	4 / 33%
Rib piece fract.	12 / 34%	4 / 36%	1 / 8%	7 / 58%
Interv. foram.	11 / 31%	5 / 45%	2 / 17%	4 / 33%
Corpus vertebrae	11 / 31%	2 / 18%	6 / 50%	3 / 25%
Vertebral proces.	10 / 29%	3 / 27%	3 / 25%	4 / 33%
Spinal cord	8 / 23%	2 / 18%	4 / 33%	2 / 17%
Plexus brach.	4 / 11%	-	2 / 17%	2 / 17%
Clavicle	2 / 6%	-	-	2 / 17%

Table 1: Frequency of Determined Injuries at Thorax and Spine

In the 6o km/h group the frequency of the single injuries increases in few kinds of injuries, when the sled deceleration is rised from 10 g to 15 g. In the first place again we find rib fractures, followed by sternum fractures. Most single injuries decrease in the 15 g group as against the 10 g group. A comparison of the medium values of the age, however, shows the lowest medium value of 38 years. Against that, it amounts 45 years for the other two test groups. Thus the decrease of the injury frequency in the 60 km/h-15g group may be explained. In addition, it is to say that the test numbers are relatively small and a single injury already amounts to 8 percent.

AIS-Spine as Function of the Resultant Acceleration Spine

The presented data material of all three test groups was subject for a more exact statistical analysis through the multiple regression (linear model).

Fig. 5 shows that there is a slight increase of the AIS-spine with the resultant acceleration spine. The increase within the measurement range of the resultant amounts about 0,6 AIS degrees, whereas the standard deviation lays at 0,5 AIS degrees. This diagram considers among others following variables as medium values: Age 43 years, body mass 69 kg, seat-head-distance 91 cm, collision velocity 53 km/h, sled deceleration 12 g and shoulder belt force 4,2 KN. The linear model has shown that the resultant acceleration spine is of lesser influence to the AIS-spine.

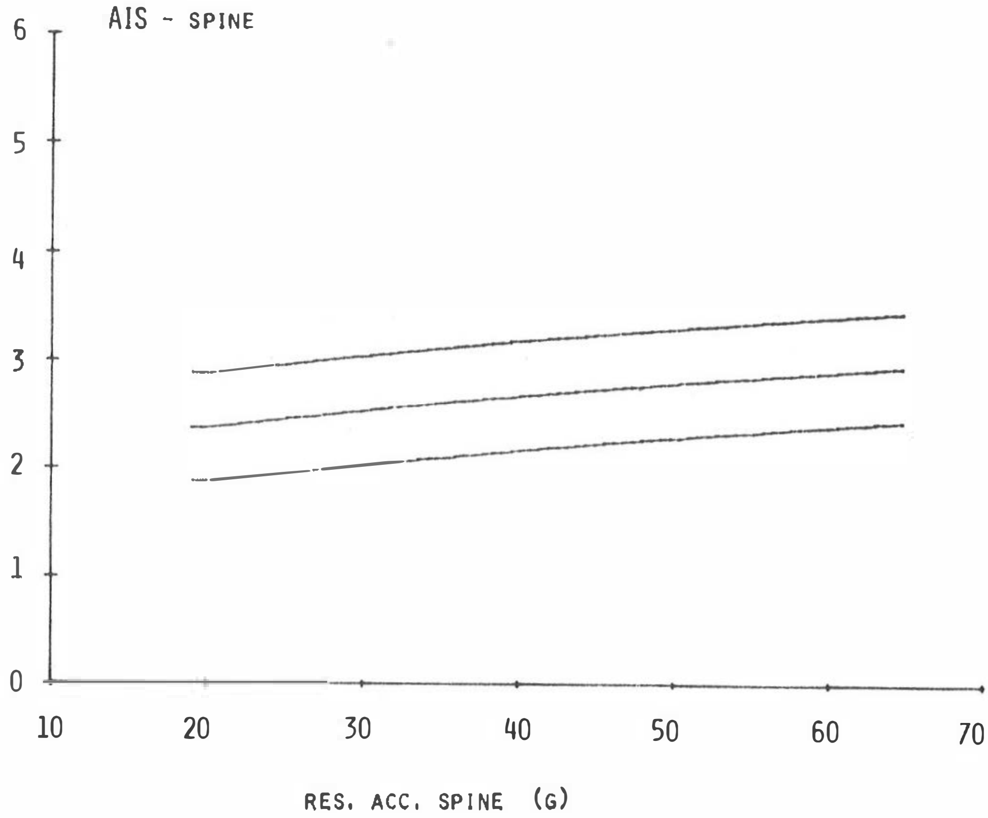

Fig. 5: AIS-Spine as Function of the Resultant Acceleration Spine

AIS-Spine as Function of the Age

The age has a somewhat stronger influence to the AIS-spine that the resultant acceleration spine (20 percent more than the resultant spine).

In Fig. 6 one can see an increase of the AIS-spine with the age. Within our age collective (18-69 years), the AIS-spine increases of about 0,8 age degrees at a standard deviation of 0,5 AIS degrees. In this diagram, the resultant acceleration spine is shown with a medium value of 26 g, the remaining variables are the same as in the previous chapter.

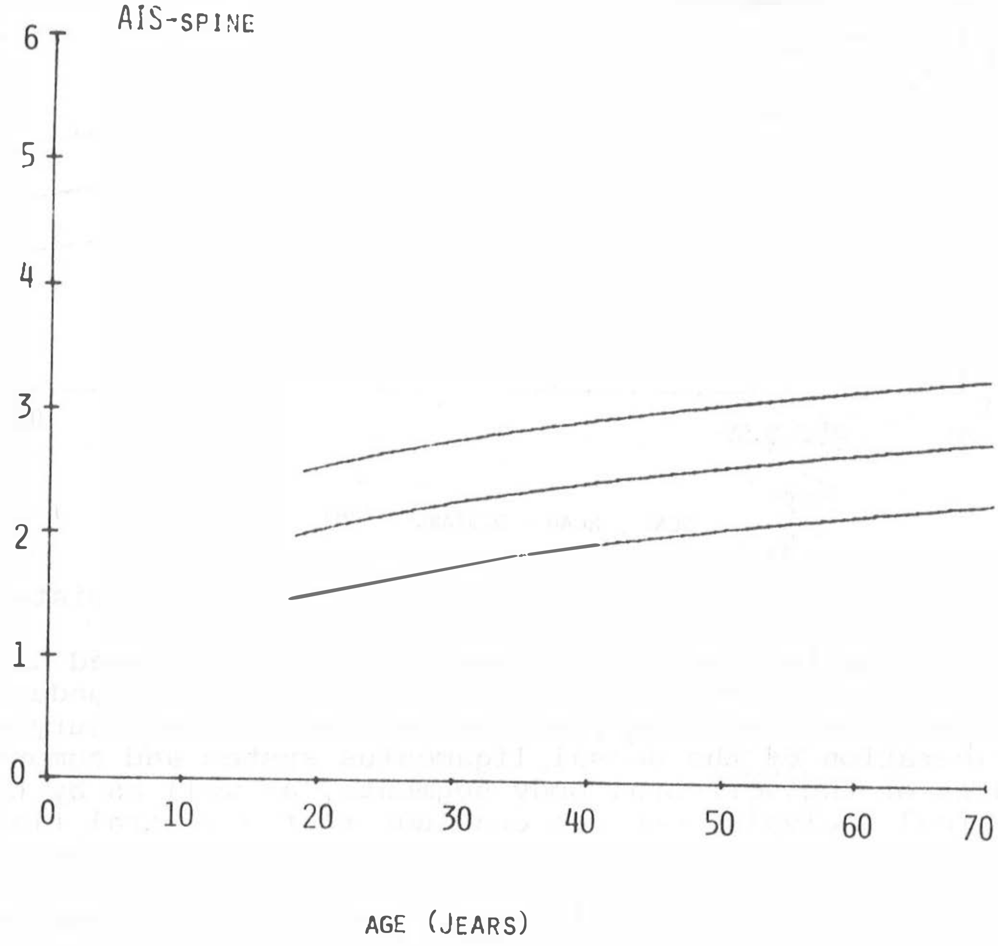

Fig. 6: AIS-Spine as Function of the Age

AIS-Spine as Function of the Seat-Head-Distance

The strongest influence of the considered variables to the AIS-spine shows the seat-head-distance; it is about 8 times as strong as the age. The seat-head-distance negatively influences the AIS-spine, i.e. with increasing seat-head-distance decreases the AIS-spine (Fig. 7).

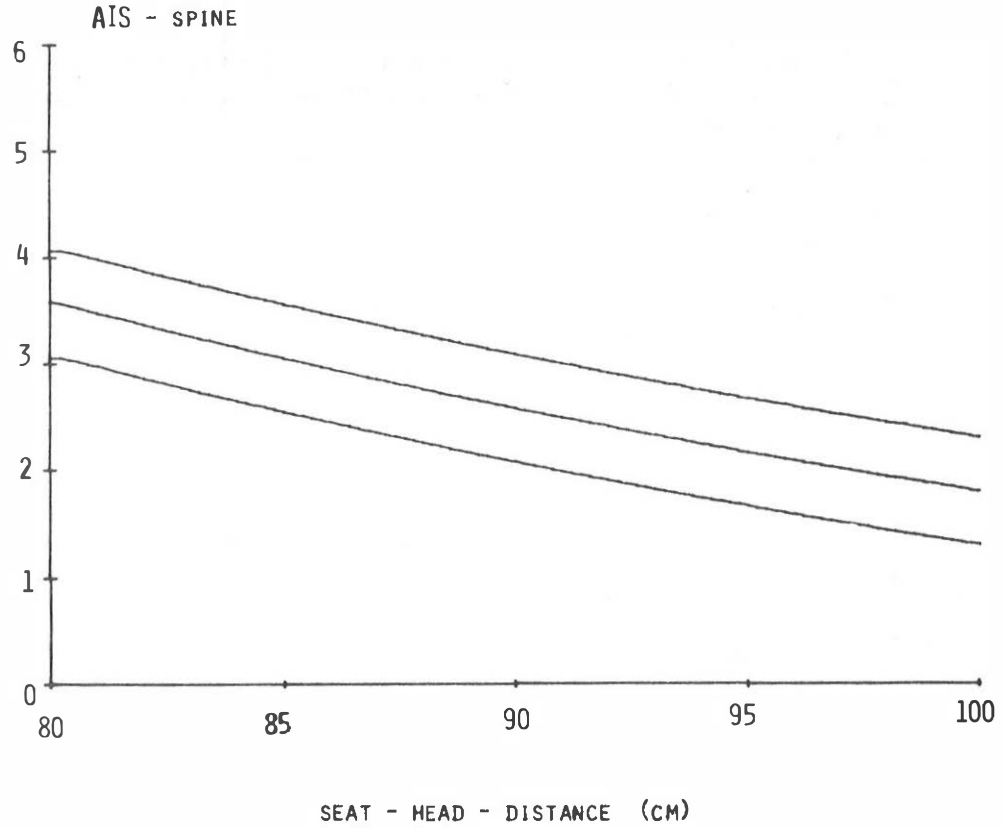

Fig. 7: AIS-Spine as Function of the Seat-Head-Distance

The reason for the negative influence of the seat-head-distance to the injury severity of the spinal column will be understandable if one considers the injury mechanism. Out of the injury pattern with laceration of the dorsal ligamentus system and compression fractures of the vertebral body segments, as well as by the kinematical analysis, one can conclude that a ventral flexion of the spine is the injury reason. In this ventral flexion, the shoulder belt effects as axis of rotation, whereby the length of the body part laying above the belt is decisive for the period of the flexion strain. This portion is big if the seat-head-distance is big and takes care for a longer and therefore lower head acceleration than at a smaller seat-head-distance. The ventral flexion then proceeds lesser jerky and has a lower strain to the spine.

Within the variation of the seat-head-distance (82-99 cm) the decrease of the AIS-spine amounts 2,6 AIS degrees at a standard deviation of 0,5 AIS degrees. The remaining variables are shown in the diagram with their already mentioned medium values.

<u>AIS-Thorax as Function of the Resultant Acceleration Spine</u>

In Fig. 8, the connection of the AIS-thorax is shown with the resultant acceleration spine. The statistical evaluation has shown that the resultant practically has no influence to the AIS-thorax. This result does not meet our expectations. The evaluation, however, has shown that the anthropometrical data of our test subjects have a much greater influence to the injury severity of the thorax, as in the resultant acceleration spine.

In the plotted function (Fig. 8) are, among others, the following variables with their medium values considered: Age 44 years, body mass 69 kg, chest size 88 cm, seat-head-distance 91 cm, collision velocity 51 km/h, sled deceleration 12g and shoulder belt force 4 kN.

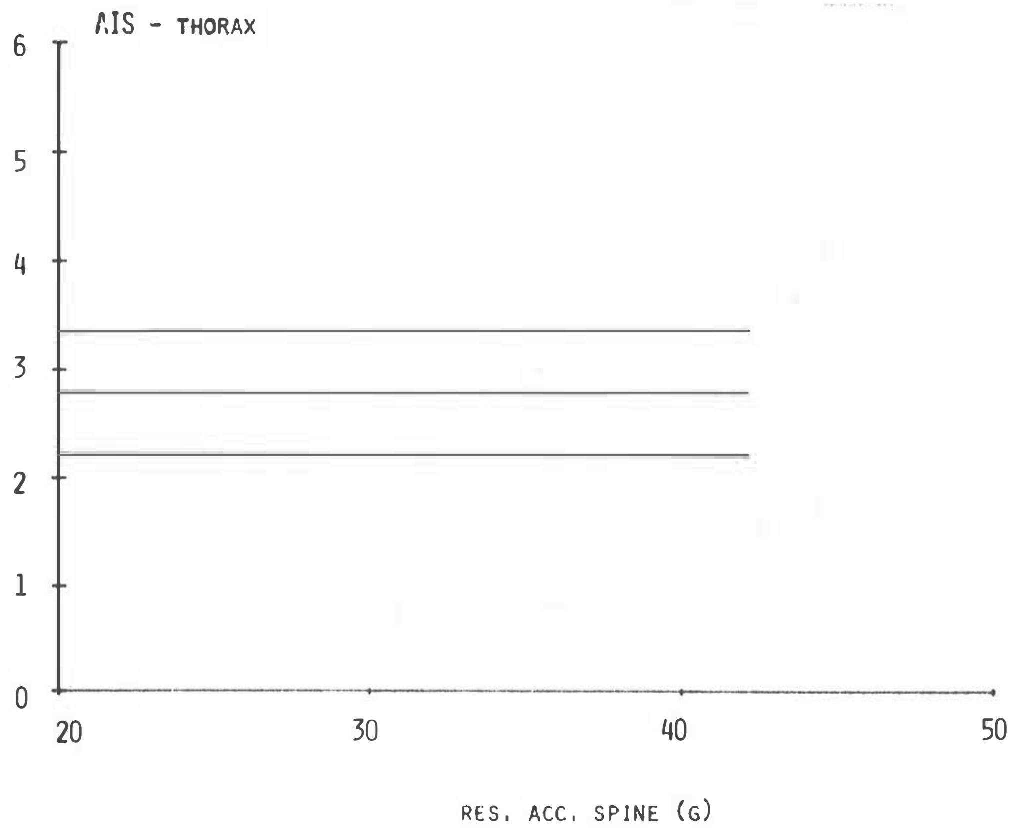

Fig. 8: AIS-Thorax as Function of the Resultant Acceleration Spine

AIS-Thorax as Function of the Seat-Head-Distance

The biggest influence of the variable considered in the evaluation of the AIS-thorax has the seat-head-distance (Fig. 9). Within the variation of the seat-head-distance of 82 - 99 cm, the AIS-thorax increases by one degree. As already mentioned, the anthropometrical data have a greater influence to the injury severity of the thorax. The thorax size is in the second place after the seating height, followed by body mass and age. Subsequently follows the shoulder belt force as the first physical magnitude in the 5th place in the order of precedence of the influence magnitudes.

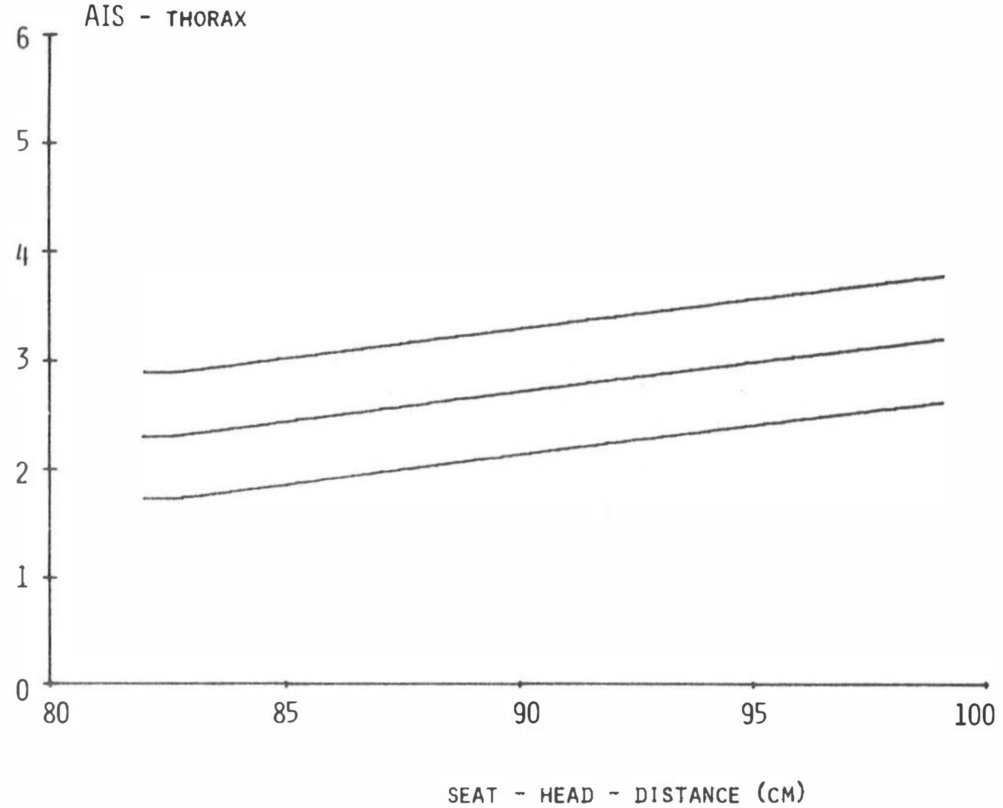

Fig. 9: AIS-Thorax as Function of the Seat-Head-Distance

AIS-Thorax as Function of the Age

From our previous investigations (KALLIERIS and MATTERN 1974, SCHMIDT et al 1978) it is known that the age has a considerable influence to the injury severity. Fig. 10 shows an increase of the injury severity with the age. Within our age collective (18-69 years) the AIS-thorax increases of 1,6 to the value of 3,4 at 69 years. The low injury degree of the thorax also follows from the relatively low sled deceleration of 12 g, a collision velocity of 51 km/h and a shoulder belt force of 4 kN.

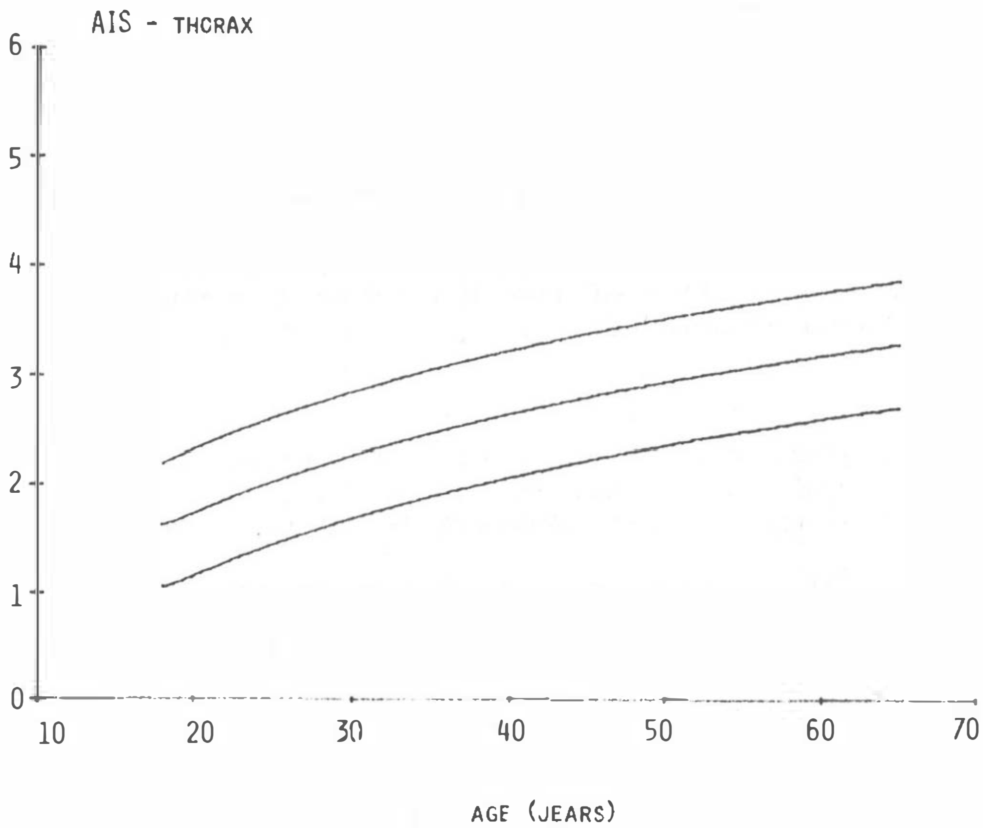

Fig. 10: AIS-Thorax as Function of the Age

Summary

In frontal collisions with belted cadavers the acceleration of the 6th thoracic vertebra is measured in x- and z-direction. Reports are made about tests with a collision velocity of 60 km/h and sled decelerations of 10 g and 15 g, respectively a collision velocity of 40 km/h and a sled deceleration of 10 g. The maximum acceleration lies in x-direction between 13 g and 39 g, in z-direction between 8 g and 33 g. The resultant acceleration lies between 19 g and 42 g. A clear increase of the spinal column acceleration with the sled deceleration but not with the collision velocity was noticed. Sternum fractures, rib fractures resp.

rib piece fractures occurred as well as injuries of the muscles, ligaments and bone injuries of the spine.

The regional AIS of the thorax lies between 0 and 4, the one for the spine between 0 and 3. The injury severity of the two collision velocity groups and the two sled deceleration groups will be compared.

According to the statistical evaluation (multiple regression) the influence of the age to the injury seriousness of thorax and spine has been confirmed. Against that are the resultant acceleration spine as well as the collision velocity and the sled deceleration of lower influence to the injury severity. Hence, anthropometrical data as e.g., seat-head-distance and thorax size turned out to have the strongest influence to the injury severity.

Acknowledgements

Our work was sponsored in part by FAT (Forschungsvereinigung Automobiltechnik e.V., Fankfurt, West-Germany) and CCMC (Commitee of Common Market Automobile Constructors), for which we are grateful. For the conduct of the statistical evaluation we thank Dr. Schmid (Daimler-Benz AG).

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