KINEMATIC AND SPINAL COLUMN INJURIES IN ACTIVE AND PASSIVE PASSENGER PROTECTION. RESULTS OF SIMULATED FRONTAL COLLISIONS

D. Kallieris, R. Mattern, Gg. Schmidt and D. Warth

University of Heidelberg

ABSTRACT

A report has been made on the kinematical analysis of cadaver tests, performed on a flat car running upon rolls in two series, simulating frontal impacts with a crash velocity of 50 km/h and a mean deceleration of 20 g. The first series involved 23 test subjects, protected with three-point belts, in driver and passenger position; in the second series, 10 tests with air-bag and knee-bar protected occupants in passenger position were conducted.

Caused by the system, there is a fundamentally different kinematic of the head between the two restraint systems.

No homogeneous differences of the two restraint systems can be derived from the mean values of the investigated displacements as well as the angular velocity and the angular acceleration.

In the three-point belt tests, the injuries may be explained with anteflexion; in the air-bag knee-bar tests with retroflexion. The mean value of the injury severity of the spinal column amounts between AIS 2 and AIS 3 for the three-point belt system and amounts between AIS 1 and AIS 2 for the air-bag knee-bar system.

It has been noticed that the angular acceleration does not represent a suitable parameter for the severity of the spinal column injuries with the given collision conditions and the restraint systems; the age represents a much greater influence than the kinematical magnitudes.

INTRODUCTION

Crash tests usually are documented with at least two high-speed cameras in frontal and side view. In spite of it, very rarely film analyses of the collision phase are found in biomechanical literature. VARRIEST et al (11, 12)* presented analyses of high-speed films using 5 high-speed cameras. They concern frontal collisions conducted with belt-protected pigs; their kinematic is relatively simple, compared with the kinematic of human cadavers and therefore much easier to evaluate. The kinematic

*Numbers in the parentheses designate References at the end of paper of dummies, e.g. ADOMEIT (1), is given through the stiffness of the dummy, which results in a poor movability, and is easier to evaluate.

In literature, more frequently the sequence photographs of the collision phase (2, 13, 14) are mentioned, which represent the first step to the film analysis.

Our Institute presented some papers (4, 5, 9, 10) dealing with film analyses of frontal collisions conducted by means of examples; thereby, the complex kinematic of the cadaver was obvious. In the present paper, larger numbers should be analysed in detail in order to investigate the correlation of spinal column injuries with the kinematic. In the tests, two restraint systems were used. A report on loadings and injuries of the same tests has been already made (6).

TEST METHOD

The tests have been performed on a flat car running upon rolls which is stopped by means of deforming a metal strap; the pulse shape is trapezoidal. The collision velocity amounted 49-51 km/h, the deceleration 18-22 g.

a) Three-point belt tests. Driver and front-car passenger positions have been simulated. In the tests we used VW beetle type I seats and three-point standard belts (17% elongation at 1135 daN). The anchorage points of the belts did not correspond to a certain type of car; they lay within the variation range of European cars. According to the seating height of the test subject it was possible to adjust the upper anchorage point in x- and z-direction. There was no steering assembly or dash board during the simulation (Fig. 1).

b) Air-bag knee-bar tests. The front seat passenger position has been simulated. We used VW-Golf seats; a combination of passenger air-bag and knee-bar served as restraint system. The seat was adjusted in such a manner that the distance between knee and knee-bar amounted about 8 cm. In the simulation, the front part (up to B-pillar) of the passenger compartment of a VW-Golf has been used and mounted on a flat car running upon rolls (Fig. 2).

AIR-BAG SPECIFICATIONS

1. Sensor time: 17 ms
2. Motive substance: Natronacid 2 x 76 g
3. Two gas generators
4. Air-bag filling time: 30 ms
5. Air-bag volume: 178 ltr
6. Blow out: 2 x 65 mm

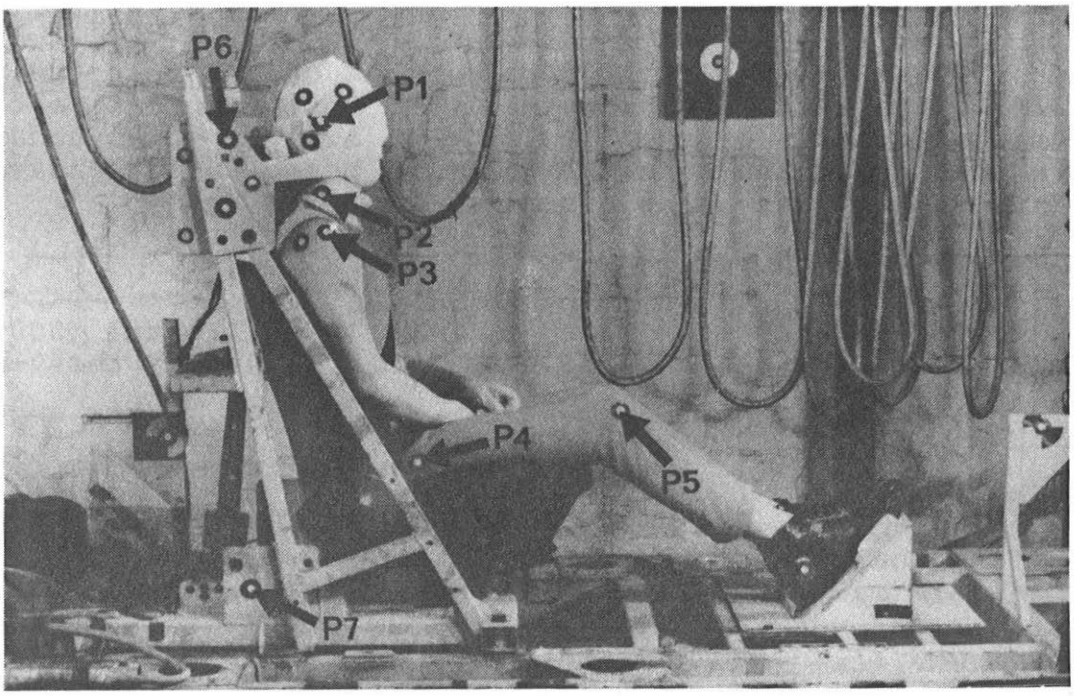

Fig. 1: Side view of test configuration, test subject with optical targets, 3-point belt system

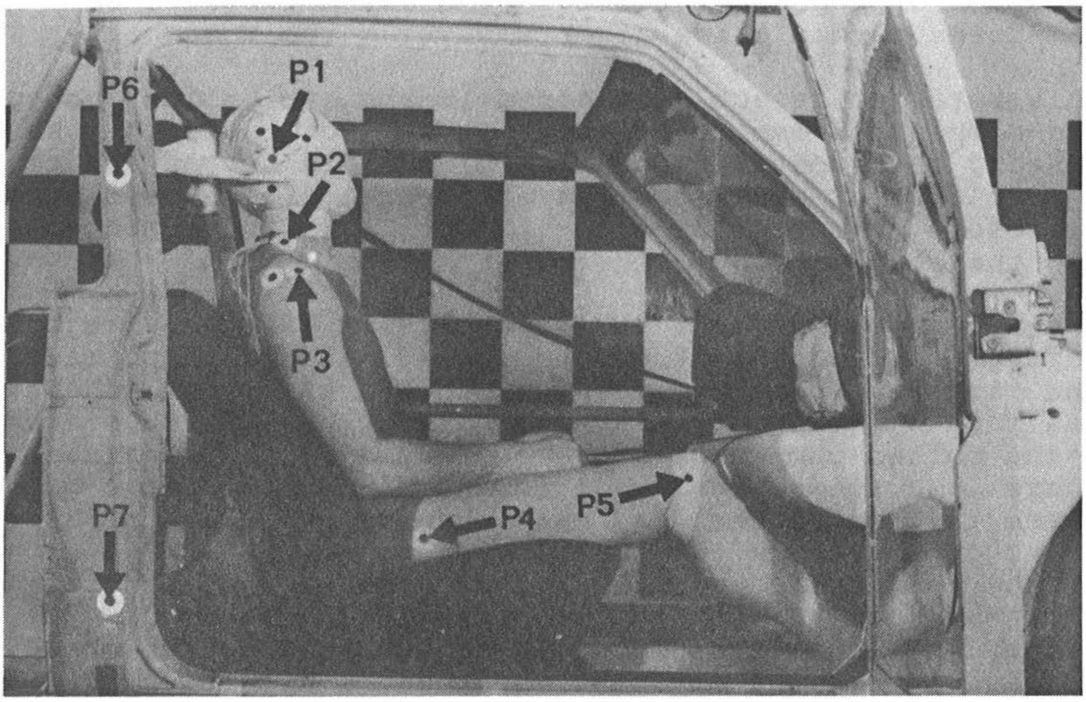

Fig. 2: Side view of test configuration, test subject with optical targets, air-bag knee-bar system

TEST SUBJECTS

Fresh, unembalmed male and female human cadavers in the age range of 14 to 66 years have been used. The most important anthropometrical data can be seen in Table 1. A total of 23 cadaver tests have been conducted using three-point belts and 10 cadaver tests using air-bag knee-bar systems.

PHOTOGRAPHIC DOCUMENTATION

High speed cameras took side (1000 p/s) and frontal (500 p/s) views. Photos have been made before and after the test.

RESULTS

KINEMATIC

The film analysis of the conducted tests resulted from the high speed film made from lateral view; the frame rate amounted 1000 p/s. Targets were installed on the cadaver (points 1,2,3,4,5 in Fig. 1 and 2) and on the seat mounting device or B-pillar (fixed points 6, 7 in Fig. 1 and 2).

Because of the complex kinematic of the human body during the collision phase, these targets were not evident at any time and therefore, additional targets were installed on the cadaver. In both restraint systems used, there was sometimes a rotation of the upper torso around the shoulder belt or the air-bag. The rotation of the upper torso in the air-bag system came about as the knees turned aside after impacting the knee-bar.

This rotation is not considered in the evaluation; because of the complex kinematic of the test subject caused by the restraint system, the frontal high-speed camera did not at any time during the collision phase show the front area of the test subject; therefore, the frontal high-speed film was not used when analysing the film.

The high speed film of the lateral view has been projected through a motion analyser, the coordinates of each target over the time have been recorded on a perforated tape; the evaluation was made by means of a tape reader, combined with a computer using suited computer programs. Caused by the restraint system, there is a fundamentally different kinematic of the head between the two systems, as also observed by CHENG et al (3).

In the test subjects using a three-point belt an anteflexion of the head occurred after a translatory displacement. The translatory movement lasts about 30 to 40 ms after the crash, then follows a combined movement in x- and z-direction. The photographic target in the center of the head describes an circular path in the time 50 to 100 ms after the crash, the radius of it differs in each test; decisive for the length of the radius is the seating height of the test subject. Also the target (P2) in the lower area of the cervical spine describes a similar course in this time period after the crash; however, the radius is smaller than the one of target P1. While the targets P1, P2 on the rebound phase move backwards in a lower level than in the primary phase, P3 (shoulder) moves in a higher level; this corresponds to the additional upwards movement of the arm during the collision. The same behavior can also be observed at the knee target. After a small turning radius, the pelvis target performs a translatory movement in the primary phase as well as in the rebound phase.

Fig. 3 shows a typical plot of displacements of photographic targets on the body of a 3-point belt protected subject. In the air-bag knee-bar tests during the first 40 to 50 ms there is a translatory movement until the air-bag head contact. Mostly, a further translatory displacement follows, however, sometimes an anteflexion or retroflexion of the head also occurs. This depends upon the filling condition of the air-bag during the head contact. In our test series, the air-bag started to inflate between 12 to 21ms after the crash. The photographic targets in the lower area of the cervical spine, shoulder and pelvis predominantly showed translatory displacements. A different course of the pelvis target was noticed if the knee turned aside the knee-bar upwards or to the side. Fig. 4 shows a typical plot of the displacements of the targets on the body of an air-bag knee-bar protected occupant.

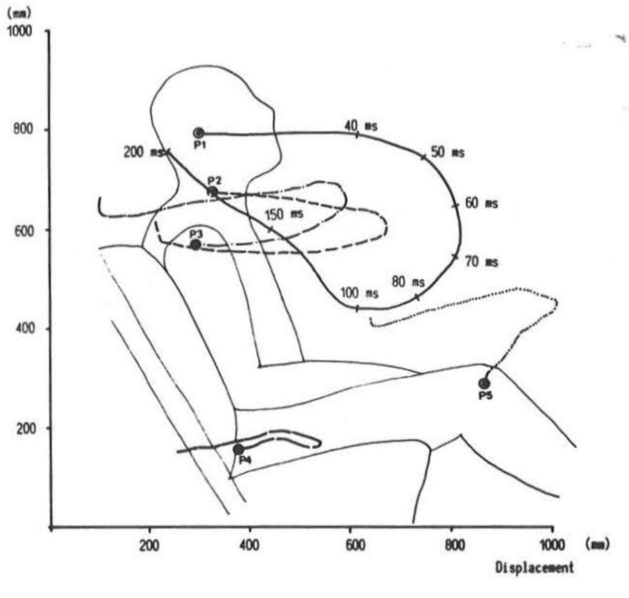

Fig. 3: Displacements of photographic targets, mounted on the head, neck, shoulder, pelvis and knee. Run No. H7427, three-point belt test

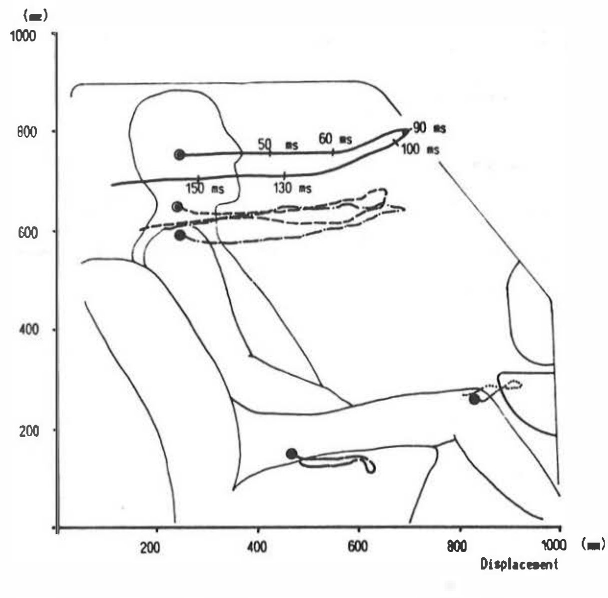

Fig. 4: Displacements of photographic targets, mounted on the head, neck, shoulder, pelvis and knee. Run No. H8003, air-bag knee-bar system

DISPLACEMENTS

Table 1 shows the most important anthropometrical data, the maximum head displacements and the corresponding shoulder, pelvis and knee displacements of the 33 cadaver tests. The maximum head displacements of the 3-point belt tests are between 39 to 57 cm and in the air-bag knee-bar tests between 37 to 60 cm. The variation of the displacement of 18 cm in the 3-point belt system can predominantly be explained through the different seating height of

Run No.	Sex	Age (years)	Body-mass (kg)	Body-length (cm)	Seat-height (cm)	Displacement (cm)				Restraint-system
						Head	Shoulder	Pelvis	Knee	
H 7427	M	65	87	186	-	54	31	16	16	3-Point belt
H 7430	M	45	81	182	84	50	43	27	27	"
H 7433	F	65	69	155	79	39	40	24	25	"
H 7542	M	39	76	175	93	52	44	18	18	"
H 7622	F	22	52	160	92	44	44	16	15	"
H 7623	M	14	58	166	93	43	40	21	20	"
H 7625	F	32	53	163	88	42	35	17	14	"
H 7626	M	29	69	175	90	46	37	20	20	"
H 7627	M	23	76	183	92	46	44	17	21	"
H 7629	M	45	75	159	93	48	38	18	18	"
H 7632	F	54	60	166	89	42	38	8	16	"
H 7633	M	20	76	178	94	49	47	31	23	"
H 7634	F	26	55	166	90	45	43	14	11	"
H 7636	F	22	48	163	88	38	38	16	18	"
H 7637	M	25	61	172	96	48	46	14	12	"
H 7639	M	21	56	169	88	48	40	17	14	"
H 7640	M	20	67	173	97	51	53	12	13	"
H 7642	M	45	62	164	88	49	38	20	20	"
H 7643	M	22	89	192	103	55	49	19	18	"
H 7710	M	55	81	163	90	44	46	25	31	"
H 7712	F	53	57	159	86	57	52	13	12	"
H 7713	F	37	49	155	87	46	39	16	16	"
H 7714	M	22	71	182	92	48	44	26	30	"
$\bar{x}$	-	34,8	66,4	169,8	90,5	47,1	42,1	18,5	18,6	"
H 7822	F	66	75	170	96	37	37	17	10	Air bag knee bar
H 7852	M	66	93	177	98	46	65	20	13	"
H 7927	M	26	64	172	94	46	52	16	7	"
H 7928	M	34	64	174	90	48	53	18	11	"
H 8003	M	65	73	178	95	44	41	16	8	"
H 8004	M	26	74	180	92	51	54	20	17	"
H 8015	M	43	85	191	100	52	61	35	16	"
H 8019	M	18	69	176	90	48	49	24	16	"
H 8022	M	18	69	176	94	60	62	24	14	"
H 8103	M	55	71	177	94	54	54	20	13	"
$\bar{x}$		41,7	73,7	177,1	94,3	48,6	52,8	21	12,5	"

Table 1: Subject specifications and displacements for the 23 3-point belt tests and the 10 air-bag knee-bar tests

the test subjects. The seating height amounts between 79 cm and 103 cm. The correlation of the head displacement with the seating height is presented in Fig. 5. It has been noticed that the head displacement increases with the seating height. The Pearson correlation coefficient amounts r = 0,58. In the air-bag knee-bar system, however, no correlation between head displacement and seating height could be observed. On one hand, this depends on the special, above all, translatory kinematic of the air-bag system, on the other hand, according to our opinion, to differences in the air-bag filling (different inflating time, rate of pressure rise, final pressure).

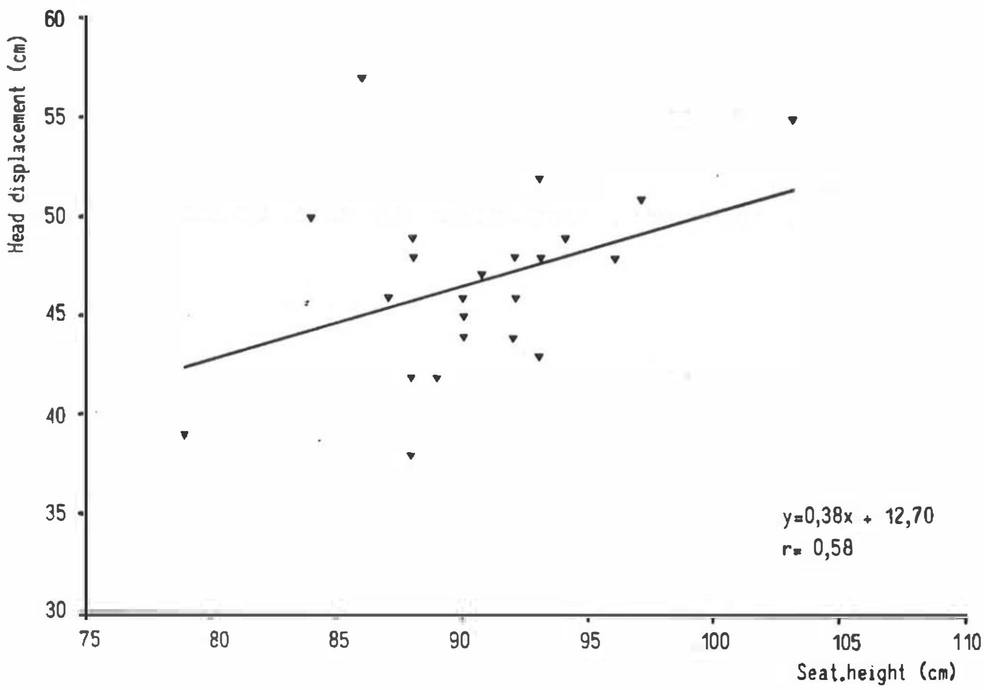

Fig. 5: Head displacement as function of the seating height

The shoulder displacement of the air-bag knee-bar system has an higher average value (caused by the system) than in the 3-point belt system. Because of the adjusted distance (prior to the crash) of the knee to the knee-bar of about 8 cm in all tests, the knee displacement showed, as expected, only a relatively small scattering and is lower than the one in the 3-point belt tests. In the air-bag tests, displacements between 7 cm and 17 cm (mean value 12.5 cm) have been measured. Displacements achieving more than 8 cm of the adjusted initial distance occurred because the knees slided upwards over the knee-bar and therefore reached further forward.

Surprisingly in the air-bag system, the displacement of the pelvis with 16 cm to 35 cm (mean value 21 cm) was somewhat higher than in the 3-point belt tests (8-31 cm, mean value 18.5 cm). Especially the knee displacement value was significantly exceeded. A possible explanation could be that in the collision phase an upwards movement of the knee over the knee-bar occurred (z-direction) or a passing away of the knee in lateral direction. In the 3-point belt tests, however, the displacements of pelvis and knee were equally high. This is a necessarily consequence of the specific kinematic of the lap belt as the pelvis movement is determined by the belt and the knee movement by the pelvis because of the anatomical connection of the knees and the upper thigh.

ANGULAR VELOCITY - ANGULAR ACCELERATION

In former evaluations of our simulated frontal collisions with belt protected occupants we observed among other injuries also injuries at the spinal column. These injuries were concentrated at the transition of the cervical spine to the thoracic spine and the thoracic spine to the lumbar vertebral column. The more serious injuries, however, occurred at the transition of the cervical spine to the thoracic spine. In this paper, we try to kinematically analyse this area in more details and to investigate the correlations with the injuries. As measurement, the change of the angle has been used, consisting of the connection of the targets P1-P2 (head center - lower cervical spine, Fig. 1 and 2) and the targets P2-P4 (lower cervical spine - pelvis, Fig. 1 and 2); this angle became smaller during the collision phase and reached values of 30° to 90°. The relatively low angle values determined here may be explained because the upper torso rotated around the shoulder belt and because of the selection of point P4 including the total thoracic- and lumbar vertebral column. Because of the bending of the single segments of the thoracic spine the actual angle at the transition cervical spine to thoracic spine remains larger than we investigated here. A more convenient point around the middle of the thoracic spine could not be investigated in this evaluation.

Furthermore, the angular velocity of the angle has been evaluated, which is formed by the axis P2-P1 and the vertical. This angle, at first, increases in the course of the head bending and decreases in the rebound phase. It only differs from the above mentioned angle through the fact that one side of the angle is moving, while the other, the vertical axis, remains firm. The above mentioned angle, however, includes the moving component of the axis P2 P1 as well as the axis P2 P4.

The angular velocity-time-histories for the angle P1 P2 P4 were filtered with 100 Hz. All 23 diagrams reached their maximum 60 to 70 ms after the start of the crash. During this time interval the head has not yet reached the maximum of the displacement and is still above the turning area. The angle velocity maxima show great scattering; they lie between 28 rad/sec and 58 rad/sec.

Figure 6 shows the scattering diagram of the angular velocity over the time for all 23 tests conducted with 3-point belts.

The scattering diagram of the angular velocity of the head bending angle P1 P2 calculated to the vertical is shown in Fig. 7. The maxima are reached after about 80 ms from the crash beginning and lie between 26 rad/sec and 60 rad/sec. In the presentation, the angular velocity-time-histories of the single cases have been averaged in 10 ms intervals.

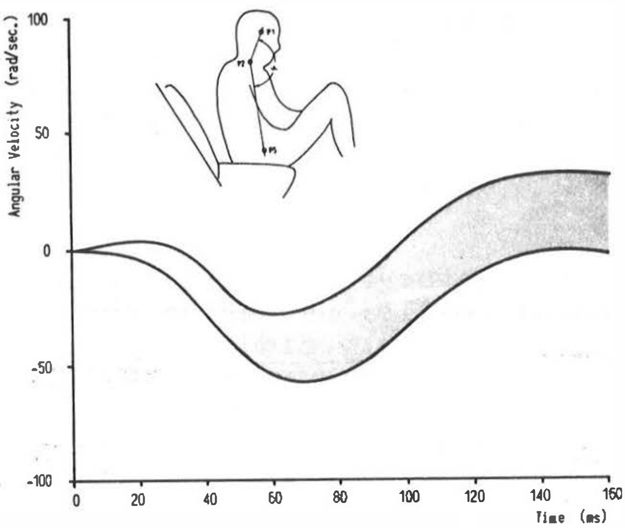

Fig. 6: Interval of the angular velocity-time history, 23 tests by using three-point belt

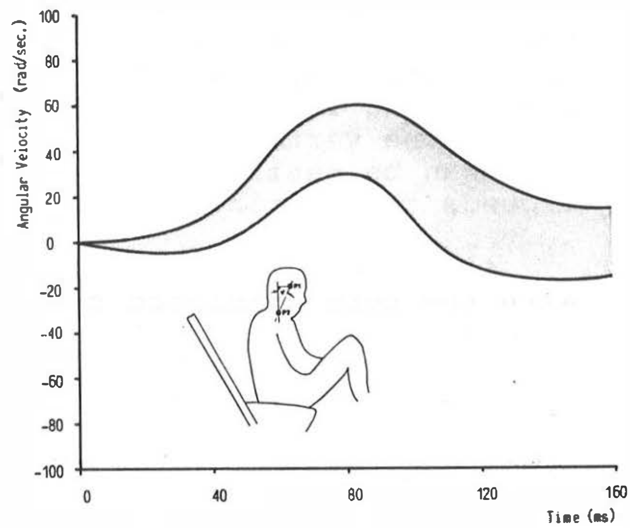

Fig. 7: Interval of the angular velocity-time history, 23 tests by using three-point belt

In the air-bag knee-bar tests, also angular velocity-time-histories of the angle P1 P2 P4 (Fig. 2) have been made. The histories have been filtered with 100 Hz as in the 3-point belt tests; however, they cannot be presented in the same manner as in the 3-point belt tests. In each test, considerably different courses can be seen. These courses are partly uni-directed, partly also countercurrent in the same test. The angular velocity maxima lie between -49 rad/sec and +44 rad/sec and were reached in different times between 75 ms and 162 ms.

The angular acceleration has been calculated from the angular velocity-time-history, as in the range of the maximum velocity change (= maximum ascent) the quotient has been formed from the velocity difference and the corresponding time difference ($a_{max} = \frac{\Delta v}{\Delta t}$). The evaluated maximum values of the angular acceleration are shown in Table 2.

INJURY FINDINGS AT THE SPINAL COLUMN

In all test subjects, the injuries at the spinal column have been diagnosed, using the previous described technique (7), (8). To it, at first, followed a preparation of the vertebral muscular system and an evaluation of the bony and ligamentous injuries recognizable on the outside after removing the muscular system. After that, the total spinal column has been removed "en bloc" together with the rear base of the skull, frozen up, and in this condition, by means of a band-saw, dissected in three fronto-dorsal longitudinal sections, one of it through the middle of the vertebral column as well as left and right through the vertebral joints. By using this technique, injuries of the vertebral bodies, the longitudinal ligament apparatus, the intervertebral discs, the vertebral joints, the spinal ganglions and the spinal cord can be easily recognized. The diagnostical security by far exceeds the routine x-ray method.

a) Spinal Column Injuries with the Three-Point Belt System. With the here simulated severe frontal collisions, using the 3-point belt restraint system, a typical injury finding at the spinal column was the combination of injured structures as follows: Tear drop fracture of a vertebral body; laceration of the intervertebral disc of the above adjoining intervertebral disc; laceration of the ligamentum flavum of the same segment. This injury combination occurred one- or poly-segmental and predominantly fell upon the area between the third cervical segment and the fourth thoracic segment (Fig. 8). The lower thoracic vertebral column (Th5 - Th10) very seldom was injured. Occasionally, injuries of vertebral bodies, intervertebral discs and one time also of the ligamentous system occurred at the thoracic-lumbar transition; the segmental combination injury, described for the cervical-thoracic transition, however, was not observed.

A fracture of a vertebral body was hardly ever combined with a more severe ($>$ 20%) compression. Frequently the rear, but never the anterior longitudinal ligament apparatus was lacerated. The intensity of the injury is significantly influenced through age, constitution and degenerative degree.

b) Spinal Column Injuries with the Air-Bag Knee-Bar System. Using this restraint system, no laceration of the ligamentum flavum occurred. Characteristically may be the laceration of the anterior longitudinal ligament or the ventral laceration of the intervertebral discs. In severely injured test subjects, such injuries were combined with a laceration of the ventral top edge and/or the bottom edge of the adjoining vertebral body. In two of the older test subjects this injury combination occurred in several segments. Here too, the injury area was located at the cervical-thoracic transition, however, contrary to the three-point belt system also injuries were found at the lower thoracic spine (Fig. 9). Only in one case remained the thoracic-lumbar

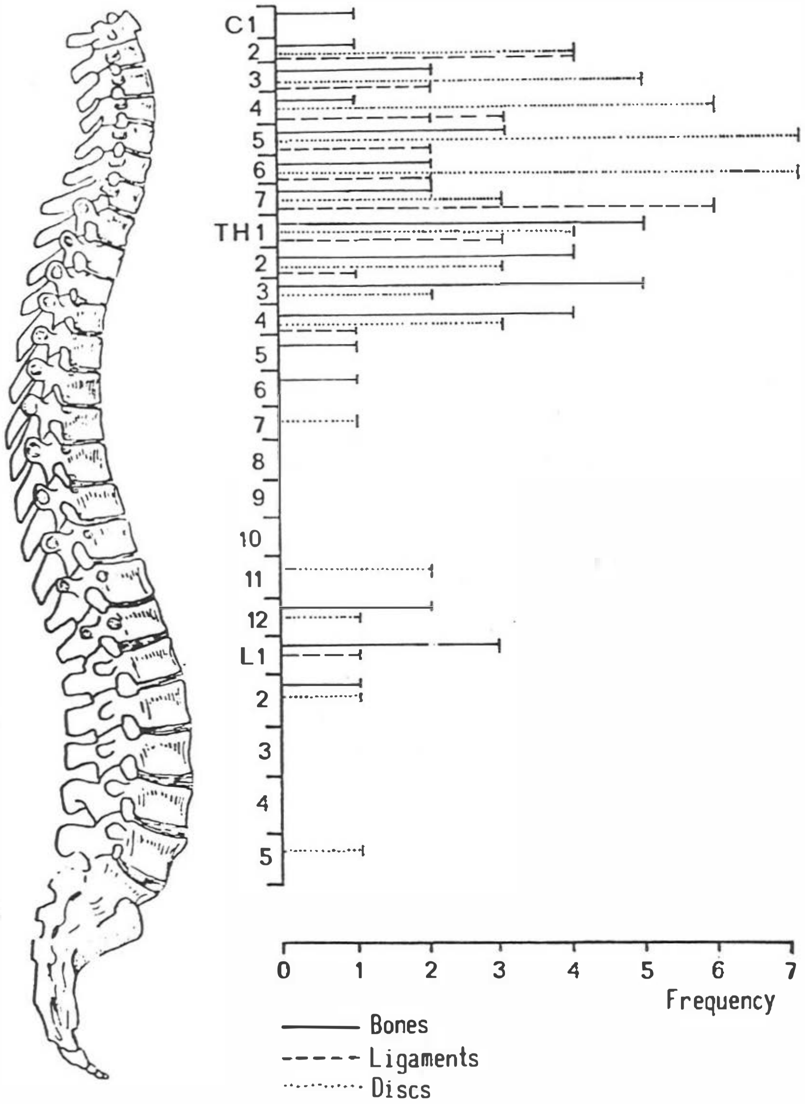

Fig. 8: Topographical location of the vertebral column injuries (23 three-point belt tests)

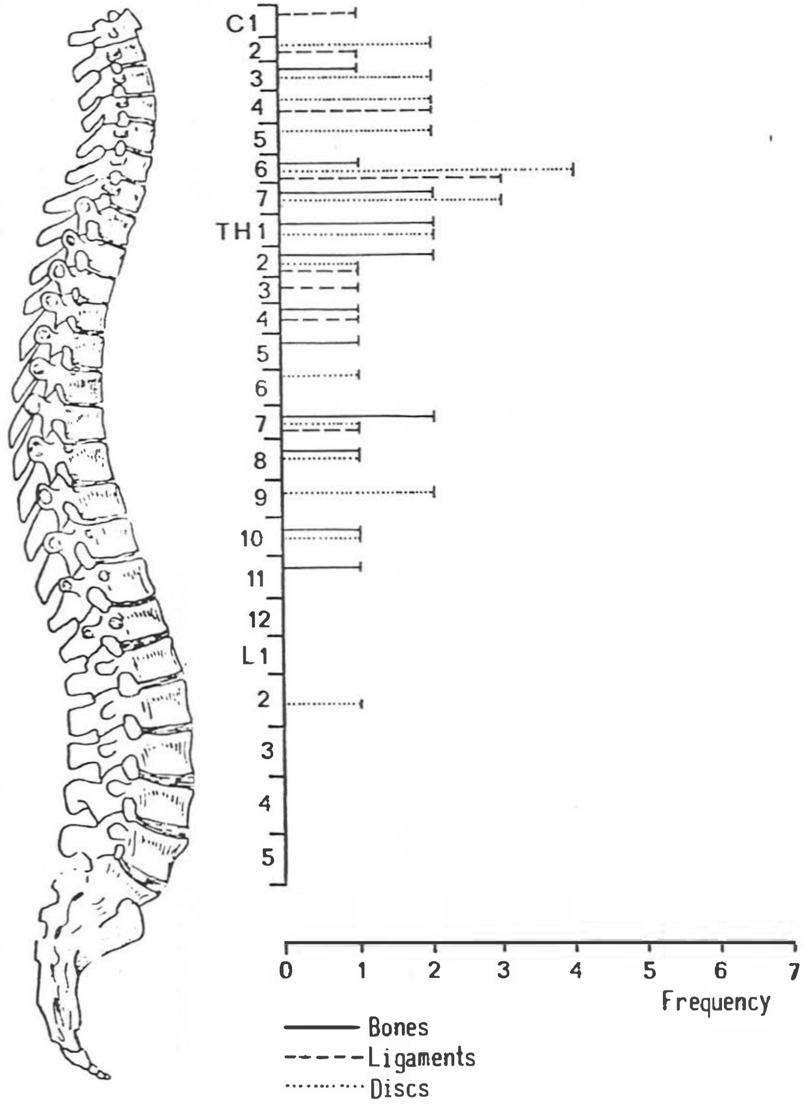

Fig. 9: Topographical location of the vertebral column injuries (10 air-bag knee-bar tests)

transition area uninjured.

DISCUSSION

Correlation Between Physical Magnitudes and Spinal Column Injuries

Table 2 shows the most important anthropometrical data of the test subjects, the maxima of the angular velocities ω_1 and ω_2, the maxima of the angular accelerations a_1 and a_2, as well as the severity degrees of the spinal column injuries of the 23 three-point belt tests and the 10 air-bag knee-bar tests.

The severity of the spinal column injuries has been stated according to two methods:

1) According to AIS. Detail injuries, not explicitly mentioned in the AIS 80 revision have been evaluated analogical to general criteria (especially health threat).

2) According to the number of spinal column injuries. Similar as in the evaluation of the thorax injuries according to Thorax AIS and number of the rib fractures, we have tried to determine the number of the spinal column injuries as severity parameter. Fractures of the bones, lacerations of the intervertebral discs and ligaments were counted as equivalent injuries. Further injuries were not considered.

In the attempt to describe the injury severity of the spinal column as function of the angular accelerations a_1max and a_2max, no convincing functions could be found either for the AIS findings or for the number of the spinal column injuries.

In the 3-point belt system, spinal column injuries of AIS 3 can already occur below 1000 rad/sec², but also at 3000 rad/sec² or more (Fig. 10, 11).

Considering the number of spinal column injuries they also show great scatterings (Fig. 12, 13).

In the air-bag knee-bar tests, similar large scatterings have been observed. For the investigated collectives it can be determined that the defined kinematical magnitudes are no reliable predictors.

In older test subjects, we observed severe and/or numerous spinal column injuries. Therefore, the age factor seems to be an important parameter also in this analysis, although even young test subjects show injuries of AIS 3 with the 3-point belt system.

With the air-bag knee-bar system we had the impression that higher injury degrees only occurred in older test subjects.

Run No.	Sex	Age (years)	Body-mass (kg)	Body-length (cm)	Seatr height (cm)	ω_{1max} (rad/sec)	ω_{2max} (rad/sec)	a_{1max} (rad/sec²)	a_{2max} (rad/sec²)	Regional AIS Spinal Col.	Number of spine injuries	Restraint-system
H 7427	M	65	87	186	-	53,0	57,0	3111	2816	3	7	3-Point belt
H 7430	M	45	81	182	84	47,5	44,0	2423	2750	2	5	"
H 7433	F	65	69	155	79	49,0	43,0	2882	2611	3 +	4 +	"
H 7542	M	39	76	175	93	47,0	46,0	1403	2563	3 o	4 o	"
H 7622	F	22	52	160	92	50,0	52,0	2778	2486	2	5	"
H 7623	M	14	58	166	93	52,0	44,0	2167	1868	0	0	"
H 7625	F	32	53	163	88	49,0	45,0	1690	1324	3	8	"
H 7626	M	29	69	175	90	57,5	50,0	1643	1815	2	4	"
H 7627	M	23	76	183	92	47,0	53,0	1306	3088	2	4	"
H 7629	M	45	75	159	93	32,5	46,0	2167	2360	2	5	"
H 7632	F	54	60	166	89	35,0	26,0	1591	813	3	8	"
H 7633	M	20	76	178	94	57,5	48,0	1779	1990	2	4	"
H 7634	F	26	55	166	90	42,5	45,0	1288	1528	2	4	"
H 7636	F	22	48	163	88	45,0	34,0	1452	1806	2 x	6 x	"
H 7637	M	25	61	172	96	58,0	49,0	3588	1578	3	8	"
H 7639	M	21	56	169	88	32,0	45,0	970	1500	1	2	"
H 7640	M	20	67	173	97	37,5	63,0	3125	2010	1	1	"
H 7642	M	45	62	164	88	51,0	57,0	2217	2979	3	7	"
H 7643	M	22	89	192	103	39,5	65,0	1197	2241	1	1	"
H 7710	M	55	81	163	90	25,0	36,0	1190	1532	3 *	3 *	"
H 7712	F	53	57	159	86	28,0	46,0	1000	1892	3	11	"
H 7713	F	37	49	155	87	57,0	51,0	1966	2012	3	10	"
H 7714	M	22	71	182	92	26,0	44,0	1529	2282	2	4	"
$\bar{x}$	-	34,8	66,4	169,8	90,5	44,28	47,3	1933	2080	2-3	5	"
H 7822	F	66	75	170	96	22,5	48,0	1184	2994	3	5	Air bag knee bar
H 7852	M	66	93	177	98	24,0	26,0	1200	1780	4	17	"
H 7927	M	26	64	172	94	49,0	62,5	2513	3485	0	0	"
H 7928	M	34	64	174	90	22,0	46,5	1692	4247	1	1	"
H 8003	M	65	73	178	95	19,0	34,5	613	1975	4	18	"
H 8004	M	26	74	180	92	44,0	42,5	1660	3333	2	2	"
H 8015	M	43	85	191	100	42,0	43,5	1680	2749	1	1	"
H 8019	M	18	69	176	90	30,0	32,0	1818	1626	2	3	"
H 8022	M	18	69	176	94	57,0	37,0	1727	2090	1	1	"
H 8103	M	55	71	177	94	23,0	28,0	1438	2537	1	2	"
$\bar{x}$	-	41,7	73,7	177,1	94,3	33,3	40,1	1552,5	2681,6	1-2	5,5	"

Table 2: Subject specifications, angular velocity, angular acceleration and injury severity of the spinal column (+ compression fracture Th2 > 20%, x multisegmental strain, * subluxation Th 12/L 1, o body fracture with subluxation C1/C2). ω_1, a_1: correspond to the angle P1 P2 P4 (Fig. 1), ω_2, a_2: correspond to the angle between the vertical and the axis P1-P2 (Fig. 1)

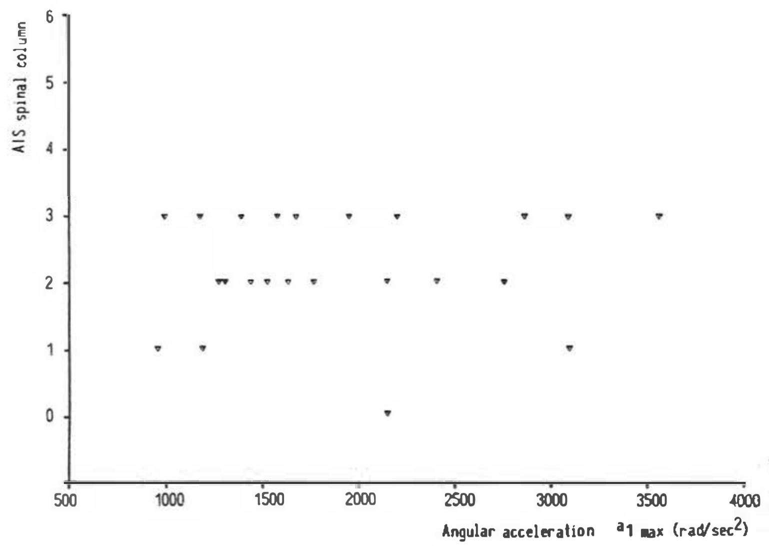

Fig. 10: AIS spinal column injuries as function of the angular acceleration

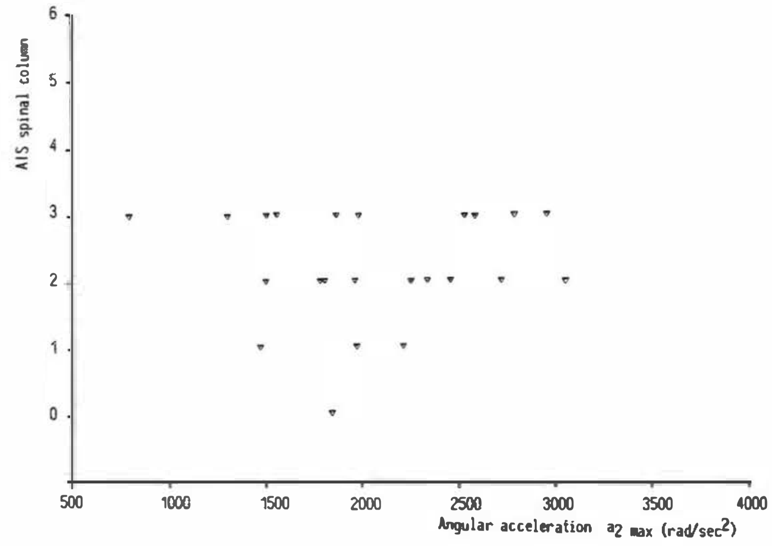

Fig. 11: AIS spinal column injuries as function of the angular acceleration

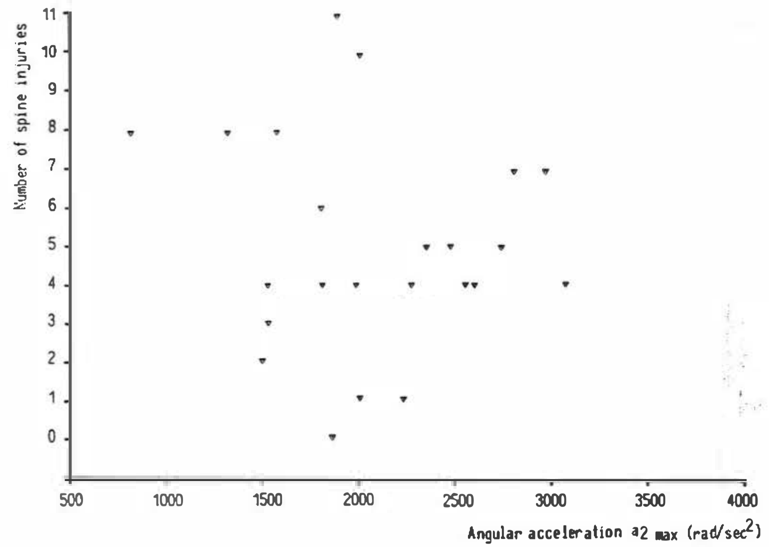

Fig. 12: Number of spine injuries as function of the angular acceleration

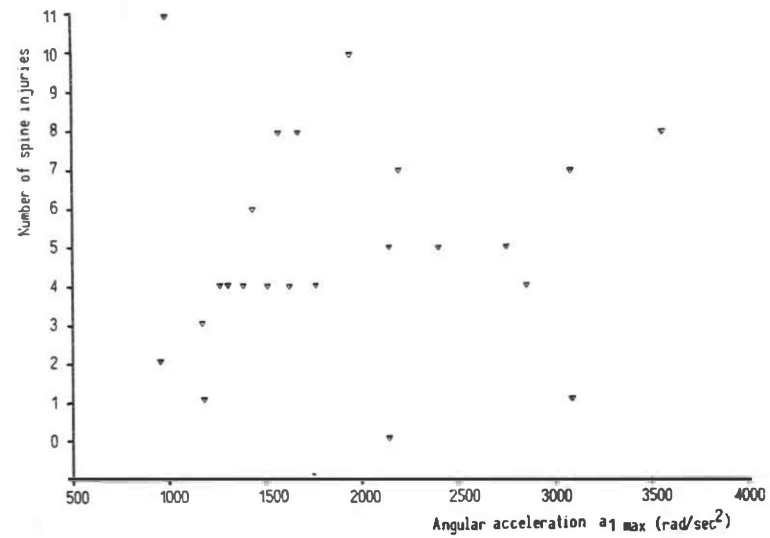

Fig. 13: Number of spine injuries as function of the angular acceleration

In two test subjects (age 65 and 66 years) even occurred spinal column injuries AIS 4, whereas such serious injuries were not observed in 3-point belt tests. When comparing the injuries caused post-mortal with injuries clinically determined from real accidents, the difference in the diagnostical method has to be considered. Accident statistics very seldom give information on such kinds of injury patterns at the spinal column of car occupants as these mentioned in detail. In our forensic autopsies of real accidents we observe corresponding injury findings at ligaments, intervertebral discs and vertebral bodies in applying our detailed preparation technique, if comparable accident influences did exist like in our experimental traumatisations. Often, the proof of such injuries is even easier, because they indicate themselves through strong hemorrhages if they arise intravital; whereas, there are only small hemorrhages if they arise post-mortal. According to our previous experience, we have no indications that the injury severity of the spinal column is heavier in post-mortal traumatisations than in real accidents.

Concerning the clinical relevance of the cervico-thoracic spinal injuries, one cannot surely conclude from post-mortal traumatisations to clinical functional diseases.

In our present tests, we have not observed spinal cord injuries; however, it is possible that due to the acting loads, contusions of the spinal cord may occur, causing temporary or remaining paralysis; post-mortal we did not find a reliable evidence.

CONCLUSIONS

1) The angular acceleration is no reliable predictor for the severity of the spinal column injuries of both restraint systems at the given test conditions. The influence of the age in regard to the injury severity is larger than the one of the kinematical parameters.

2) With the same test conditions (50 km/h, 18-22 g, frontal collision) in the air-bag knee-bar system occurred in the average less severe spinal column injuries than with the 3-point belt system. However, the most serious injuries (AIS 4) were observed in two air-bag tests.

3) In both systems, the injuries of the vertebral column were concentrated at the cervical-thoracic transition. The injury pattern with the 3-point belt system obviously resulted from an anteflexion; with the air-bag knee-bar system from a retro-flexion.

4) If the kinematic is described by the parameter displacement, angular velocity and angular acceleration, no homogeneous differences of the systems can be derived from the mean values of these magnitudes.

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This paper is kindly dedicated to Prof. Wolfgang Schwerd, Würzburg, on the occasion of his 60th birthday.