LOADING AND LOCATION OF RIB FRACTURES IN SIMULATED 90-DEGREES CAR/CAR SIDE IMPACTS WITH POST MORTEM HUMAN SUBJECTS

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ABSTRACT

The paper rewiews 58 simulated 90 degrees car/car side impacts with post mortem human subjects (PMHS). The collision velocity amounted 40,45,50 and 60 km/h, the situation of the belted near-side passenger was simulated. PMHS in the age range of 19 to 65 years were used. Accelerations (1-axial and 3-axial according to the 12-accelerometer array) were measured at the thorax of the PMHS.

The mean values of the acceleration maxima of the locations of lower sternum, 8th rib impact side, 12th thoracic vertebra are higher than the corresponding values of the locations of upper sternum, 4th rib impact side and at the 1st thoracic vertebra.

Only in 8 of the 58 conducted tests no rib fractures occurred. In the remaining 50 tests 1 up to 30 rib fractures were observed.

The number of rib fractures is on one hand depending of the age of the PMHS, on the other hand of the impact severity. The rib fractures predominantly concern the front- and rear region of the impacted body part and more rarely the far-side body region. Fragment fractures at the impacted body region and fractures at the far-side body region occurred in older PMHS.

The most predominantly occurring fractures were incomplete and without dislocation. Fractures with transfixing of the parietal pleura and the lung rarely happened.

In cases with numerous rib fractures mostly the 2nd to 9th rib of the impacted body region was concerned.

By including the film analysis, the injury mechanism is investigated, connections of the load severity and thorax injuries in dependence to the age of the PMHS are examined.

INTRODUCTION

In the 90 degrees car/car lateral collision in the area of the passenger compartment the thorax of the belted near-side occupant is directly concerned by the intrusion of the car side. Dependent of the collision severity, rib fractures occur at the side of the thorax exposed to the intrusion. Because of the loading asymmetry and higher age additional rib fractures occur at the far-side of the thorax.

This is confirmed by real accident investigations, accident reconstructions and simulations (9,10). In 58 conducted 90 degrees lateral collisions with PMHS the MAIS was determined by the thorax injury severity in 57 % of the cases, thereby the rib fractures were decisive.

In real accident analyses (7,11) as well as in experimental studies of lateral collisions (6) up to now the location of rib fractures were not investigated in detail.

The aim of this paper is to analyse rib fractures according to the location, the kind, the number, the age of the PMHS, the collision severity and the loading.

TEST SUBJECTS

58 human male and female PMHS in the age range of 19 up to 65 years were used as test subjects (Tab. 1). The test subjects were located in the position of near-sided car passengers and restrained with a 3-point belt.

Tab. 1: Test matrix according the impact velocity and age of the subjects.

IMP.VELOCITY (km/h)	(n)	AGE (years) max.	min.	mean
40	9	65	24	41
45	20	64	25	42
50	24	63	21	39
60	5	50	19	32

METHOD

Striking vehicle:
The striking vehicle was a car, the front of which carried a special deformation element (3). The deformation behaviour of this element corresponds to the front structure of a middle-class European car at a frontal impact (2). Each element was only used for one test. The mass of the car amounted 950 kg and was accelerated by means of a falling weight. The velocity of the striking vehicle amounted 40,45,50 and 60 km/h.

Struck vehicle:
An Opel Kadett body-in-white, mounted onto a movable platform (dolly) was used as the struck vehicle (3). The mass of the

struck vehicle, consisting of dolly, car-body, seat, test subject and supplemental mass also amounted 950 kg. The vehicle was impacted under an angle of 90 degrees and was used for both sides; the velocity of the struck vehicle was 0 km/h.

MEDICAL INVESTIGATION

The external and interior injuries of the thorax were documented by means of a word protocol. Furthermore, a skeleton sketch with the location of the rib fractures was made. By that, on each thorax side 10 regions were defined (Tab. 2). Five types of fractures occurred (incomplete, without dislocation, with dislocation, comminuted, transfixing of the parietal pleura or of the lung). The injury severity was scaled in accordance with the AIS 1985 (1).

Tab. 2: Regions to define the location of rib fractures.

Reg.	1: paravertebral	6: up to front axil.line
	2: up to paravertebral	7: up to medioclav.line
	3: up to med.scapul.line	8: cartilage-bone trans.
	4: up to rear axil.line	9: cartilage
	5: up to med.axil.line	10: parasternal

RESULTS

Deformation at the outside of the impacted vehicle

The remaining deformation of the vehicle's lateral side is shown in Fig. 1 for the individual velocity groups. The deformation lines of the individual velocity groups correspond to the medium deformation of several individual tests. As expected, one can recognize that the deformation in the average increases with the velocity in all three measuring point levels.
No difference of the side of the struck vehicle was noticed between the right and left impacts, therefore the results of the left and right-side impacts are summarized.

Impact velocity of the intruding car-side to the thorax

In the present collective the impact velocity of the intruding lateral car-side to the thorax was evaluated by integration of the measured acceleration at the middle of the door. In the so determined velocity-time-history the velocity value was read in the moment of the start of the acceleration signal of the 4th rib impact side. From this value the velocity of the dolly was subtracted at the time considered.

The inclusion of further lateral collisions (EUROSID- tests (4)), whereby the velocity was not only evaluated from the acceleration but also directly measured, leads to the conclusion that the collision velocity of the intruding lateral car-side against the thorax amounts Δv = 30-40 km/h.

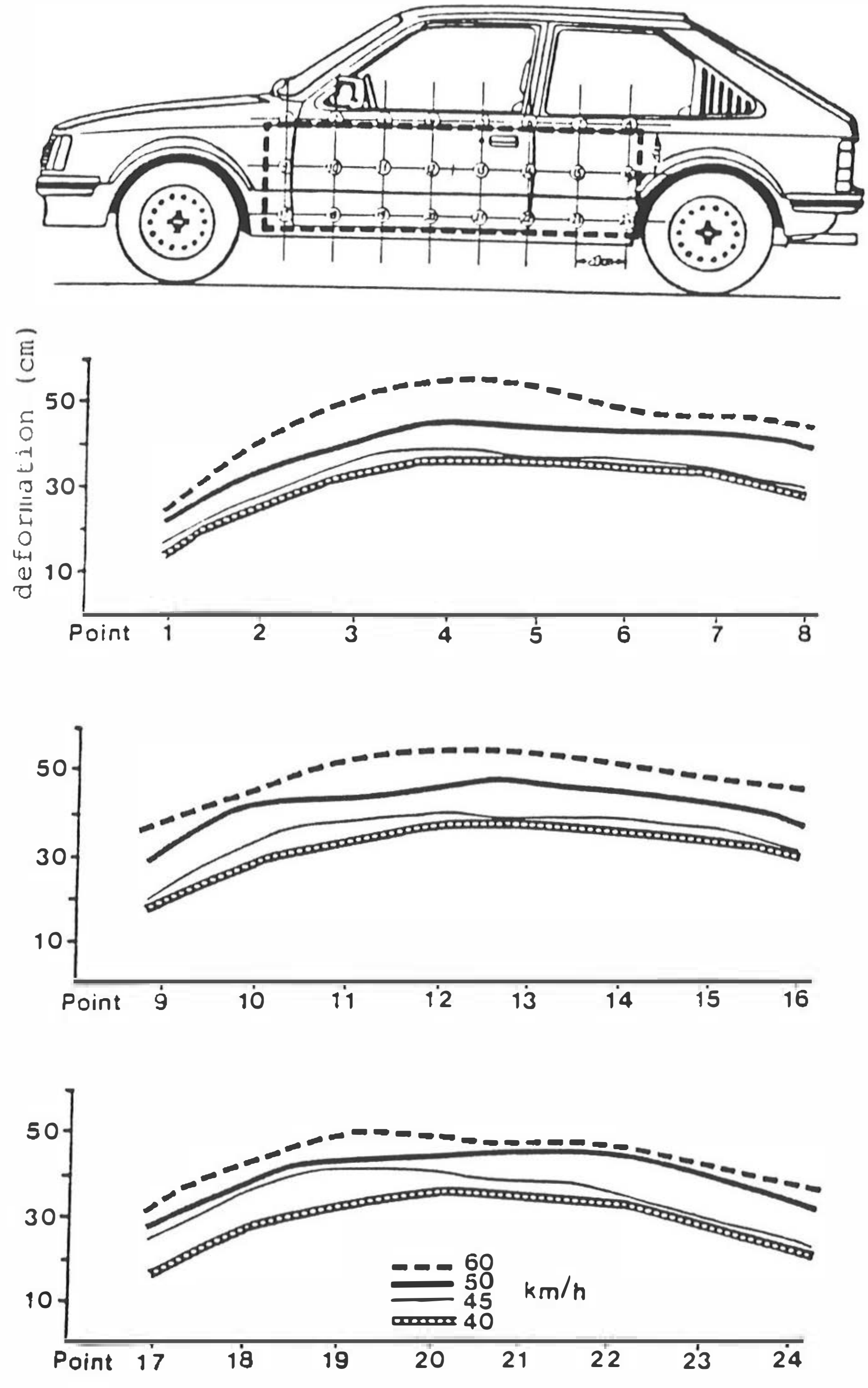

Fig. 1: Permanent deformation of the impact zone in 3 horizontal planes (as illustr. at top) according the impact speed (40 km/h: 9 tests, 45 km/h: 14 tests, 50 km/h: 21 tests, 60 km/h: 3 tests).

Thorax accelerations

Fig. 2 shows the mean values and the standard deviations of the 3 ms acceleration values for the 4th and 8th rib of the impacted side, lower and upper sternum as well as for the resultant acceleration of the 1st and 12th thoracic vertebra classified according to the collision velocity. The illustrations show that in all velocity groups the 8th rib in the average has higher 3 ms values than the 4th rib. Similar behaviour is observed for the measuring locations at the lower sternum and the upper sternum as well as for the resultant of the 12th thoracic vertebra to the 1st thoracic vertebra. Furthermore, the expected increase of all measuring locations according to the velocity was noticed.

Viscous Criterion (VC) and Thoracic Trauma Index (TTI)

Fig. 3 shows the mean values and the standard deviations of the VC (5) evaluated from the acceleration at the 8th rib, impact side and the TTI (6). The illustration indicates the expected increase of the VC as well as of the TTI with increasing collision velocity. This increase is steeper in the velocity group from 50 km/h to 60 km/h.

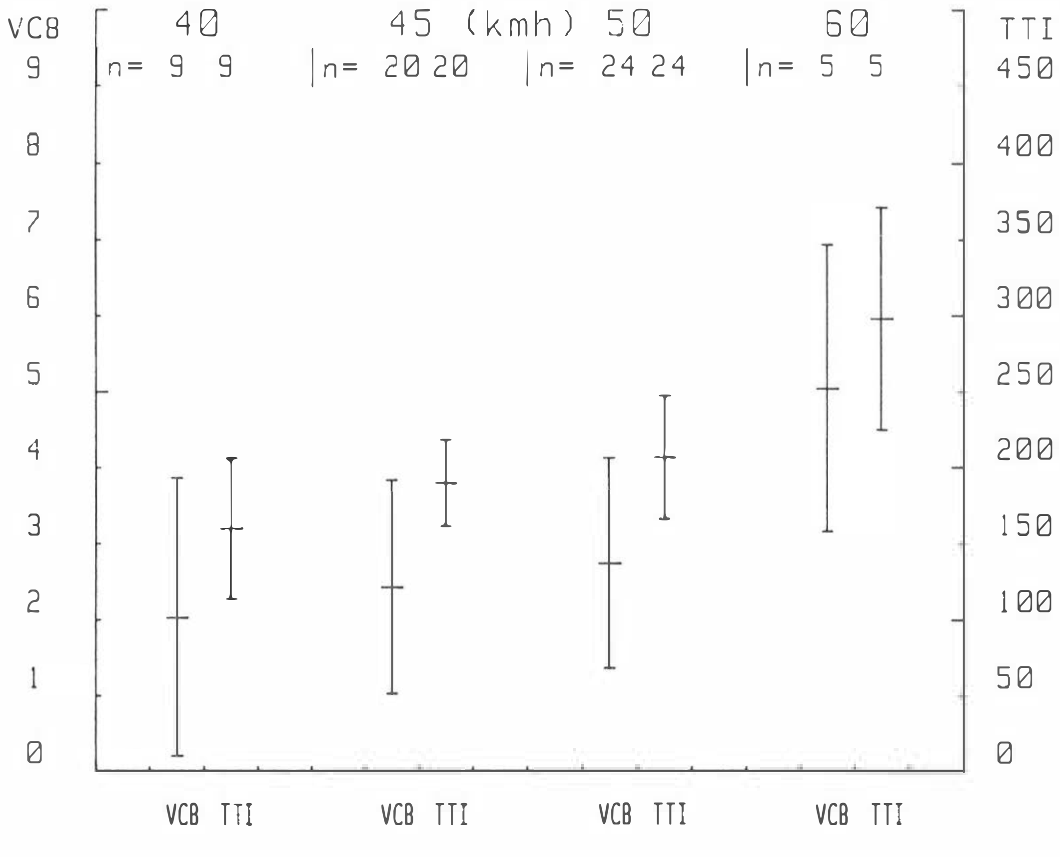

Fig. 3: Mean values and standard deviations of VC8 and TTI according to the collision velocity.

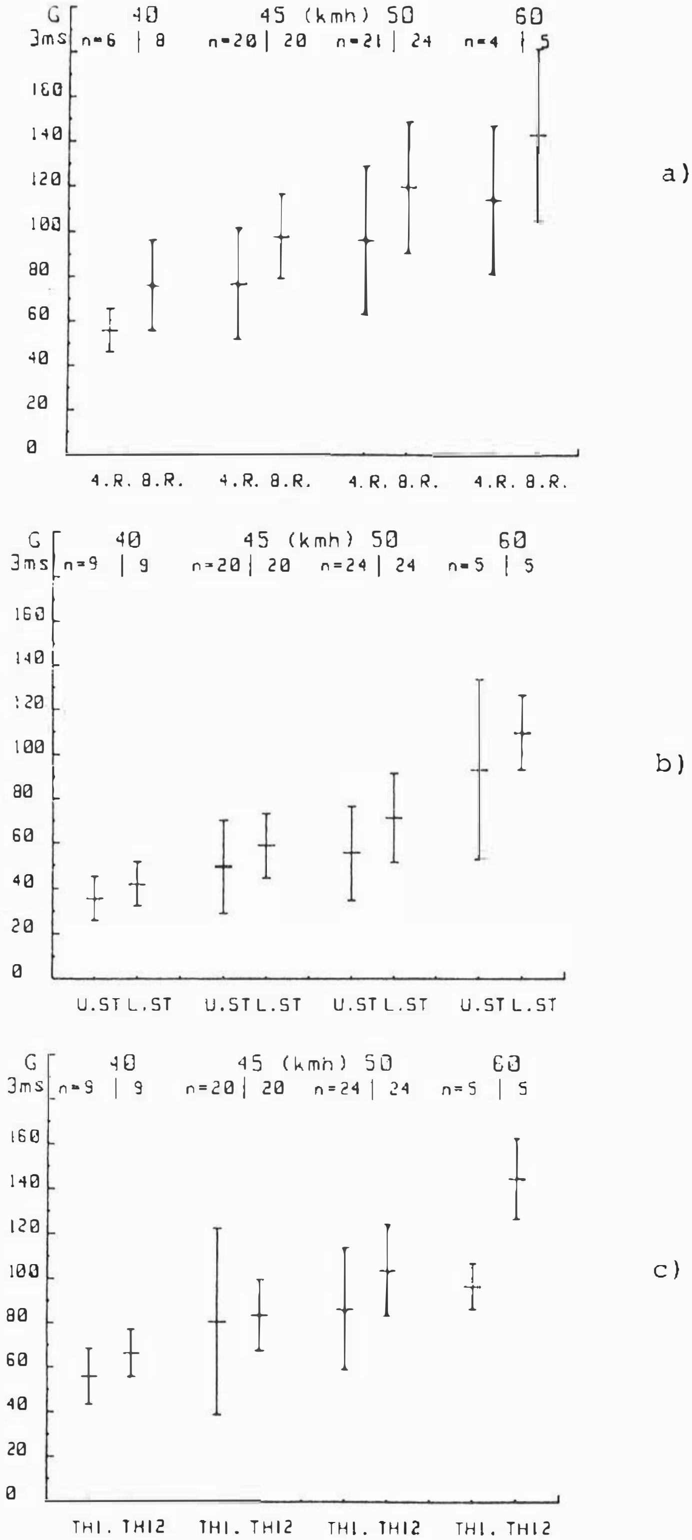

Fig 2: Mean values and standard deviations of the 3 ms-acceleration values according to the collision velocity.
a) 4th and 8th rib impacted side;
b) upper sternum, lower sternum;
c) resultant acceleration 1st and 12th thoracic vertebra.

Thorax injuries

Rib fractures were the most frequent injuries observed; predominantly occurred fractures without dislocation and incomplete fractures. Fractures with transfixing of the parietal pleura or the lung rarely occurred, and in one case a comminuted fracture.

Only in 8 of the 58 tests no rib fractures occurred (2 tests with 40 km/h, 2 tests with 45 km/h, 3 tests with 50 km/h, 1 test with 60 km/h). In one test a lung contusion occurred and in another a scapula-clavicula-joint bursted open. In 3 cases the clavicula of the impacted body side was fractured.

Fig. 4 shows the number of rib fractures classified according to the age of the test subjects and the collision velocity. For all collision velocities the expected increase of the number of rib fractures can be noticed with increasing age. The correlation coefficients lay between 60 % and 90 %. On the other hand test subjects with the same age show scatterings in the number of rib fractures which also has been observed in frontal collisions with belted PMHS (8).

The evaluated regression straight lines show a noticeable steeper increase with increasing collision velocity.

The injury severity according to AIS of the thorax was nearly almost determined by the number of rib fractures. Tab. 3 shows the frequency distribution of the AIS values classified according to the velocity.

Tab. 3: Frequency of AIS-Thorax according the impact velocity

IMP.VELOCITY	FREQUENCY AIS-THORAX				
(km/h)	0	1	2	3	4
40	2	1	2	1	3
45	2	-	1	5	12
50	3	-	2	4	15
60	1	-	-	-	4

A thorax AIS 4 (flail chest) was supposed with 15 rib fractures. Pleura transfixings or lung injuries can lead to an AIS 4 value of the thorax injury severity at a lesser number of rib fractures. This occurred in 3 cases with rib fractures in the investigated collective.

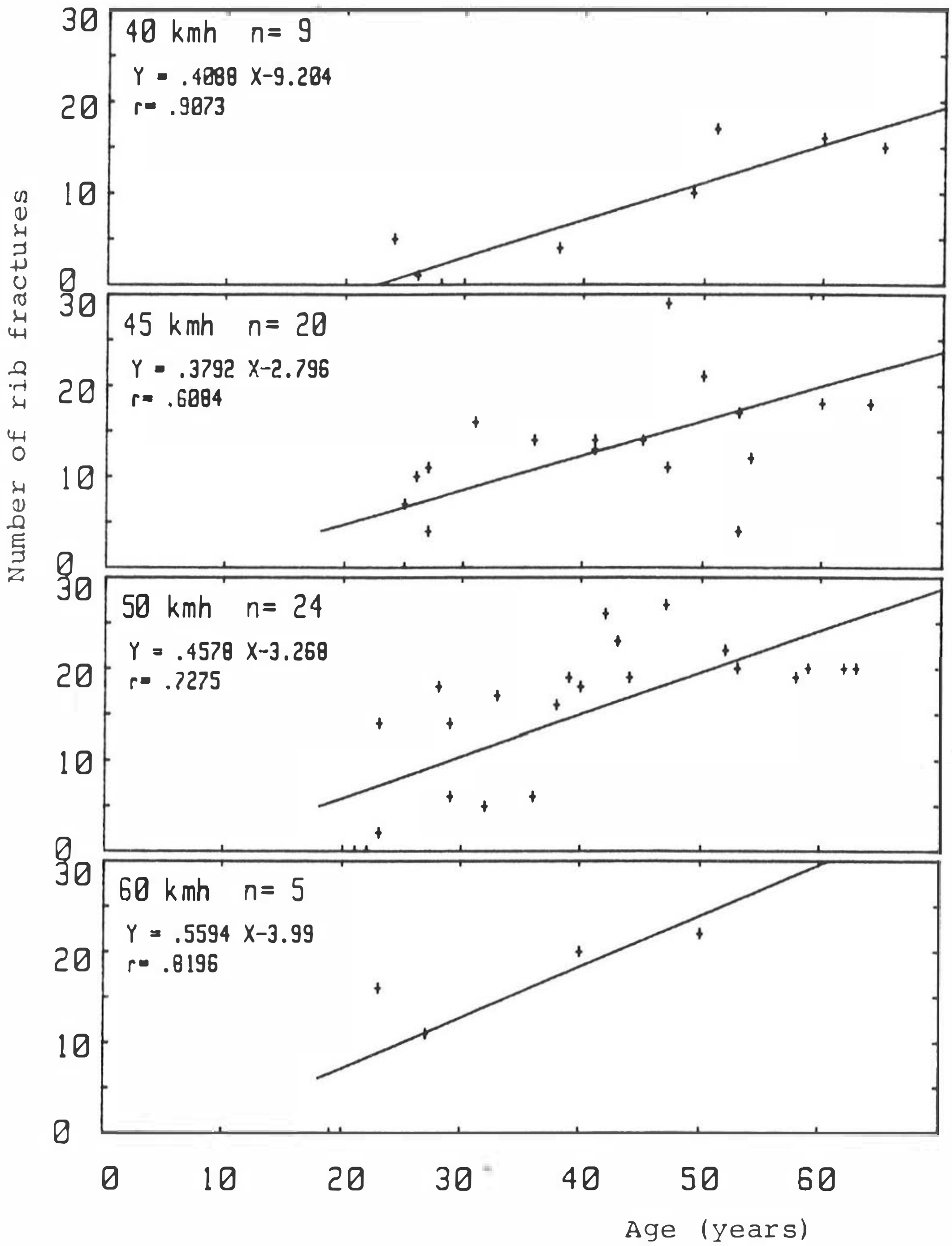

Fig. 4: Number of rib fractures classified according to the age and the collision velocity.

Injury mechanics of the rib fractures

Decisive for the injury mechanics of the impact-side rib fractures is the force influence to the thorax caused by intrusion of the car side. Considerable deformations at the near-side thorax side occur, as also seen in film analyses, causing maximum loading strains in the fracture area of the ribs.

For the more rarely rib fractures at the far-side of the thorax, above all the transmission of loading strains to the far-side of the thorax is taken into consideration as injury mechanism, especially at asymmetrical thorax load (e.g. the rotation of the test subject during the collision phase).

Frequency of the fractures at the ribs 1-12

If one considers the frequency of the fractures at the single ribs 1 to 12 after summarizing the right and left thorax side, a distribution as illustrated in Fig. 5 related to the velocity range of 40 km/h to 60 km/h occurs.

In more than 50 % of the cases the ribs 2 to 9 were fractured; most frequently (about 80 %) fractures occurred at the ribs 3 to 6.

The lowest frequency of fractures is recognized for the 11th and 12th rib with 15,5 % and 5,2 %. A fracture of the 11th rib occurred in single cases for all velocities, the 12th rib was only fractured in 3 cases (two times at 45 km/h and one time at 60 km/h).

An evaluation of the location of the rib fractures relatively to the front and rear side of the thorax in the velocity range 40 km/h to 60 km/h is shown in Fig. 6 for the investigated collective.

It is noticeable that the most frequently fractured ribs 3 to 6 show nearly the same fracture frequency in the rear and frontal thoracic region. Above the 3rd and below the 6th rib, however, the fractures at the rear side of the thorax are predominant. For anatomical reasons, at the ribs 11 and 12, only fractures at the rear-side of the thorax can occur, because both ribs don't reach over the medium axillary line to the front. Also the extension of the ribs 8 to 10 reaches less far to the front side as the ribs lying above.

These three ribs are connected by a cartilaginous part with the costal arch and have, in opposite to the ribs 1 to 7, no direct connection with the sternum. This leads to the conclusion that for the ribs 7 to 10 under lateral load, lesser bending strains are to be expected in the front thorax. A similar behaviour exists for frontal loads.

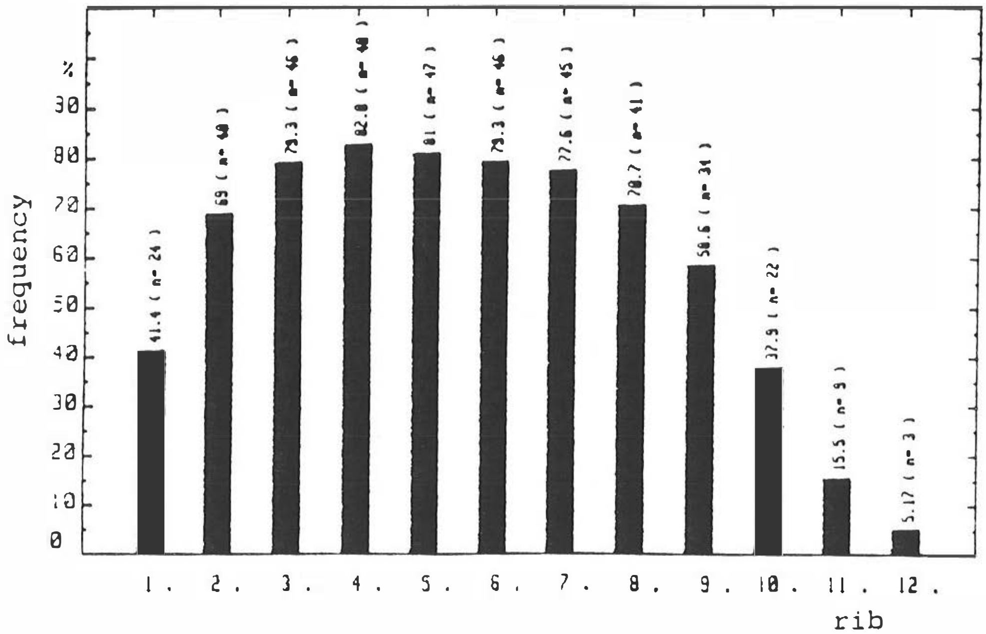

Fig. 5: Frequency of the fractures at the ribs 1 to 12 independent of the impacted side related to the velocity range of 40-60 km/h.

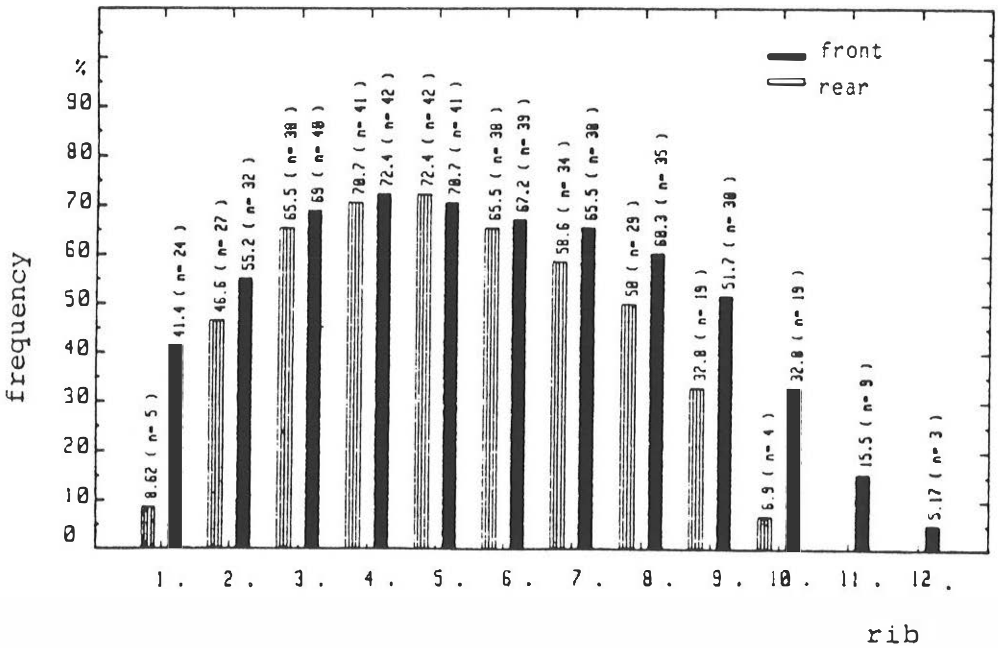

Fig. 6: Frequency of the fractures at the ribs 1 to 12 independent of the impacted side relativ to the front and rear side of the thorax in the velocity range 40-60 km/h.

Frequency of rib fractures according to the location

Fig. 7 shows the frequency according to the location of the fractures of each rib in various thorax regions in the velocity range 40-60 km/h. Ten regions in the impacted thorax-side were defined in order to record the exact location of the rib fractures. They are explained in the illustration text.

Most frequently rib fractures in the regions up to the frontal axillary line (region 6) and up to the paravertebral region (region 2) occurred. The ribs 2 to 9 are mostly concerned. whereas the 5th rib in the region up to the frontal axillary line showed the highest frequency (was fractured in 31 PMHS). Somewhat smaller frequencies were observed in the paravertebral region (region 1), the slightest frequencies in the regions from the medio-clavicular line (region 7)up to the cartilage (region 9). In no case a parasternal fracture occurred (region 10).

DISCUSSION

The analyses of the acceleration values at the 4th and 8th rib has shown that the values are about 28 % higher in the 8th rib. This can be explained by the anatomy of the thorax which is characterized by a form getting broader downwards.

The 8th rib is therefore closer to the intruding car-side than the 4th rib and is therefore loaded earlier and stronger. Also the accelerations at spinal column and sternum correspond with the conclusion that the loading of the bony thorax is lesser in the upper than in the lower part.

Additionally, the intrusion maximum is higher at the level of the 8th rib than at the level of the 4th rib; also a reason to expect a higher load at the 8th rib. Differences in the seating height and the individual thorax formation lead to an overlapping of the anatomically caused portion of the loading differences, for the part determined by the intrusion geometry. Therefore and for other reasons of the individual anthropometry, significant overlappings of the loading values at the 4th and 8th rib were observed.

In these tests, the impact velocity of the intruding side to the thorax amounted 30 to 40 km/h (v) in the area of the middle of the door (intrusion maximum). This loading velocity of the near-side passenger was also evaluated by real world car/car lateral impacts by Thomas et al. (11).

In nearly all tests (86 %) rib fractures occurred. They were mainly found at the near-side and, with exceptions also at the far-side of the thorax. The detailed analyses showed that above all, the ribs 2 to 6 were concerned; a similar distribution was described by Thomas et al.(11). In the present

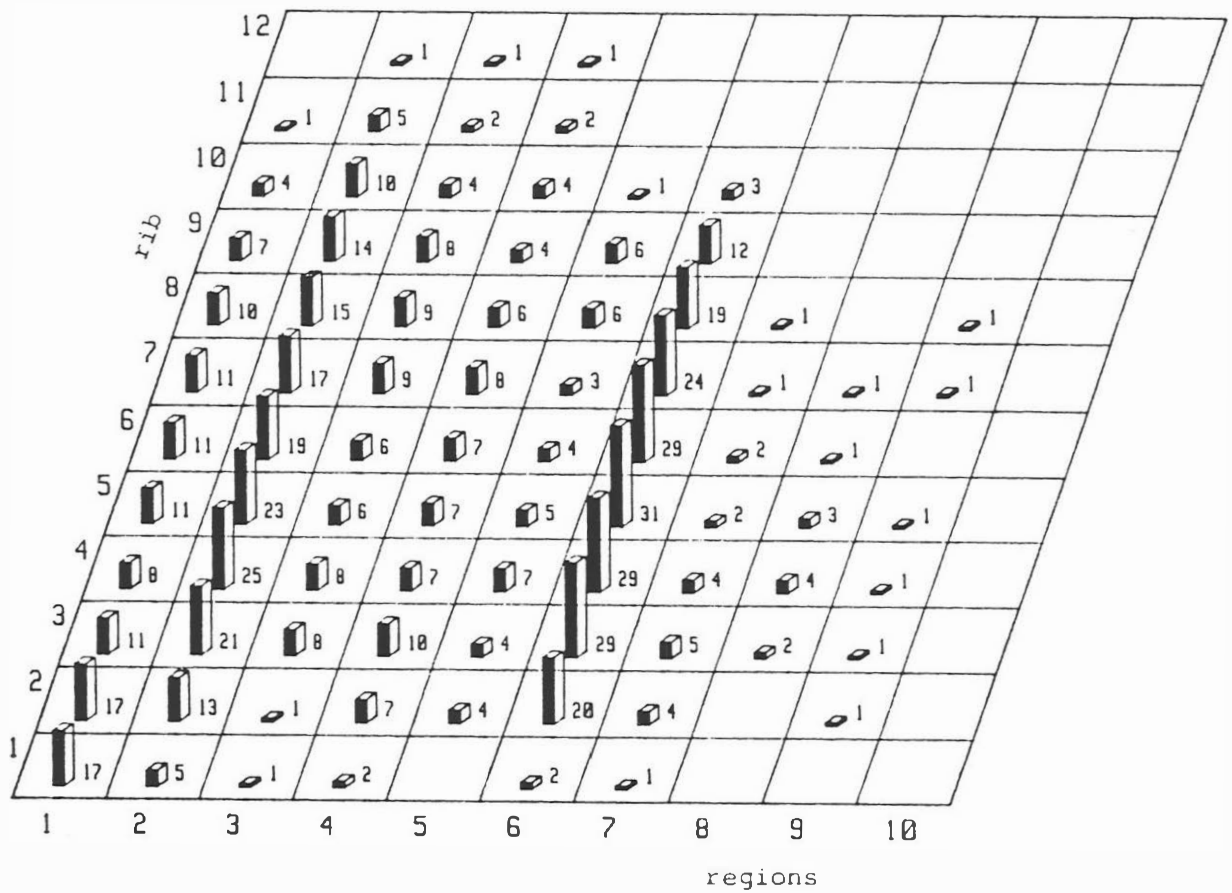

Fig. 7: Frequency according to the location of the fractures for each rib in various thorax regions in the velocity range 40-60 km/h (number in the squares means absolute frequency).

Reg. 1: paravertebral	6: up to front axil.line
2: up to paravertebral	7: up to medioclav.line
3: up to med.scapul.line	8: cartilage-bone trans.
4: up tc rear axil.line	9: cartilage
5: up tc med.axil.line	10: parasternal

collective, the 4th rib was most frequently fractured (83 %); in the paper of Thomas et al. (11) it was the 5th rib.

At the 8th rib, where as already mentioned, higher loads of about 28 % excess were measured, only 70 % of the cases showed fractures. This contradictory behavior however also finds an explanation in anatomical reasons, determinant for the biomechanical reaction: the 4th rib (as well as the ribs 1 to 7) stands, above a more or less ossified cartilaginous part, in direct connection with the sternum and produces a deformation of the thorax in x-direction at a lateral load. Thereby maximum loading strains in the area of the frontal and rear thorax regions occur. According to that, these are the regions where rib fractures are to be expected and were actually observed. The anatomical situation of the 8th rib is different compared to the 4th rib. The 8th rib generally has no direct connection to the sternum. It reaches up to the cartilaginous part of the 7th rib, and sometimes to the 6th rib, and forms with those two ribs the costal arch and is therefore finally connected with the sternum. At the 8th rib lower bending strains exist as in the 4th rib because of the connection of a longer area with a bigger deformation tolerance. Therefore, despite of higher acceleration values a smaller number of fractures of the 8th rib was observed. The analysis of the fracture location at the front and rear thorax confirms the biomechanical explanation.

At the thorax front, where a bigger deformation tolerance can be expected because of the longer connection of the cartilaginous part, rib fractures occurred more rarely than at the rear side. At the rear, the 8th rib is conncected with the spinal column in the same manner as the ribs lying above (especially also the 4th rib).

CONCLUSIONS

1. The topographical distribution and frequency of rib fractures in the lateral collision show a characteristical pattern which is determined by the anatomy and the intrusion geometry.

2. The frequency of rib fractures of the 4th and 8th rib is not proportional to the loads measured at these ribs.

3. In the prediction of the thorax injury severity and the using of rib accelerations these circumstances have to be considered.

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