CONTRIBUTION TO DEFINING THE HUMAN TOLERANCE TO PERPENDICULAR SIDE IMPACT *

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The protection of the passengers of private cars which are struck side-on is a major problem as yet unresolved. Too little data is available on the human tolerance to side-on impacts. The behaviour of conventional impact test dummies differs too much from the behaviour of the human. Lastly, private cars do not possess anv veritable padding, the effectiveness of which could be studied by means of multi-disciplinary surveys of accidents.

The present study uses the results of the free fall of eighteen human subjects. These strike rigid surfaces or surfaces covered with shock-absorbing materials side-on at the thorax and pelvis. These tests were reproduced with Hybrid II dummies. A contribution will be made to knowledge of human tolerance to lateral impacts, the desirable characteristics of a dummy for side-on impact and for protection paddings.

This work follows from that already published (1)(2) concerning lateral impact against the head and has been conducted with the same mental approach.

EXPERIMENTAL METHODS

The subject or dummy is hung and then released in order to drop freely against the side, in the position shown in figure 1. The side struck varies for reasons related to the experimental conditions.

Two configurations for the arms with relation to the trunk were used.

In the first position, the arm on the side struck lies at only a slight angle to the thorax, in a position similar to that of a passenger in a car. This results in a fairly realistical interference between the arm and the thorax.

In the second position, the arm on the side struck is at an angle of about 90° to the thorax and does not compress it when the impact occurs.

(*) This research was performed with the collaboration of Anatomy Laboratory of the Biomedical Research and Teaching Department (U.E.R) of René Descartes University - Paris - Pr Delmas.

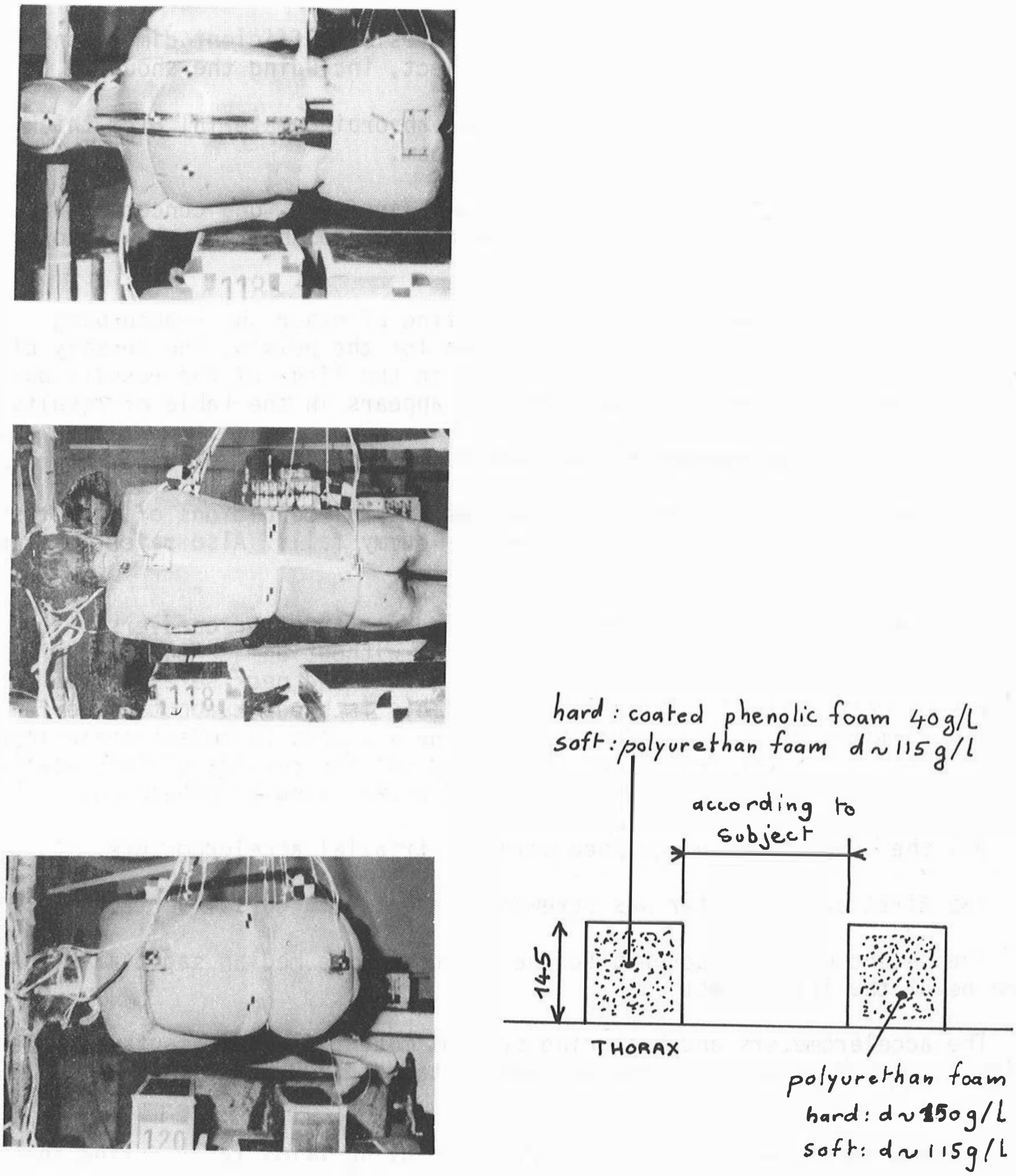

Figure 1 - typical dummy and subject positions, before impact.

Depending on the particular test, the following are the types of surface struck:

a) a rigid plane consisting of metal plates of sufficient dimensions to extend beyond the complete trunk of the subject, including the shoulder.

b) The same plane, covered with a shock-absorbing material 8 cm thick. This material was a semi-rigid polyurethan foam.

c) A set of two rigid but separate plane surfaces, one concerning the thorax and the other the pelvis. This combination does not directly involve the shoulder.

d) A set of two parallelepipeds consisting of other shock-absorbing materials , one for the thorax and the other for the pelvis. The density of these shock-absorbing elements was modified in the light of the results obtained in the initial tests: a modification appears in the table of results.

In this last configuration, the shoulder is not struck directly.(*)

The tables of results indicate the experimental conditions of each test and the heights through which the subject or dummy falls. Also refer to figures 2 and 3.

The subjects consist of fresh non-embalmed cadavers or cadavers which have already been subject to a head impact but without damage to the thorax, as reported in (1)(2). In the later case, the head and neck were removed and the tissues were treated to stabilise them. This is brought about by perfusion with a mixture of water, formol and china ink used to detect brain injuries during head impact tests, but in no case can the results of this stabilisation of the tissues onto the skeleton be assimilated to embalming.

All the subjects were equipped with two triaxial accelerometers.

The first accelerometer was screwed to the fourth dorsal vertebra.

The second was also screwed to the sacrum in the median sagittal plane, 90 mm below the iliac crests.

The accelerometers and measuring systems meet the requirements for measuring acceleration of the thorax of Safety Standard 208 (SAE J 211 b and 180 Hz).

Deflection of the thorax was measured by using films taken during these tests (with a Stalex 1000 frames per second camera).

During the tests made against a rigid surface, the relative movement of sighting marks on the thorax seen from the back was observed.

(*) described on figure 1

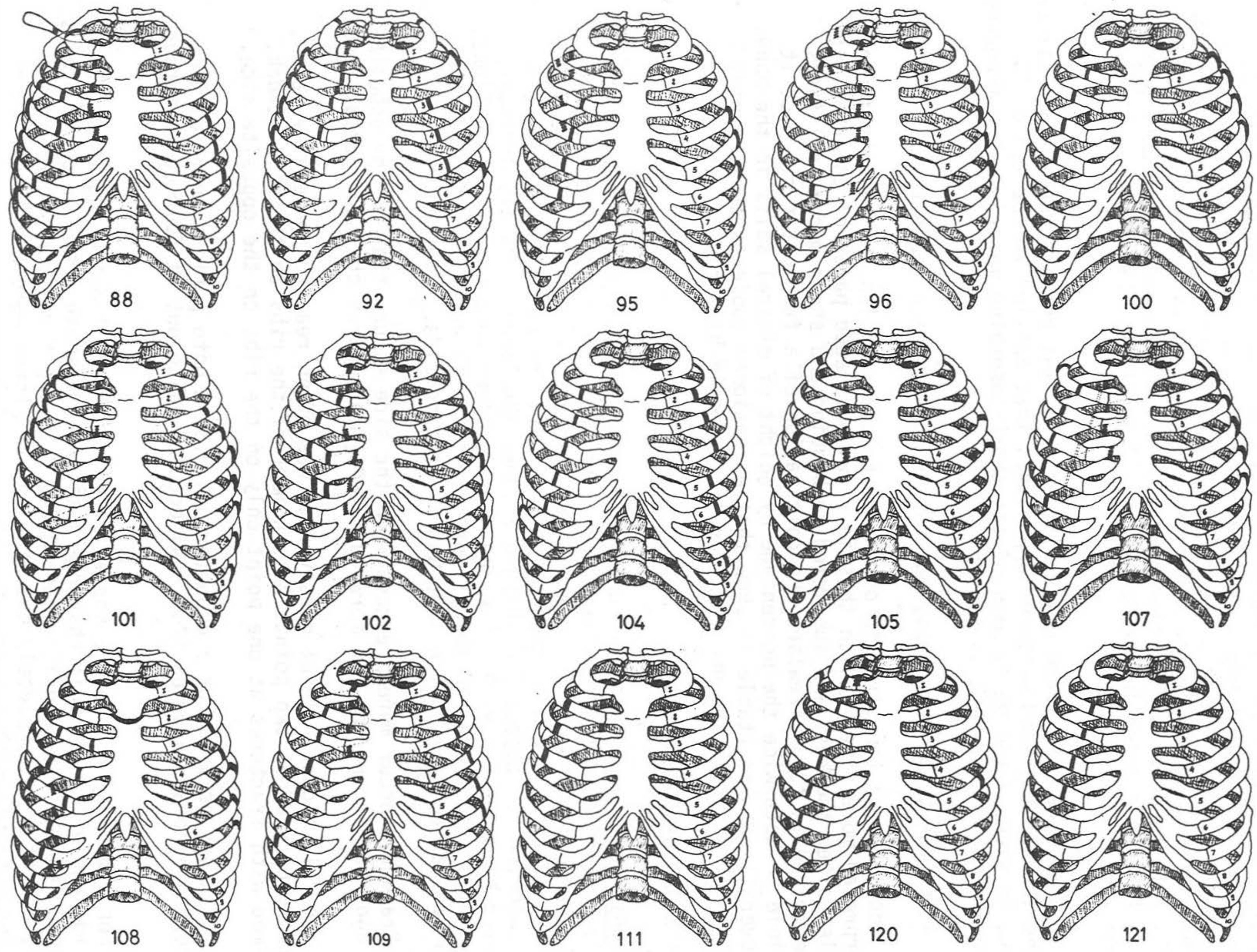

Figure 3 - thorax injuries after tests

During the tests against a shock-absorbing material, the penetration of the thorax into the material makes it impossible to observe the reference plane directly. This is why a cylindrical rod was used inserted cross-wise through the thorax. One of its ends was attached to the contour of the thorax of the side struck, while the other carried sighting marks the movement of which, with relation to the thorax, was observed. The deflection considered was that which occured in the mean plane of the thorax between the third and fourth ribs.

A load measuring plate using Kistler cells was beneath the surface struck by the thorax. The load measured approaches that applied to the top of the trunk, in view of the small mass of the shock-absorbing material. The frequency F_H in this measurement is 600 Hz.

After the test, an autopsy was carried out on each subject.

Knowledge ot the strength of their skeleton enables the results to be interpreted more finely. With this in view, undamaged parts of the ribs were sampled after the test and subjected to bending and shear mechanical tests as described in (3). Likewise, the calcination of a fragment of rib made it possible to determine the percentage by weight of mineral salts in the bone. The overall results (table 1) show that exceptional subjects the skeletal strength of which is too great or too small, would bias the results.

RESULTS AND DISCUSSION

Injuries - On the thorax, under the experimental conditions brought about, a great many rib fractures were observed. Subject 88 also presented a broken collar bone on the impact side; this subject is one of those which struck a surface involving the entire shoulder. Fracture of the sternum was also observed in subject 108. Figure 3 shows the location of the fractures revealed by the autopsy. All the impacts are shown as occuring on the right hand side of the thorax in this figure; certain rib cages were therefore shown schematically with the left and right hand sides inverted.

Fractures occur more frequently on the side struck than on the opposite side and more occured on the forward face of the thorax than the dorsal face.

The "flail chest" level of severity was often reached; generally, also, fractures occured at two points on a number of the ribs on the side struck, combined with fractures at one point only on the ribs on the opposite side.

No injury occured for a drop through 0.50 m onto a rigid surface, and unacceptable thorax injuries (AIS = 4) occured twice out of four drops through 1 m.

For a drop of 2 m onto a shock-absorbing material measuring 14 cm along the side and with dynamic characteristics very remote from the optimum ones, the injuries were of severity index AIS $\leqslant$ 3 in the three corresponding subjects, one of them completely escaping injury. These were the least severe injuries obtained with a shock-absorbing material.

At the pelvis (table 2), no injuries occured in the majority of cases.

Table I - Results of rib testing

Subject No	Static bending tests			Static shearing tests		c/m mineral salts
	energy J	F max daN	deflection mm	2 W J	2 F max daN	%
104	0.21	17.6	8	2.8	101	29
105	1.05	17.2	12	1.7	46	27.5
109	0.44	6.6	16	0.8	31	21.5
111	1.49	16.8	16	2.0	64	24
118	1.0	16.5	8.5	2.9	74	30
119	0.55	12	8.5	0.9	39	26
92	-	-	-	-	-	37
100	1.80	22	-	2.1	122	37.5
101	0.71	10.4	12	2	86	26
88	0.23	25.1	-	1.2	55	32
95	-	-	-	-		27
96	-	-	-	-		27
102	0.91	31.8	4	4.6	120	34
107	0.25	6.4	5.7	1.	47	27.5
108	0.74	13.3	14.5	2.2	59	27
120	0.96	17.	9	2.2	66	26.5
121	1.4	26.	8	3.2	84	32.5
122	0.3	15.4	3	4.9	163	40.5
	Averages - from 28 previously tested male subjects					
A	0.8	20	6.5	2.6	75	26.5
	Averages - from 5 previously tested female subjects					
B	0.44	17	-	2.5	120	28

Table III - Measurements concerning thorax

Test No	fall height m	γ_R peak g	γ_R 3ms g	Gadd S.I.	Force max. (daN) measured/normalized	deflection %	AIS	arms position
			continuous rigid surface					
104	1.	62	55	187	590/690	30	4	displaced
105	1.	56	50	189	700/870	32	3	"
109	1.	34	29	62	- -	17.5	4	normal
111	1.	48	44	126	460/580	15	3	"
			2 separate rigid surfaces					
118	0.5	34	29	45	250/330	11	0	normal
119	0.5	27	26	33	240/360	20	0	"
			continuous padding - e = 8 cm					
92	2.	69	59	324	1090/ -	-	4	displaced
100	2.	54	51	209	630/770	-	4	normal
101	2.	42	38	131	800/1020	-	5	"
88	3.	84	65	436	950/ -	-	4	normal
95	3.	83	74	410	1240/ -	-	4	displaced
96	3.	≥ 78	-	688	1160/ -	-	4	"
			2 separate molded elements - hard					
102	3.	82	60	345	870/1100	-	5	normal
107	3.	75	70	392	640/940	-	4	"
108	3.	70	62	335	840/1100	-	5	"
			2 separate molded elements - soft					
120	2.	40	32	100	890/930	35	3	normal
121	2.	42	37	114	1020/1020	24	3	"
122	2.	44	40	147	560/780	22	0	"

This absence of injuries occured every time for the less severe tests. 3 m drops resulted in three fractures in six subjects.

The type of fracture which seems to appear the most often is a fracture of the pubial ischio and ilio branches on the side struck (involving little or no displacement). The corresponding AIS level is 2 or 3, depending on whether displacement occurs or not.

Relationships between thorax injuries and the measurements of acceleration - The results of measurements of the acceleration on cadavers are given in table 3. The maximum accelerations measured at D4 lie between 27 and 84 g. Clipping of the peaks of the curves for an interval of 3 ms reduces this bracket to 26 to 74 g.

Partial interference between the arm and the thorax probably reduces the acceleration when this interference occurs.

The unacceptable injuries obtained for the lowest acceleration (29 g during 3 ms and an AIS of 4) appeared in subject 109. This 68 years old female subject showed the lowest level of mineralisation in all subjects, as is shown in table 1 giving results of the rib tests. The same table also shows that this subject is amongst the weakest ones, in particular dissipating the least energy of all the subjects during the static shear test. It can therefore be eliminated from the analysis.

Aside from subject 109, the lowest level of acceleration accompanied by an AIS value of 4 is 38 g (subject number 101). The corresponding skeleton has mean strength within a reference sample consisting of all the subjects undergoing biomechanical tests. Their strength is well below that of a population of road accident victims.

The highest acceleration associated to an AIS of 3 is 50 g for subject 105, which, like subject 101, is a "mean" subject.

The results as a whole of the measurements of acceleration display no distinct relation between the maximum acceleration and the injuries (figure 2). One should not forget that the tests were made at several impact speeds, resulting in different application times for the accelerations and the loads. This represents an additional factor unconducive to this relation. It would therefore be unfounded at this juncture to situate the tolerance of the subjects within the 40-50 g, as one might be tempted to do so. A series of experiments under identical and realistical conditions is necessary to determine whether the maximum acceleration may or may not act as an indicator to the impact severity for the subject, this severity originating from phenomena other than the acceleration, which is only the material manifestation of their effects.

Correlevance with the dummies - The tests made under identical conditions with a Hybrid II dummy revealed considerable differences in the behaviour between the dummy and the human subjects.

In the event of impact against the shoulder, the loads are transmitted directly to the spine of the dummy. Nothing simulated the relatively flexible chain running from the humerus to the sternum via the shoulder blade and the

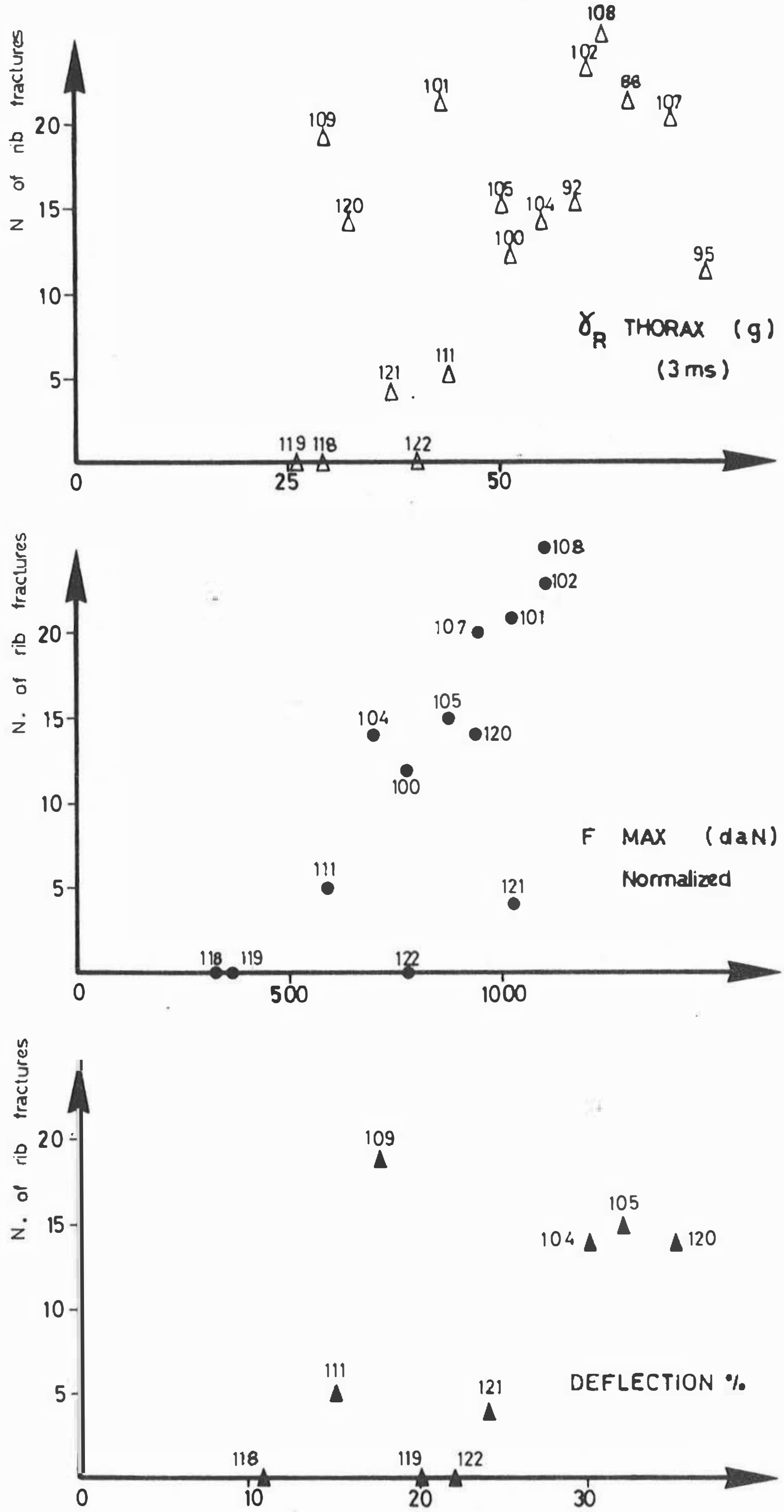

Figure 2 - Results of some measurements on subjects versus injuries

Table II - Anthropometric data and results concerning pelvis

Test No	fall height m	Age	Sex	Impact side	Weight Kg	Thorax breadth cm	Thorax depth cm	γ_R peak	γ_R 3ms	AIS	Pelvis injuries
against one continuous rigid surface											
104	1.	70	M	R	59	27	20	55	40	0	
105	1.	47	M	R	54	27	20	153	66	0	
109	1.	68	F	R	49	27	21	90	70	3	f. little displacement, R. ischio and ilio-pubic branches
111	1.	52	M	R	53	28	21	89	47	0	
against two separate rigid surfaces											
118	0.5	46	M	L	49	28	20	62	33	0	
119	0.5	52	M	L	41	25	20	34	30	0	
padding - continuous - e = 8 cm											
92	2.	69	F	L	-	25	19	82	50	2	f. R+L ischio and ilio-pubic branches
100	2.	34	M	R	56	28	18	44	38	0	
101	2.	41	M	R	52	26	20	110	77	0	
88	3.	71	F	L	-	20	17	65	60	0	
95	3.	55	M	L	-	28	23	120	105	3	f. little displacement L ischiopubic branch
96	3.	53	M	L	-	30	20	135	90	0	
two separate molded elements - hard											
102	3.	69	M	R	53	27	21	62	57	3	f. R iliopubic, f. R iliac wing, f. + displacement R cotyle
107	3.	55	F	R	42	26	17	77	66	2	f. ischio and iliopubic branches
108	3.	64	M	R	50	27	19	74	53	0	
two separate molded elements - soft											
120	2.	51	M	L	70	30	23	37	30	0	
121	2.	57	M	L	75	32	23	32	31	0	
122	2.	42	F	L	45	26	16	34	34	0	

f = fracture

collar bone. The loads recorded on the dynamometer plate at the top of the thorax are therefore much greater than those reached under similar circumstances on human subjects; as a result, the accelerations display a high peak of no signification.

In the case of impact of the side of the thorax of the dummy against a shock-absorbing material without any intervention of the shoulder, on the other hand, a considerable reduction in the accelerations of the thorax of the dummy compared to those of the human subjects can be observed. Possible explanations may be the differences in weight those this would appear to be inadequate (subject 121 weighs 75 kg); another explanation may be the difference in equivalent masses for the same weight, since a human, as opposed to the Hybrid II dummy, does not consist of parts practically solidly connected together, but of masses that are practically uncoupled, such as the entrails compared to the skeleton. The main reason, however, resides in the differences in the dynamic rigidity of the thorax of the Hybrid II and the human subjects and the ensuant ratios between these rigidities and those of the shock-absorbing elements used.

To illustrate this, subject 121, which weighs the same as that of Hybrid II depresses the shock-absorbing element against the thorax by 65 mm, whereas the dummy presses in almost completely along one side and by 115 mm in the middle. In contrast, the deflection of the half of the thorax struck of subject 121 located below the accelerometer, is 50 mm. The dummy displays very little corresponding deflection. The path of the accelerometer of the dummy is greater, since this accelerometer lies approximately on the side of the shock-absorbing element undergoing the most deflection.

It can therefore be said that the human subject and the Hybrid II do not undergo comparable tests, which is in agreement with Melvin (4).

fall height m	impacted area	id. cod. tests	Thorax γ_R peak	Thorax γ_R 3ms	Thorax Gadd S.I.	Thorax Force daN	Pelvis γ_R peak	Pelvis γ_R 3ms	Observations
1.	continuous rigid surface	104/105	51	47	193	1190	92	68	dummy without arm and "clavicle"
		109/111	106	54	248	2600	180	100	complete
0.5	2 rigid surfaces	118/119	17	16	15	840	78	58	complete - no shoulder impact
3.	8 cm padding	88	132	85	556	2400	116	93	complete
3.	" " "	95/96	64	60	335	1000	60	55	without arm and "clavicle"
2.	" " "	92	55	52	220	860	52	51	complete - broken "clavicle" during test
2.	2 molded elements - soft	120/121 122	27	26	80	1240	54	52.	complete - no direct shoulder impact
3.	2 molded elements - hard	102/107 108	53	49	-	-	67	63	complete. But shoulder "bottomed out" after impact

Table IV - Results of measurements with dummies

Injuries and loads applied to the thorax - A priori, the differences in the duration and method of application of the loads resulting from testing conditions render any generalisation of the results impossible (table 3). Furthermore, the individual variations of the weight of the subjects increase the spread of the values of the loads.

In order to reduce the effect of the differences in weight in the analysis, we have applied the formula (*) published by Eppinger (5) based on application of dimensional analysis (6). This formula was not established with restricted conditions as to the method of application of the loads on the subjects. We propose to call in what follows the "normalized force", that resulting from application of this formula in order to fictitiously correct the weight of the weight of the subject to 75 kg (dummy weight)

We can then write that the subject without a fracture having supported the highest load on the thorax has in fact supported a normalized load of 780 daN (subject 122, a robust subject) and that the severity of AIS 3 corresponding to the highest load is that of subject 121, also fairly robust, on which a force of 1020 daN (true or normalized) was exerted.

Conversely, the severity of AIS 4 attained with the lowest load measured on the plate is a normalized 690 daN.

These load figures are close to the values actually applied against the rib cage alone; at the moment of maximum load, the arm is inserted in front of the cage or has been stopped for some time.

Injuries and deflection of the thorax - The results are given in fig. 2 The deflection considered is the relative deflection, referred to the initial width of the thorax. Subject 109 is different from the remainder, and has al- been eliminated following the observations concerning accelerations. The aspect of the cluster would suggest a correlation between the injuries and the deflection, but subjects 118, 119 and 122 lie below the threshold of appearance of fractures and should be plotted further to the right on the figure.

We shall confine ourselves to stating that 30 % of the relative deflection of the thorax occurs in conjunction with unacceptable injuries. These findings agree with those of Stalnaker (7).

Use of the quantity δ_r (width/thickness of the thorax) defined as the "morphology factor" (7) did not reduce the spread of the results.

Injuries of the pelvis and measurements of the acceleration - The subjects displayed no injury up to 50g /3ms, regardless of the test concerned. If one considers the group of subjects falling onto paddings from a height of 3m, i.e. at a velocity of almost 27 Km/h on impact, one finds a mean maximum acceleration for 3ms of 72g, together with a mean AIS of 1.33 for six subjects. The Hybrid II dummy gives 68.5g. Since the pelvis distorts only little, the measurements of acceleration are much more coherent for the pelvis, whether in the cadavers or the dummies.

(*) $F_{Norm.} = F_{measured} \times \left[\frac{75}{\text{true weight}} \right]^{2/3}$

In view of the greater strength of the victims involved in accidents (compared to that of the cadavers), of the absence of injuries of AIS$>$3, and of low average AIS obtained, it would seem valid to accept an acceleration of 80g on the Hybrid dummy as protection level criterion.

However, this number can only be withold when associated with a padding and an important enough ΔV.

For an impact associated to a lower ΔV, human tolerance in g's is probably higher; without padding, the dummy indicates more g's than a human subject. We would contemplate then higher values for a protection criterion.(*)

CONCLUSION -

The development of systems fitted inside the car for protecting the thorax against lateral impact and the evaluation of their effectiveness are not possible with a dummy with characteristics similar to those of the Hybrid II. However, such dummies do enable the protection of the pelvis to be roughly investigated.

A dummy which would be appropriate for the thorax should comprise a less rigid link between the shoulder and the rib cage, which should also be made much more flexible. Protection criteria could then be adapted to such a dummy.

The measurements made on human subjects would suggest a maximum human tolerance to relative deflection of the thorax slightly lower than 30 % and would also suggest that a distributed load of over 800 daN should not be applied. This figure is, however, only an order of magnitude which could be used for temporarily determining internal protection elements; this figure cannot be used in connection with an anthropomorphic test dummy.

Finally, it should be pointed out that the present study merely represents the starting point for subsequent research.

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(*) on dummy - if low ΔV or no padding