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Thoracic and Pelvis Human Response to Impact

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ABSTRACT

This paper gives a new approach to provide information on the human tolerance against the impacts with selected unembalmed cadavers ; whose principal physical characteristics follow the distribution of the 5th, the 50th and the 95th percentile male.

A series of tests was conducted with a horizontal steel bar impactor. The extremity area is plan and rigid. Two energy levels used were intended to be without bone fracture and to cause bone fracture for two impacted areas ; the thorax at the mid-sternum in frontal impact or sub-axillary in lateral impact and the pelvis at the H point in lateral impact.

Before the tests, each subject was intrumented. Three mounting plates for tri-axial accelerometer were screwed to the lumbar spine at D1, D12 and at the sacrum. Three small balls were installed on each accelerometer to serve as points of reference in the 3 dimentional analysis with the films from three high speed cameras. The impactor acceleration and the impactor forces were recorded.

After each impact, the subject was examined, photographed and positioned to the next impact. After the final impact, the subject was removed for autopsiy to determine the injuries.

This experimental work contribute for the evaluation and the validation for tri-dimentional space haman model.

PREFACE

The main purpose of this study is to model the behaviour of a human occupant of a vehicle when subjected to frontal and lateral impacts.

Several French laboratories have worked together on this project:

- Laboratory of Biomechanics and Accidentology
  PSA PEUGEOT CITROEN - RENAULT (LAB)
  Segment studied: Head, neck, thorax and abdomen.

- Laboratory of Biomechanics
  Ecole Nationale Supérieure d'Arts et Métiers (ENSAM)
  Segment studied: Pelvis.

- Laboratory of Fundamental Biomechanics
  Université Claude Bernard Lyon I (UCBL)
  Segments studied: Upper limbs.

- Laboratory of Impacts and Biomechanics
  Institut National de Recherche sur les Transport et leur Sécurité (INRETS)

The first three laboratories worked on the mathematical model for one or several segments of the human body; INRETS carried out dynamic tests on human subjects.

INTRODUCTION

Within the scope of its participation in preparing a new mathematical model for the human body, INRETS Impact and Biomechanical laboratory offered to carry out the experimental phase necessary to validate the different segments of this model. The collaboration of the Lyon anatomical laboratory of the Faculty of Medicine was vital for carrying out this work successfully.

In this study, all dynamic tests will be analysed so that a data base can be made which can be used during the "biofidelity" verification of the anthropometric dummies or the mathematical models being developed.

In the report which follows, the analysis primarily concerns the response of the pelvis to a lateral or frontal impact and of the thorax to a frontal impact. In both cases, the collision element is a guided impact hammer. As the experimental phase has not been completely finished the lateral shock analysis of the thorax will not be treated in this paper.

TEST SET UP

The tests were carried out using a 23.4 kg. linear impact hammer. The striking surface is flat and rigid. In the thorax impact case (figure 1), the impacting surface is in the form of a 152 mm diameter circle; and for the pelvis impact (figure 2) the impacting surface is in the form of a 100 x 200 mm rectangle. In both cases, the mass located in front of the load transducer is 1.9 kg. To obtain the applied load at the contact point we apply a coefficient of 1.088 to the measured load corresponding to the ratio of the total mass to the mass behind the transducer.

Positioning the Subject (figure 1 & 2)

The subject is seated on a horizontal Teflon plate in contact with a height adjustable Teflon covered support. The subject is kept in the correct seating position, with head and shoulders straight, by means of an electromagnet and then freed for a few milliseconds just before the impact. The body is suspended by the head using a nylon cord separated in two parts by a traction force transducer. This latter enables the tension to be verified and thus be sure that the body is free at the moment of impact.

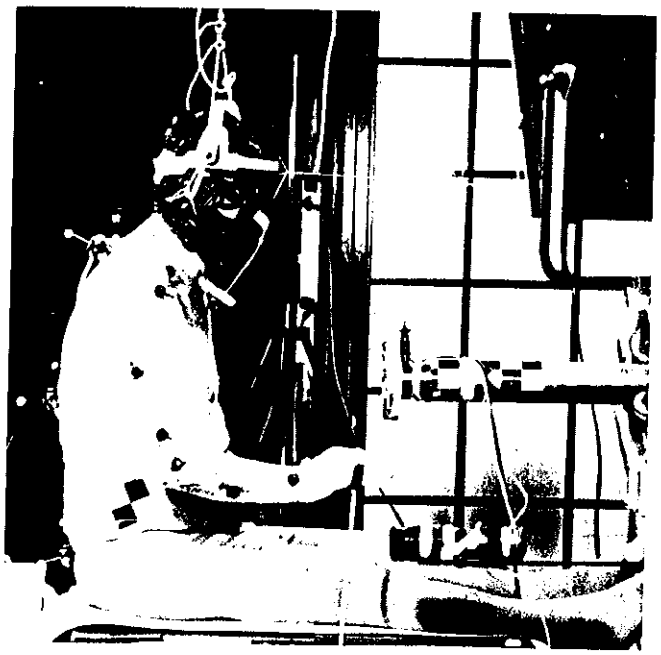

Figure 1 : Thorax subjected to a frontal impact.

Cinematic Environment

In order to make a three dimensional analysis of the movements from the cameras, a space calibration was recorded prior to each test. This calibration was achieved by using variously coloured spherical sights fixed at the top of a parallelepiped whose dimensions are fixed and positions very precisely indexed. Three or four cameras operating at 1000 frames/second were used during these tests.

Selection and Preparation of Subjects

At the start of the study, the conditions were to select subjects representative of certain people categories: men whose weight and height were close to values representative of the 5th, 50th or 95th percentile. Any bodies outside these values can be considered as "rare". Looking at table 1, we can consider that 2 subjects correspond to the 5th percentile, 4 to the 50th and 1 to the 95th percentile.

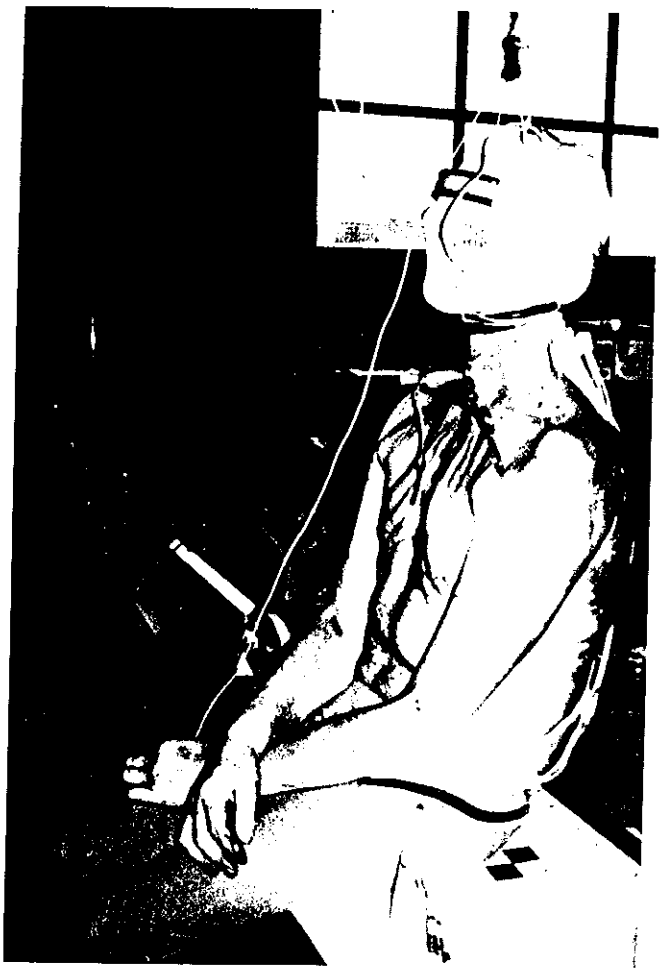

Figure 2 : Pelvis subjected to a lateral impact.

The experiments were carried out on fresh unembalmed corpses, having died within the last four days, conserved in cold storage at (2°C) and removed from the latter several hours before the test. thirty four anthropometric measurements were systematically taken.

A tracheotomy was done on the subject. An injection of air prior to each impact on the thorax enabled the intrathoracic viscera to be put back in place.

Three triaxial accelerometers were fixed to the spinal column at the following points: first and twelfth dorsal vertebrae (T1 and T12) and sacrum. Each triax is mounted on a metal plate which in turn is rigidly maintained against the column with four screws which penetrate into the vertebrae.

Three spherical sights were also connected to each triax to assure easy indexing on the films.

Objectives in terms of anthropometric characteristics :

Subject category	Weight (kg)	Height (m)
5ème percentile	58.0 ± 3.0	1.61 ± 2%
50ème percentile	73.5 ± 3.5	1.72 ± 2%
95ème percentile	94.5 ± 4.5	1.83 ± 2%

Male subject, maximum age is 70 yrs

Subject Number	Weight (kg)	Height (m)	Age
MRT 01	82	1.73	76
MRT 02	76	1.74	57
MRT 03	69	1.72	66
MRT 04	52	1.64	69
MRT 05	54	1.62	69
MRT 06	86	1.81	38
MRT 07	60	1.70	63
Average	68.4	170.9	62.6

Table 1 : Main anthropometric characteristics of the subjects.

TESTING

Each body was subjected to four impacts. the impact zone and impact hammer speed are given in table 2 below:

Subject N°	Test N°	Impact zone	Impact speed (m/s)
MRT 01	MRB 01	L. Pelvis	3.50
	MRB 02	L. Pelvis	6.74
	MRS 01	Sternum	3.36
	MRS 02	Sternum	6.83
MRT 02	MRB 03	R. Pelvis	3.40
	MRB 04	R. Pelvis	6.50
	MRS 03	Sternum	3.43
	MRS 04	Sternum	5.81
MRT 03	MRB 05	R. Pelvis	3.41
	MRB 06	R. Pelvis	6.77
	MRS 05	Sternum	3.39
	MRS 06	Sternum	5.88
MRT 04	MRB 07	R. Pelvis	3.43
	MRB 08	R. Pelvis	6.46
	MRS 07	Sternum	3.40
	MRS 08	Sternum	5.77
MRT 05	MRB 09	R. Pelvis	3.29
	MRB 10	R. Pelvis	6.??
	MRL 01	R. Thorax	3.23
	MRM 01	L. Arm	5.79
MRT 06	MRB 11	R. Pelvis	3.34
	MRB 12	R. Pelvis	6.64
	MRL 02	R. Thorax	3.31
	MRL 03	R. Thorax	5.68
MRT 07	MRB 13	R. Pelvis	3.35
	MRB 14	R. Pelvis	6.44
	MRL 04	R. Thorax	3.26

Table 2 : Test list
R. = right side impact L.= left side impact

ANALYSIS OF RESULTS

To be able to compare the results of the measurements taken it was necessary to take into account the weight and height differences of the subjects. Some correction coefficients were defined to correct either the force or acceleration values. The principle adopted is that the force value is inversely proportional to both weight and height; whereas the acceleration value is inversely proportional to the height and proportional to the weight. In the MERTZ method, these so called standardisation coefficients given in table 3 were calculated by taking a standard subject; of height 1.74 m and weight 76 kg. In this study the number of subjects per category (5th, 50th and 95th percentiles)

	Mt kg	Ht cm	Weight ratio Rm 76 / Mt	Height ratio Rk 174 / Ht	Force Standardisation Factor Rf √ (Rm * Rk)	Acceleration Standardisation factor Ra √ Rk / √ Rm
MRT 01	82	173	0.927	1.006	0.96550	1.04172
MRT 02	76	174	1.000	1.000	1.00000	1.00000
MRT 03	69	172	1.101	1.012	1.05558	0.95836
MRT 04	52	164	1.462	1.061	1.24525	0.85202
MRT 05	54	162	1.407	1.074	1.22950	0.87359
MRT 06	86	181	0.884	0.961	0.92171	1.04298
MRT 07	60	170	1.267	1.024	1.13863	0.89892

Table 3 : Standardisation coefficients

was too small to enable the results to be separated. The corrective calculations were therefore carried out to standardise all the results obtained in relation to the 50th percentile.

Before superimposing the measurement curves recorded during the test, we therefore applied the standardisation factors to both the force and accelerations values.

The results analysis is broken down into two major parts:

- Behaviour of the pelvis to lateral shocks
- Behaviour of the pelvis to frontal shocks

PELVIS BEHAVIOUR TO LATERAL SHOCK

Each of the seven corpses used were subjected to two dynamic tests (see table 4). The first shock was carried out at a low energy level and normally did not cause any fracture; the second shock was carried out at an energy level likely to initiate the first fractures, a fact verified 6 times out of 7. Only the youngest body (38 yrs) correctly resisted such a loading. A 500 Joules energy level can thus be considered as a first bony lesion threshold of the pelvis, and this knowing the average age of the subjects tested is 62.6 years. The results published by Viano (33rd STAPP 892432) about pelvis shocks using a 23.4 g pendulum, indicated that the two fractured bodies out of the five tested at high speed corresponded to the oldest people and that an energy level in excess of 1,000 Joules did not cause any damage to the bodies of the younger subjects.

Two main measurements were chosen to carry out the superposings. These relate to the force obtained at the tip of the impact hammer and the transverse acceleration measured on the subjects sacrum. The curves of each graph obtained were sufficiently close to enable corridors to be defined representative of the human body's behaviour. To clarify matters further, the results obtained at low speeds (figures 3 and 4) were separated from the high speed ones (figures 5 & 6).

Lateral shock tests on the pelvis were analysed by Viano (33 rd STAPP 892432). Although these tests were carried out by using a pendulum on a suspended body, it was interesting to compare the impact forces, because the striking weight was the same in both cases. In figure 11, the upper and lower corridor limits proposed by Viano were superposed onto those previously defined (figures 9 and 10). The impact speeds were not the same, but it appeared that the maximum force levels fully develop as a function of these average speeds. The testing and recording conditions at the moment of impact could be the cause of the slight time lag of the force peaks.

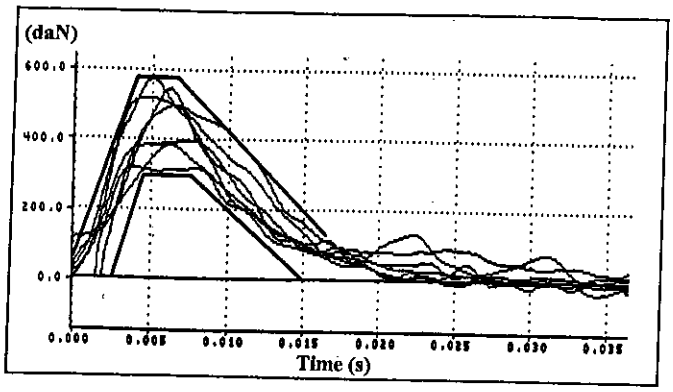

Figure 3 : Superposition of the force curves as a function of time obtained at the pelvis during the low speed tests.

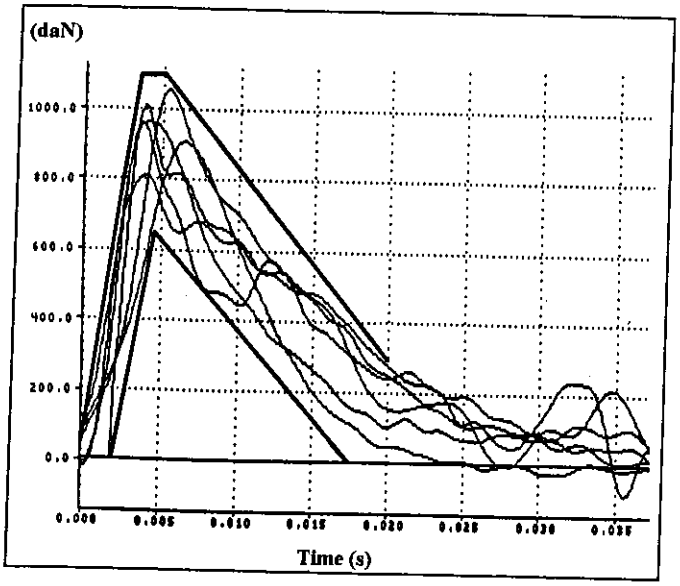

Figure 4 : Superposition of the force curves as a function of time obtained at the pelvis during the high speed tests.

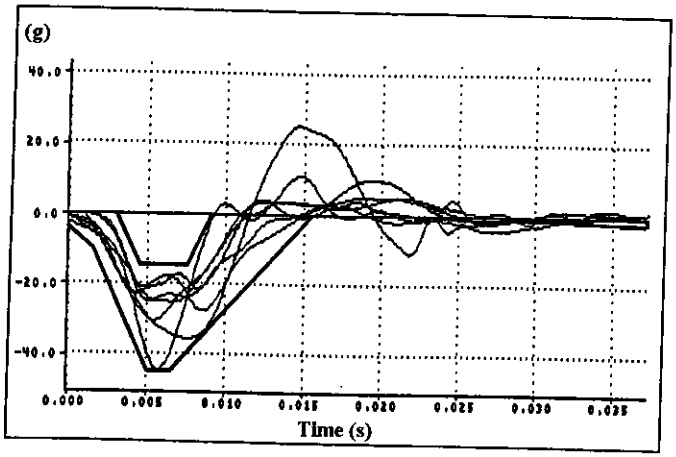

Figure 5 : Superposition of the acceleration curves as a function of time obtained at the sacrum level of the pelvis during low speed tests.

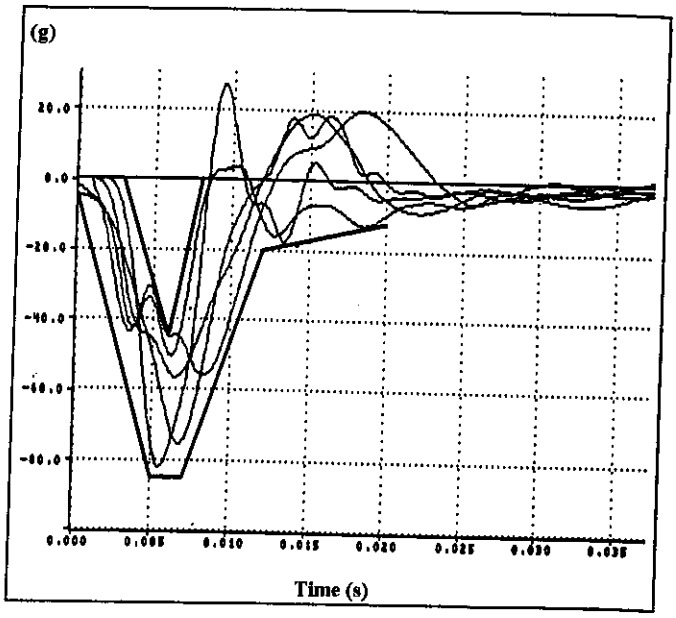

Figure 6 : Superposition of the acceleration curves as a function of time obtained at the sacrum level of the pelvis during high speed tests.

Upper corridor		Lower corridor	
Time seconds	Acceleration G	Time seconds	Acceleration G
0.003	+0	0	-4
0.0045	-15	0.0015	-10
0.0075	-15	0.005	-45
0.009	+0	0.0065	-45
		0.0155	+0

Table 5 : Tests at 3.46 m/s: Upper and lower acceleration corridor limits.

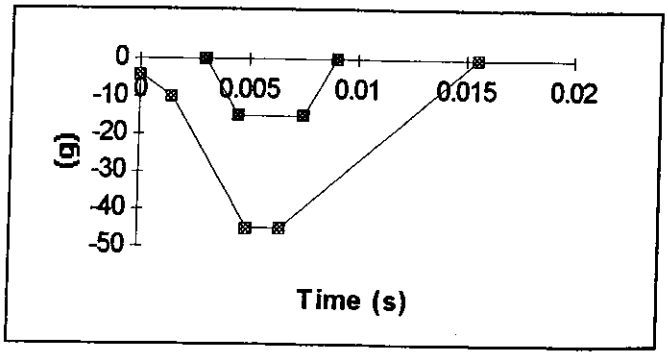

Figure 7 : Tests at 3.46 m/s: Upper and lower acceleration corridor limits.

	Speed (m/s)	Energy (J)	Fractures identified at autopsy
Left side shocks			
MRB 01	3.50	143	
MRB 02	6.74	531	2 branches illium and left ischium pubis + irradiation at the cotyle
Right side shocks			
MRB 03	3.40	135	
MRB 04	6.50	494	1 right side ischium pubis branch
MRB 05	3.41	136	
MRB 06	6.77	536	1 right side ischium pubis branch
MRB 07	3.43	138	
MRB 08	6.46	488	1 right side ischium pubis branch
MRB 09	3.29	126	
MRB 10	6.75	533	comminuted fracture of right cotyle
MRB 11	3.34	130	
MRB 12	6.64	516	no fracture
MRB 13	3.35	131	
MRB 14	6.43	484	latero pubis fracture + irradiation at the coyle
Average :			
Low speed	3.463	134	
High speed	6.663	512	

Table 4 : Results of pelvis autopsies

Upper corridor		Lower corridor	
Time seconds	Acceleratio G	Time seconds	Acceleratio G
0.003	0	0	-5
0.006	-45	0.005	-85
0.008	0	0.007	-85
		0.012	-20
		0.02	-12

Table 6 : Tests at 6.66 m/s: Upper and lower acceleration corridor limits.

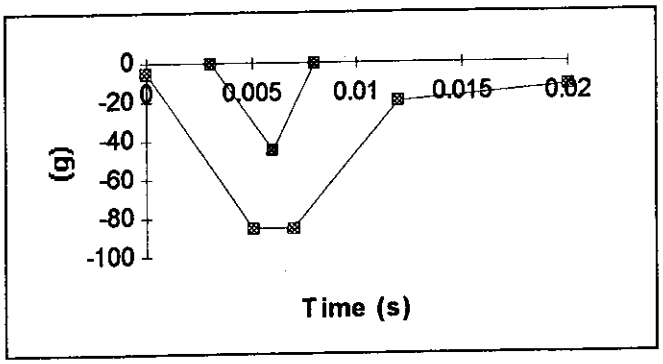

Figure 8 : Tests at 6.66 m/s: Upper and lower acceleration corridor limits.

Lower corridor		Upper corridor	
Time seconds	Force daN	Time seconds	Force daN
0.0025	0	0	60
0.0045	300	0.004	580
0.0075	300	0.0065	580
0.015	0	0.0165	130

Table 7 : Tests at 3.46 m/s: Upper and lower impact force corridor limits.

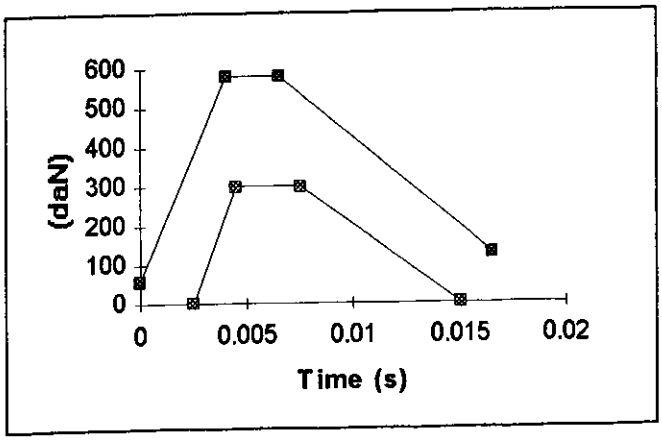

Figure 9 : Tests at 3.46 m/s: Upper and lower impact force corridor limits.

Lower corridor		Upper corridor	
Time seconds	Force daN	Time seconds	Force daN
0.002	0	0	50
0.0045	650	0.0035	1100
0.0175	0	0.005	1100
		0.02	290

Table 8 : Tests at 6.66 m/s: Upper and lower impact force corridor limits.

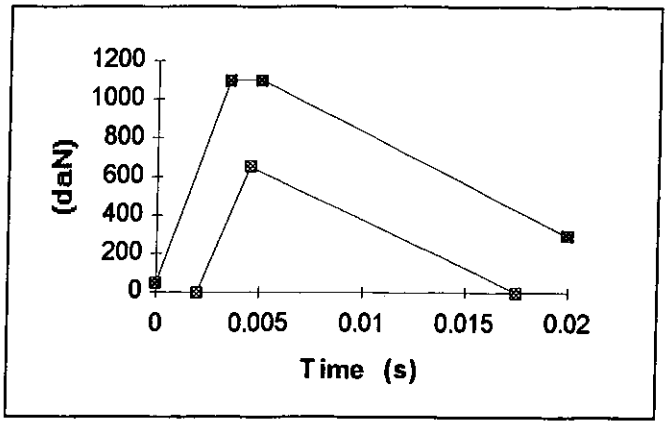

Figure 10 : Tests at 6.66 m/s: Upper and lower impact force corridor limits.

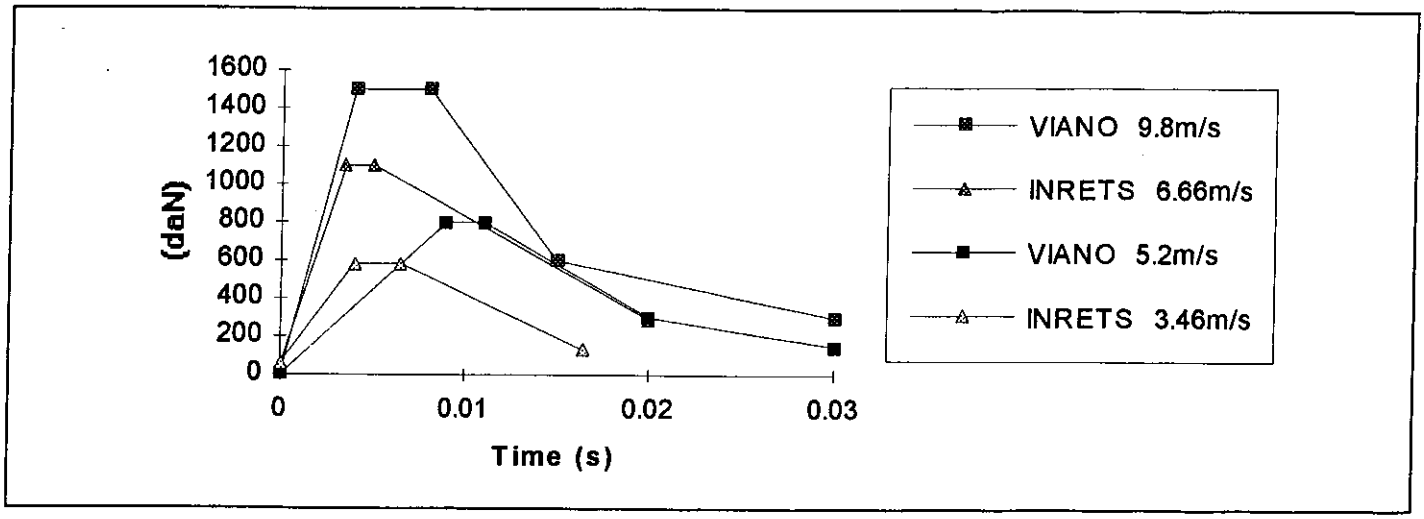

Figure 11 : Superposition of the upper impact force corridor limits as a function of time.

THORAX BEHAVIOUR TO A FRONTAL SHOCK

Each of the first four bodies available for this test series was subjected to two impacts on the sternum. A first impact was made at low speed to avoid any thorax injuries. The second shock should result in a few fractures. Table 9 below summarises the observations made during the autopsies. We obtained very serious damage on the thorax of the first body tested, so we reduced the impact hammer speed during the second impact on subsequent bodies.

The thoracic compression was determined from the cinematic analyses. The available markers were located at points D1 and D12 on the spinal column. To evaluate the thoracic compression, it was necessary to measure the distance variation between the central point of the impact hammer's front face and a fixed datum of the straight line linking points D1 and D12. The analysis was carried out at about 100 ms for each test except for body MRT1 (no film); which gave 20 frames per test at 5 ms intervals. Figures 12, 13 & 14 show how this compression on bodies N°2, 3 & 4 develops with time.

No analysis was done on the bone samples taken on the thorax but the calcination carried out on the illium and ischium pubium branches gave the following information: The ratio of the calcinated bone weight to its dry weight was about 50% for bodies 2 and 3, whereas for body 4 it was about 30%. It is a fact that body N° 4 had a more fragile skeleton that the others.

Body N° & Test Date	Axillary Thoracic Thickness	Sub-sternal Thoracic Thickness	Thorax Fractures	Rib Number
MRT 01 2/19/92	25	25	Middle arch right	2, 3, 4, 5
			Anterior arch right	3, 4, 5, 6, 7
			Middle arch left	2, 4, 5, 6
			Anterior arch left	3, 4, 5, 7
			Sternum	*
			TOTAL	18 fractures
MRT 02	22	23	Anterior arch right	5
3/30/92			TOTAL	1 fracture
MRT 03 4/15/92	21	21	Middle arch right	5, 6
			Anterior arch right	2, 3, 4
			Middle arch left	2, 3, 4, 5, 6, 7
			Sternum	*
			TOTAL	12 fractures
MRT 04 4/17/92	21	21	Middle arch right	2, 3, 4, 5, 6, 9
			Middle arch left	2, 3, 4, 5, 6
			TOTAL	11 fractures

Table 9 : Thorax autopsy results.

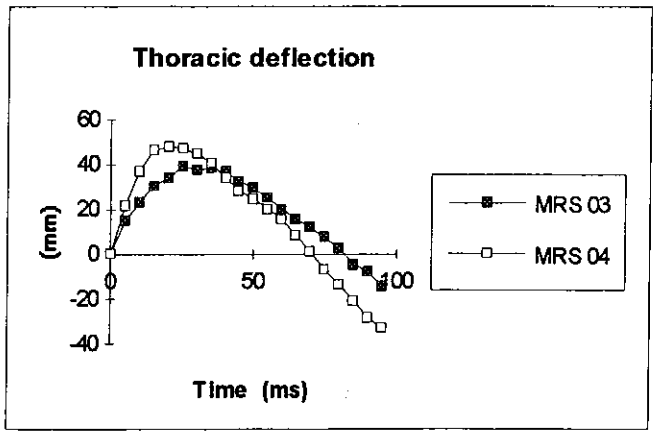

Figure 12 : Thoracic deflection of body N°2 at low and high speeds.

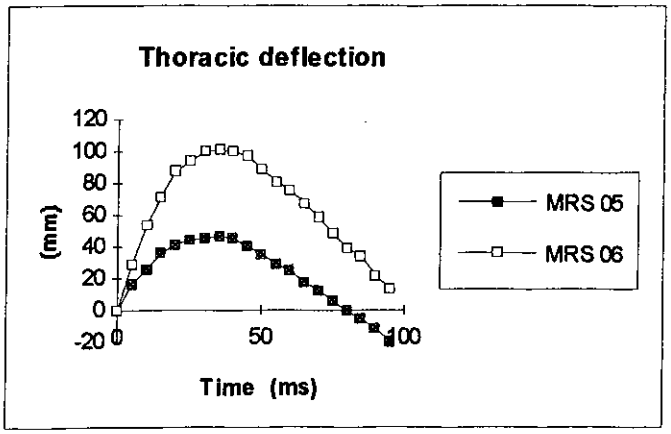

Figure 13 : Thoracic deflection of body N° 3 at low and high speeds.

The thoracic compression reverts to zero before 80 ms because there is only one rib fracture during the second test. The thorax's elasticity remained good, and gave part of its energy back to the impact hammer; which explains the rapid separation of the thorax and impact hammer.

The thorax elasticity of body N° 3 during the second test was less than that in test N° 2. This was due to the fractured 12 ribs counted. The rebound of the impact hammer after the shock was slower.

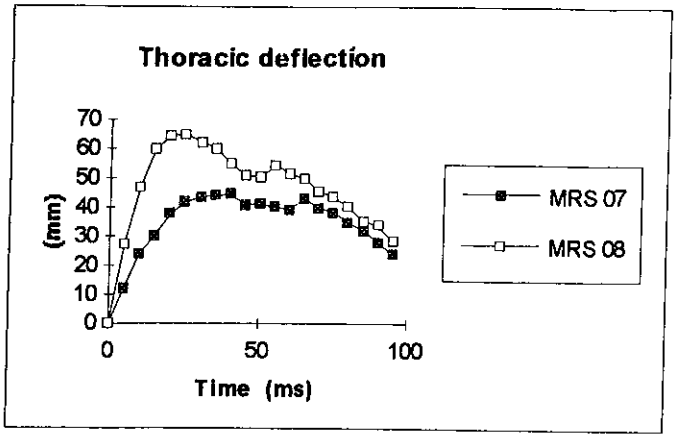

Figure 14 : Thoracic deflection of body N° 4 at low and high speeds.

The results show that this thorax was partly broken during the first low speed test, because the impact hammer stayed longer than normal in contact with the thorax.

During the low speed impacts applied against each of the 4 bodies, the thorax depression value obtained from the film analysis were respectively 63, 39, 46, and 44, which represents 25, 17, 22 and 21% of the thorax's thickness. These depression percentages are normally well supported by the human body.

During the high speed impacts, only the tests on bodies 2, 3, and 4 were filmed. The measured depressions were very different: 48, 100 and 65 mm being 21, 48 and 31% of the thorax's thickness. For body N° 2 the depression seemed to be underestimated but was in agreement with the fact that only one rib was broken. The other two cases corresponded closely to critical situations which would normally result in multiple fractures.

The measurements carried out during the shocks were corrected by applying standardisation coefficients. The acceleration curves measured at the 12th dorsal vertebra level (D12) (figure 15) and the force curves taken at the sternum (figures 17 & 19) were superimposed. Two corridors were defined in table 10 and 11 and figures 16 & 18. the acceleration superimposition at the D12 level was only carried out for the high speed tests, because in the other tests the acceleration levels were very low and always below 5G. For this reason creating a low speed corridor was not considered.

Although the impact time for the four bodies lasted about 60 ms (figure 19), the forces obtained at the sternum during the high speed tests were difficult to interpret. The tests on body N° 1 occurred at a higher speed than in the other tests; thus logically giving higher values. Being frail body N° 4 quickly succumbed under the force applied. Only bodies 2 and 3 gave results sufficient close to manifest the reactions of a normal body. Nevertheless, a small difference existed at the very start of the shock as shown by a quite sharp peak. A similar reaction was found for body N° 1. Complimentary tests will be required to better analyse this situation. Under these conditions therefore no corridor was considered.

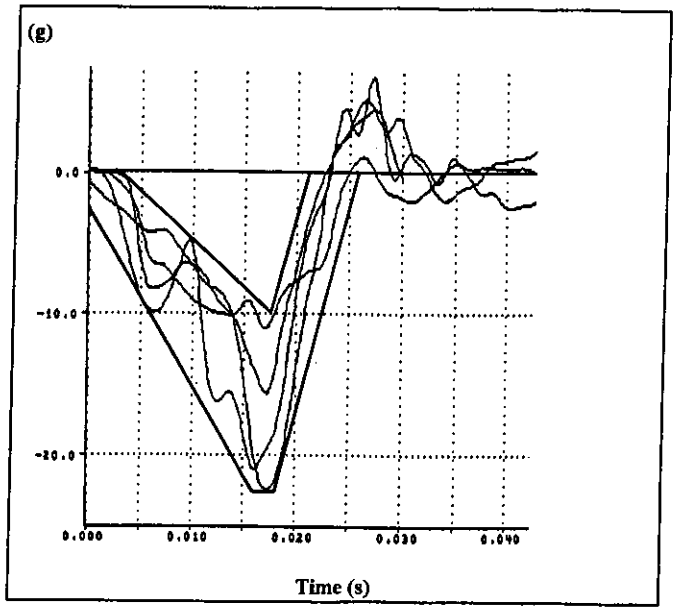

Figure 15 : Superimposing the acceleration curves (g) as a function of time (s) obtained at the 12th dorsal vertebra level during a test at 5,8 m/s.

Upper corridor		Lower corridor	
Time seconds	Acceleration G	Time seconds	Acceleration G
0.0025	0	0	-2.5
0.0175	-10	0.016	-22.5
0.021	0	0.018	-22.5
		0.026	0

Table 10 : Test at 5.8 m/s: Upper and lower corridor limits of accelerations at D.12.

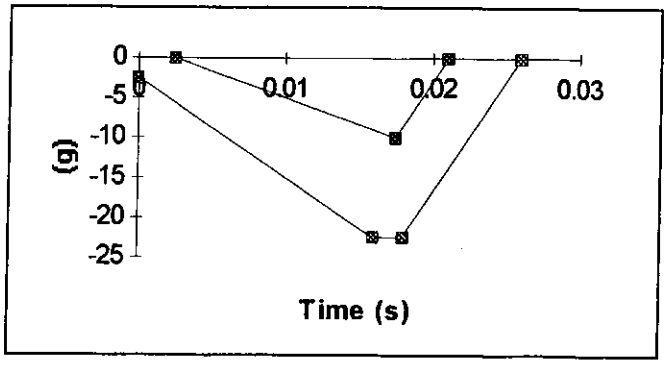

Figure 16 : Tests at 5.8 m/s: Upper and lower corridor limits of accelerations measured at D12 and standardised.

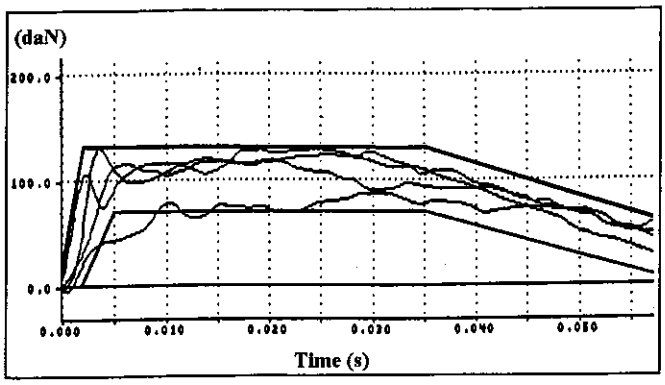

Figure 17 : Superimposing the force curves obtained at the sternum during low speed tests (3.5 m/s) as a function of time.

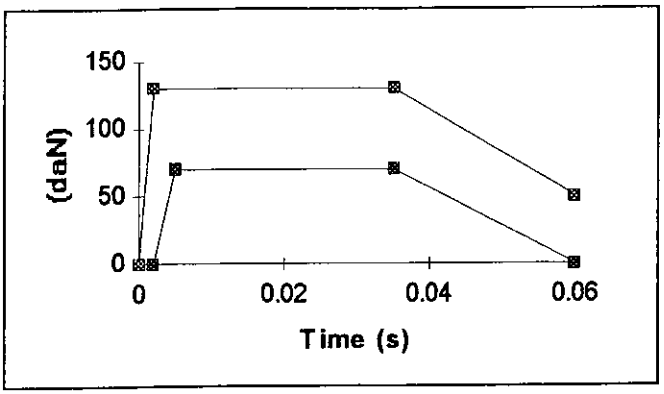

Figure 18 : Tests on the sternum at 3.5 m/s; upper and lower corridor limits of the standardised impact forces.

CONCLUSION

In order to have a new data base on the human body's behaviour when subjected to a guided impact hammer, INRETS Biomechanical and Shock Laboratory carried out a series of tests. In this report, a large part of the results obtained with the first seven bodies were analysed in the form of two independent studies:

1) Pelvis reactions induced by a lateral shock.
2) Thorax reactions induced by a frontal shock.

Although the foreseen experimental programme has not yet been finished, it was considered worthwhile regrouping the initial results and analysing them.

Each of the seven available subjects were subjected to two shocks on the pelvis. The first was an infra-lesional shock and the second a higher energy shock to produce lesions. Each body was then impacted at the thorax. The first four bodies were subjected to frontal shocks and the other three to lateral shocks. As the experimental programme on the thorax response to a lateral shock was limited, no results were analysed.

The seven low speed and high speed tests on the pelvis were sufficiently homogeneous to represent a very good

Lower corridor		Upper corridor	
Time seconds	Force daN	Time seconds	Force daN
0.002	0	0	0
0.005	70	0.002	130
0.035	70	0.035	130
0.06	0	0.06	50

Table 11 : Tests on the sternum at 3.5 m/s: Upper and lower corridor limits of the standardised impact forces.

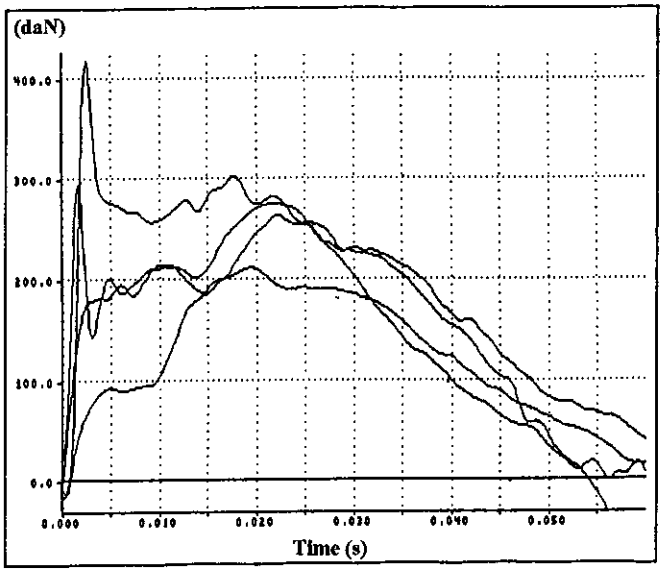

Figure 19 : Superimposing the force curves obtained at the sternum during high speed tests (5.8 m/s) as a function of time.

data base. Although the tests analysed by VIANO (33rd STAPP N° 892432), were not done under the same conditions, the results were compatible and complementary.

Concerning the thorax however, when subjected to frontal shock, the situation was more difficult to exploit because only four bodies were subjected to frontal shocks. The low speed results gave relatively homogeneous responses. The high speed tests however gave a very high dispersion which would require complementary tests to better delimit the thorax's response in the configuration chosen at INRETS laboratory.

The information gathered during the dynamic tests was standardised to be representative of the 50th percentile, then regrouped to produce the corridors delimiting the behaviour of the sections of the human body when subjected to shocks. These corridors will be the objectives to be achieved during the behavioural verifications of the mechanical or mathematical models.