SEMI STATIC LOADING OF BABOON TORSOS

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Abstract :

The static response of a baboon torso is investigated using a loading device, in which the load is applied on the torso by a safety belt. Load and deflexion are recorded and torso responses are analyzed. Tests are conducted on living and dead baboons. Response results are discussed and compared with human torso responses. Absorbed energies are calculated.

Introduction :

A number of studies are concerned with the response of human chest under static loading. Among all investigators Patrick (1966) carried out a work on cadavers and volunteers. In order to study cardio thoracic lesions, Beckman (1972) conducted static and dynamic tests on monkeys.

The analysis of chest response by conducting dynamic tests is not easy and especially because of the great difficulty in developping measure devices for recording load and associated deflexion during the impact.

Facing these problems our objective was to bring new experimental data through well controlled semi static tests using a special device which creates loads on the chest of the subject. The load is applied on the torso by a safety belt pulled by a jack the speed of the jack can be adjusted up to 2 m/s.

This study will enable us later on to carry out work in dynamic conditions in order to investigate the compensation phenomena due to the internal pressures which result from a violent collision.

Material and Methods :

A male human cadaver and two anaesthetized alive monkeys have been used for the tests which are presented in this paper. Tests on baboons have been done several times on each animal,with a lapse of two or three weeks corresponding to rest periods.After three months, the animals have been sacrificed through anaesthetic overdose. Just after the death, they have been tested in the same conditions as alive and these tests have been repeated at different times after the death. Thus, a comparative study of torso response of dead and alive animals can be effected. Xray pictures have been done before and after each test. The following photographs show the testing device and the subject's position in test conditions (fig. 1A, 1B, 1C)

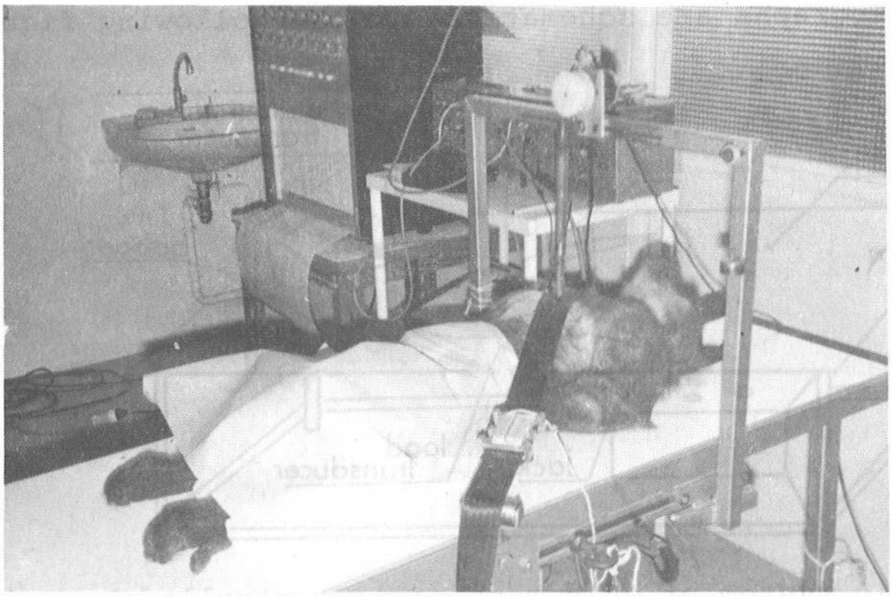


Fig. 1A. Anaesthezied baboon in test conditions

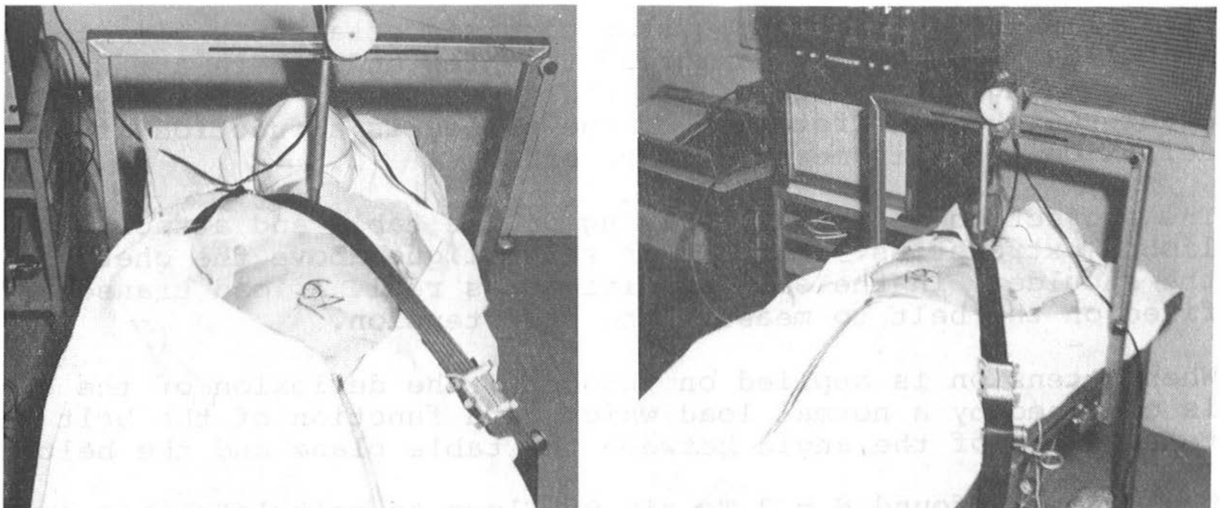
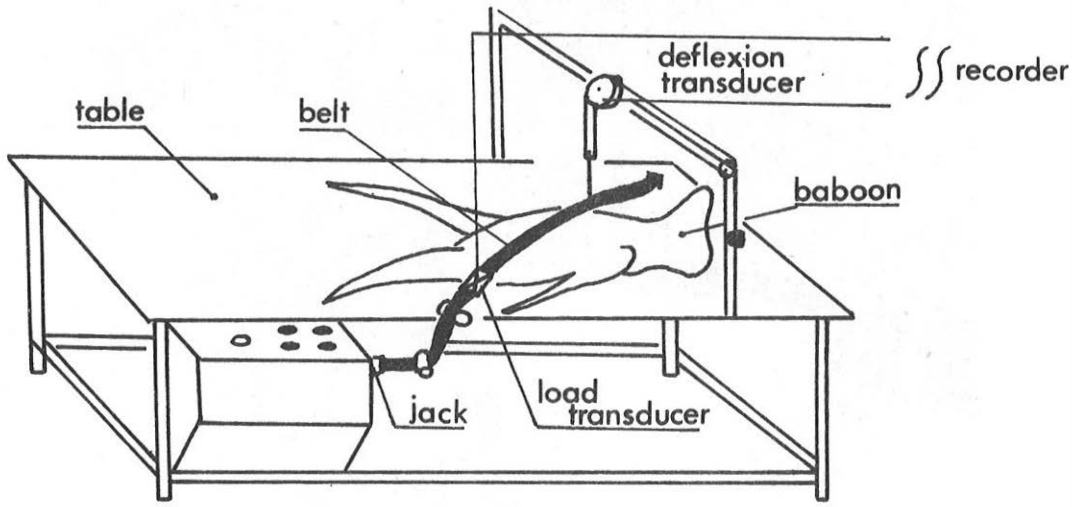


Fig. 1B. 1C. Human cadaver in experimental conditions
Face view - side view

These photographs are schematized in the following figure



The dynamic system of this machine is controlled by a jack. This one can be driven by adjusting a working pressure which allows to pull on the belt.
All tests have been carried out in graduated steps with pressures growing from 1 to 7 bars. Each test being completed by a radiographic study.

The deflexion measurement system consists of a potientiometer and a pulley rounded by a thread to which ends there are 2 weights one touching the center of the chest, the other acting as a counterweight. The rotation of the pulley is a function of the deflexion and this measure is recorded.

The subject to be tested is lying on the table and attached by the limb's extremeties. The belt is set oblique above the chest and the shoulder, in the same conditions as real. A load transducer is fixed on the belt to measure the belt tension.

When a tension is applied on the belt, the deflexion of the chest is obtained by a normal load which is a function of the belt tension and of the angle between the table plane and the belt.

The equation found $N = 2.Tc \sin \theta$ allows to calculate this normal load at the center of the chest.Normal load and deflexion are recorded on a XY recorder and from this law of variation of load versus deflexion, absorbed energies have been studied.

Results obtained :

Tables 1 to 4 give the tests results. Table 1 is corresponding to the test on human cadaver and other tables to tests made on alive and dead monkeys. These results allow to find the relation between normal load and the deflexion which is represented in fig. 3.

Studied subject : human cadaver, male

TABLE 1 2nd TEST

State : embalmed

P bars	h cm	r cm	h'=h-5,5 cm	f cm	a=h'-f cm	b cm	θ=arctg $\frac{a}{b}$	Tc kg	N=2.Tc.Sinθ kg	l cm	d cm	S=l.d cm2	σ= N/S kg/cm2	ε=f/h %
1	23.5	31	18	0.23	17.17	43.5	22.22	20	15.12	50	4.7	235	0.06	0.9
2			18	0.46	17.54	43.5	21.96	60	44.87	50	4.7	235	0.19	1.9
3			18	1.50	16.50	43.5	20.77	160	113.47	50	4.7	235	0.48	5
4			18	1.61	16.39	43.5	20.65	180	126.90	50	4.7	235	0.54	6
5			18	1.73	16.27	43.5	20.51	220	154.13	50	4.7	235	0.66	7
6			18	2.42	15.58	43.5	19.71	260	175.29	50	4.7	235	0.75	10
7			18	2.65	15.35	43.5	19.44	340	226.24	50	4.7	235	0.96	11

Studied subject : baboon n° 7

TABLE 2 5th TEST

State : alive

P bars	h cm	r cm	h'=h-5,5 cm	f cm	a=h'-f cm	b cm	θ=arctg $\frac{a}{b}$	Tc kg	N=2.Tc.Sinθ kg	l cm	d cm	S=l.d cm2	σ= N/S kg/cm2	ε=f/h %
1	17	15	11.5	2.8	8.7	44.5	11.06	37.5	14.39	34	4.7	159.8	0.09	16.47
2			11.5	3.6	7.9	44.5	10.67	75	25.71	34	4.7	159.8	0.16	21.17
3			11.5	4.0	7.5	44.5	9.57	105	34.88	34	4.7	159.8	0.22	23.52
4			11.5	4.4	7.1	44.5	9.07	150	44.42	34	4.7	159.8	0.28	25.88
5			11.5	6.0	5.5	44.5	8.06	162	44.64	34	4.7	159.8	0.28	35.29
6			11.5	7.0	4.5	44.5	6.03	258	51.91	34	4.7	159.8	0.32	41.18
7			11.5	7.6	3.9	44.5	5.01	300	52.38	34	4.7	159.8	0.33	44.70

P Jack pressure

h Chest height (A-P)

r Chest width

h' Rectified height for calculations

f Chest flexion

a Height of loaded chest

b Projection of the length of the belt, from the point attached at the center of the chest

θ angle included between the belt and the horizontal plane

Tc Belt tension

N Normal force

l Contact length between the belt and the studied subject

d Belt width

S Contact surface of the belt

σ Load supported by the unit surface

ε Percentage of the flexion at the height of the chest.

Studied subject : baboon n°7

State : dead for an hour

TABLE 3 6th TEST

P bars	h cm	r cm	h'=h-5,5 cm	f cm	a=h'-f cm	b cm	θ=arctg a/b	Tc kg	N=2.Tc.Sinθ kg	l cm	d cm	S=l.d cm2	σ= N/S kg/cm2	ε=f/h %
1	17	15	11.5	4.8	6.70	44.5	8.56	39	11.59	34	4.7	159.8	0.07	28
2			11.5	6.4	5.10	44.5	6.54	90	20.48	34	4.7	159.8	0.13	38
3			11.5	7.2	4.30	44.5	5.52	132	25.37	34	4.7	159.8	0.16	42
4			11.5	7.6	3.90	44.5	5.01	174	30.38	34	4.7	159.8	0.19	45
5			11.5	8.0	3.50	44.5	4.50	216	33.87	34	4.7	159.8	0.21	47
6			11.5	8.0	3.50	44.5	4.50	258	40.45	34	4.7	159.8	0.25	47
7			11.5	8.0	3.50	44.5	4.50	285	44.69	34	4.7	159.8	0.28	47

Studied subject : baboon n°7

State : dead for 26 hours

TABLE 4 9th TEST

P bars	h cm	r cm	h'=h-5,5 cm	f cm	a=h'-f cm	b cm	θ=arctg a/b	Tc kg	N=2.Tc.Sinθ kg	l cm	d cm	S=l.d cm2	σ= N/S kg/cm2	ε=f/h %
1	17	15	11.5	2.0	9.5	44.5	12.05	36	15.03	34	4.7	159.8	0.09	11.76
2			11.5	2.8	8.7	44.5	11.06	75	28.77	34	4.7	159.8	0.18	16.47
3			11.5	3.6	7.9	44.5	10.07	114	39.83	34	4.7	159.8	0.25	21.17
4			11.5	4.4	7.1	44.5	9.07	150	47.25	34	4.7	159.8	0.30	25.88
5			11.5	4.8	6.7	44.5	8.56	192	57.14	34	4.7	159.8	0.36	28.23
6			11.5	5.2	6.3	44.5	8.06	228	63.89	34	4.7	159.8	0.40	30.58
7			11.5	5.6	5.9	44.5	7.55	270	70.96	34	4.7	159.8	0.44	32.94

P Jack pressure

h Chest height (A-P)

r Chest width

h' Rectified height for calculations

f Chest flexion

a Height of loaded chest

b Projection of the length of the belt, from the point attached at the center of the chest

θ angle included between the belt and the horizontal plane

Tc Belt tension

N Normal force

l Contact length between the belt and the studied subject

d Belt width

S Contact surface of the belt

σ Load supported by the unit surface

ε Percentage of the flexion at the height of the chest.

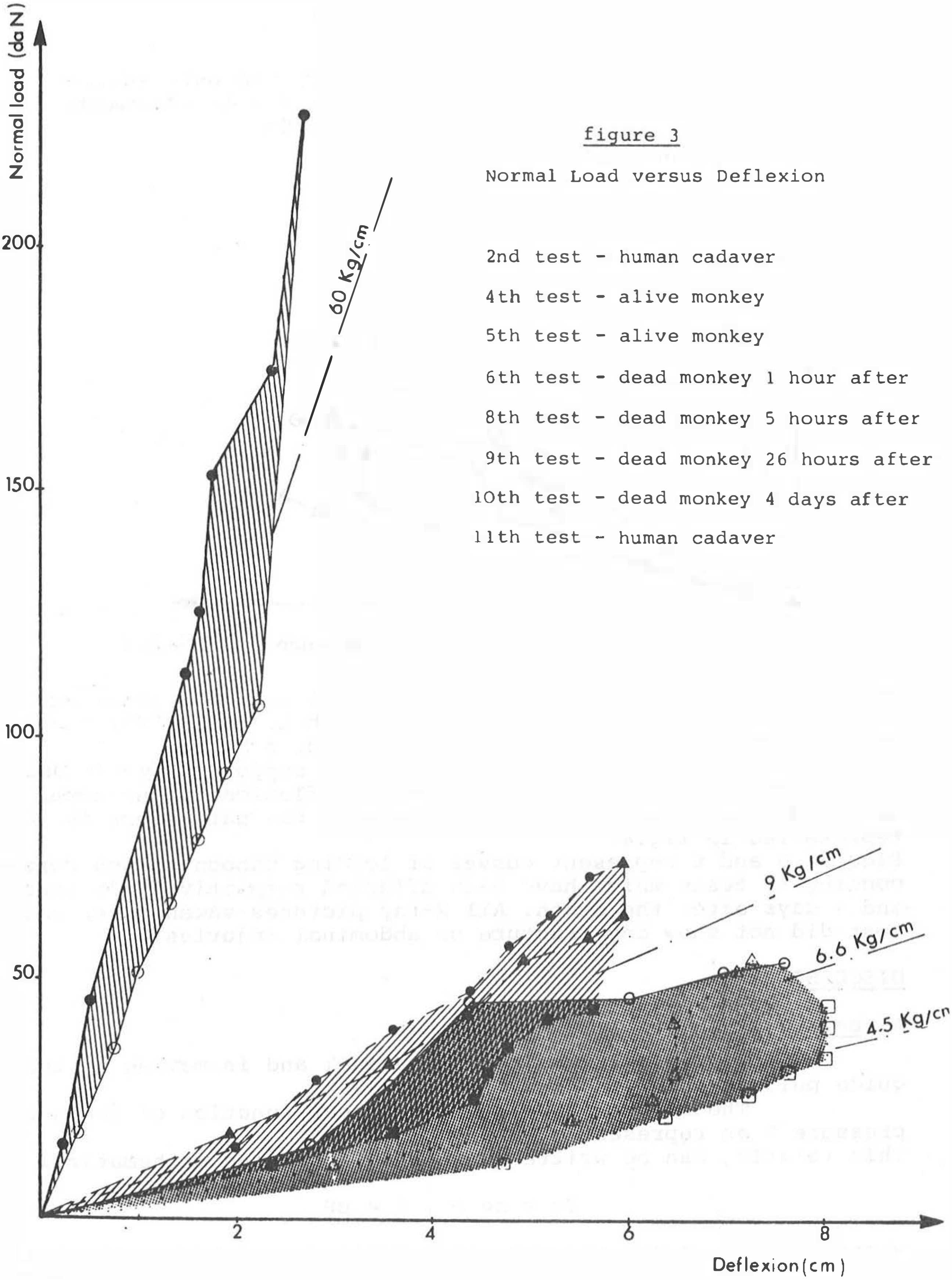


figure 3

Normal Load versus Deflexion

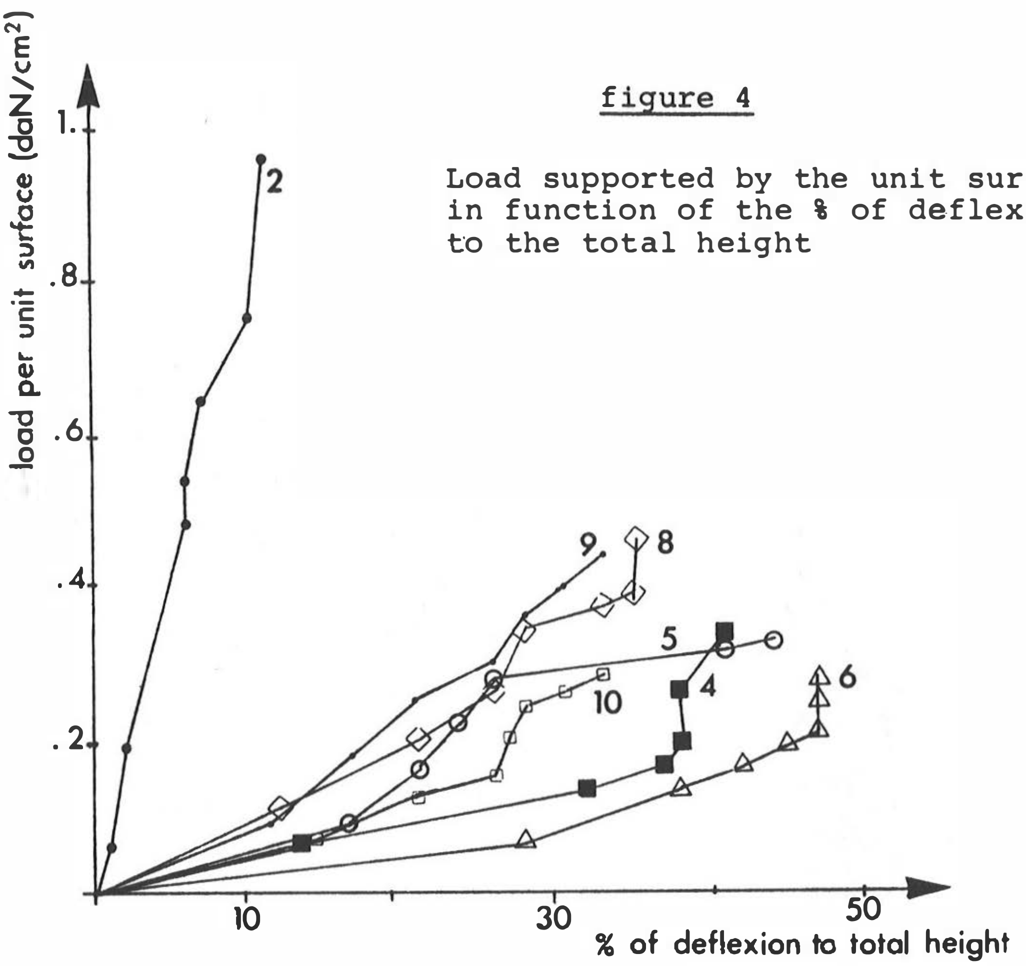


figure 4

Load supported by the unit surface in function of the % of deflexion to the total height

According to the subject tested, the chest shape and size are different ; for example : the height/width is of 23.5/31 = 0.75 for a human being and is of 17/15 = 1.1 for a baboon.
For this reason, we have studied the load supported by the unit surface according to the percentage of deflexion to the total height of the chest. The relation between the parameters is represented in fig.4.
Figures 5 and 6 represent curves of loading baboon torsos corresponding to tests which have been effected respectively 26 hours and 4 days after the death. All X-ray pictures taken after each test did not show any fracture or abdominal injuries.

DISCUSSION

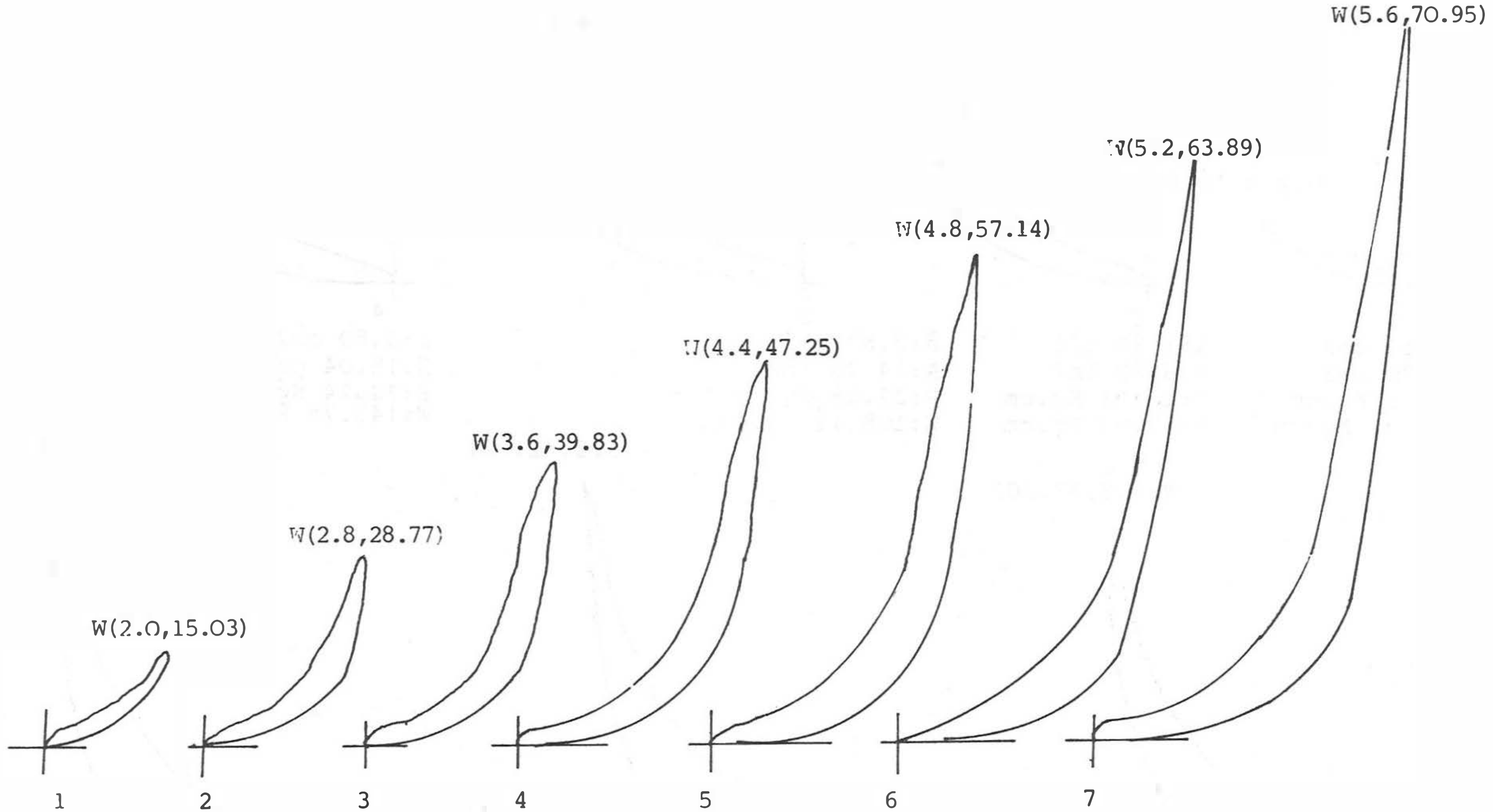
A- Belt Tension :

The belt is pulled by the jack and is moving on two guide pulleys such as shown in figure 7.

The belt tension Tc is a linear function of the jack pressure P as represented in figure 8.
This relation can be written under the following mathematical form

$$T_c = tg\ \theta \ .\ P = \mu P$$

where $\theta = 37°$ is the average slope angle of the tests. The value of $tg\ \theta$ is $\mu = 0.754$ and represents the friction factor existing between the belt and the two guide pulleys.



1	2	3	4	5	6	7
a:0.44cm2	a:1.32cm2	a:2.32cm2	a:3.60cm2	a:5.11cm2	a:3.47cm2	a:6.31cm2
A:2.85cm2	A:8.06cm2	A:13.95cm2	A:23.40cm2	A:31.92cm2	A:41.86cm2	A:54.50cm2
E:4.61kg.cm	E:13.14kg.cm	E:23.96kg.cm	E:32.00kg.cm	E:40.81kg.cm	E:43.42kg.cm	E:45.97kg.cm
W:30.06kg.cm	W:80.56kg.cm	W:143.39kg.cm	W:207.90kg.cm	W:274.27kg.cm	W:332.23kg.cm	W:397.38kg.cm

<u>Fig.5</u> : Normal Load according to thorax deflexion - 9th test: hysteresis cycles for 1 to 7 bars.

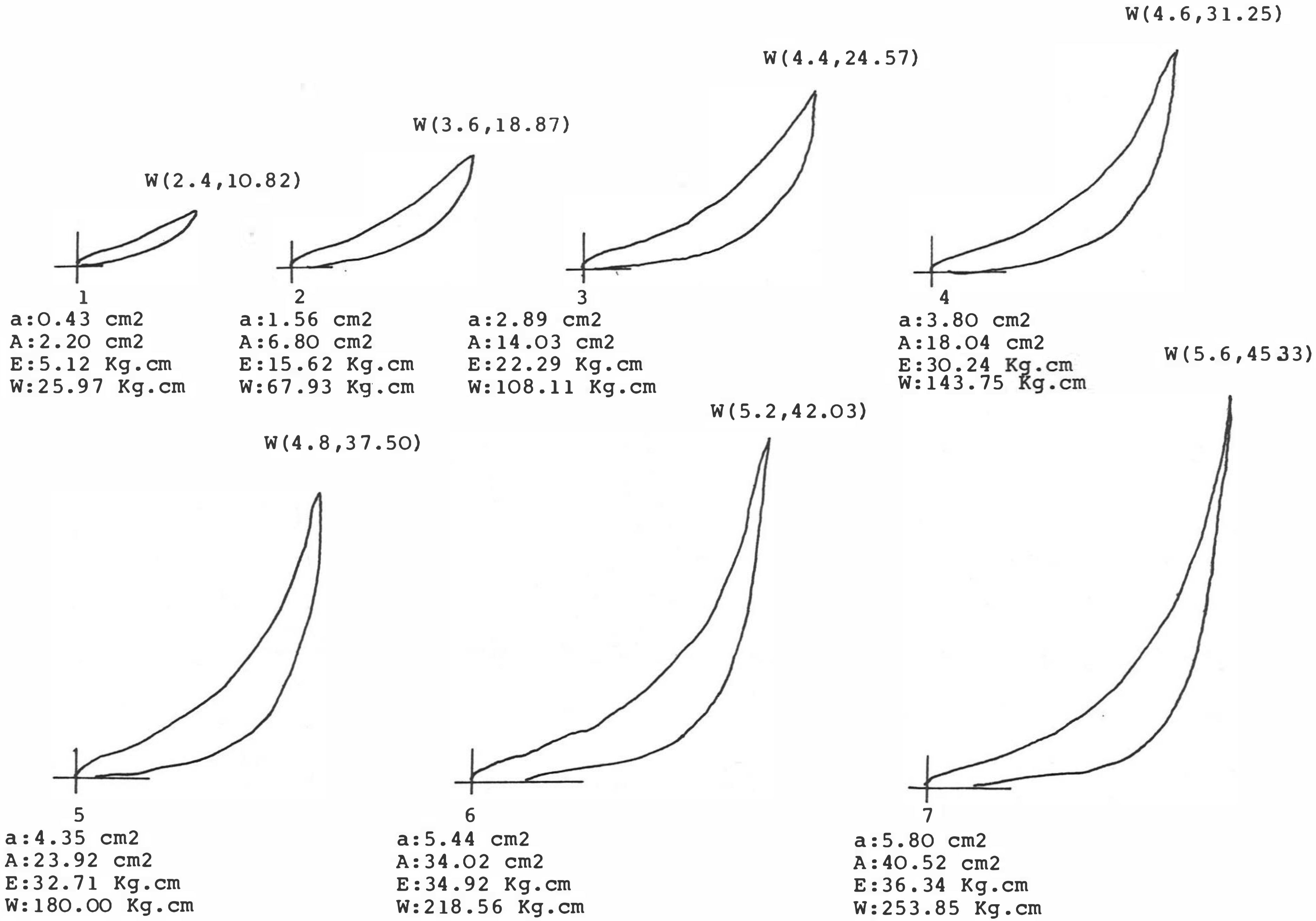


Fig.6 : Normal Load according to thorax deflexion - 10th test: hysteresis cycles for 1 to 7 bars.

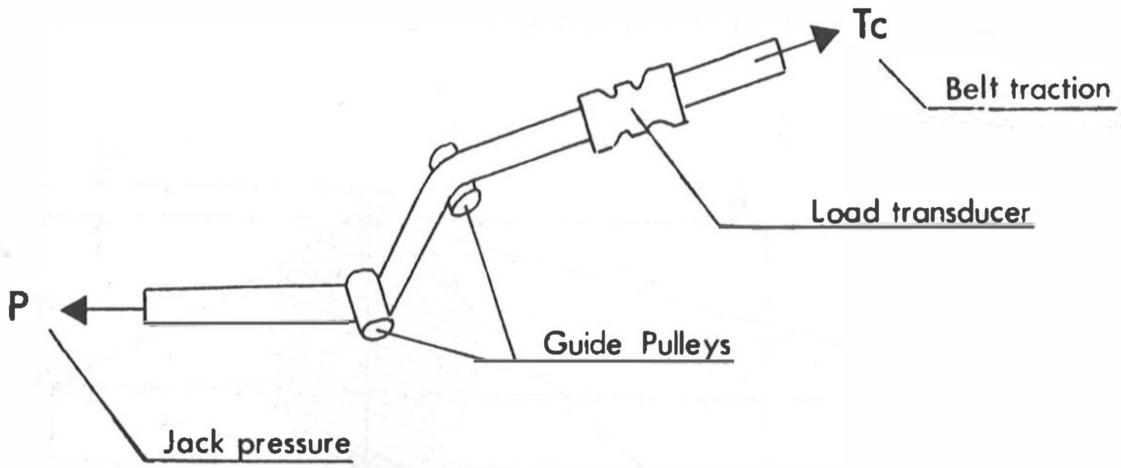


Fig.7

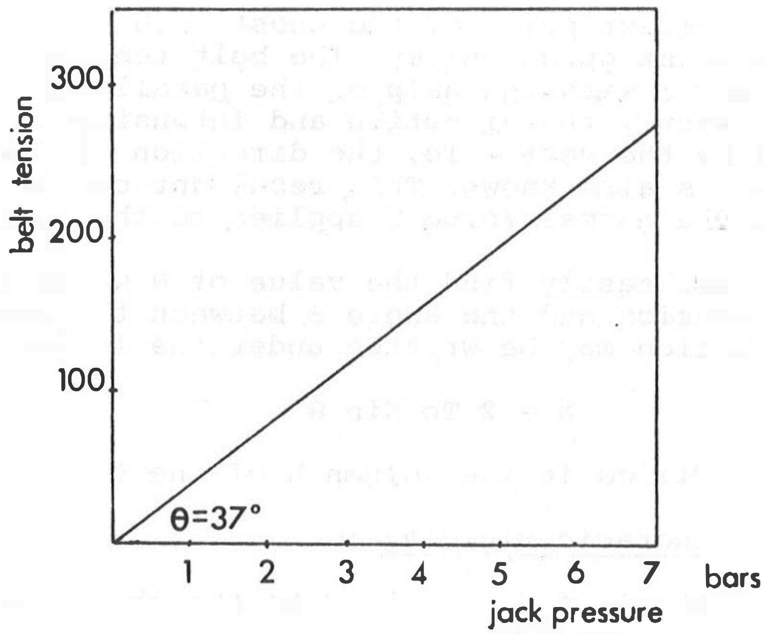


Fig.8 : Belt tension according to jack pressure.

B- <u>Normal Load</u> :

The normal load is created by the belt tension.The value of this force comes from calculation. Figure 9 represents the profile of the belt ACB in a vertical plane.

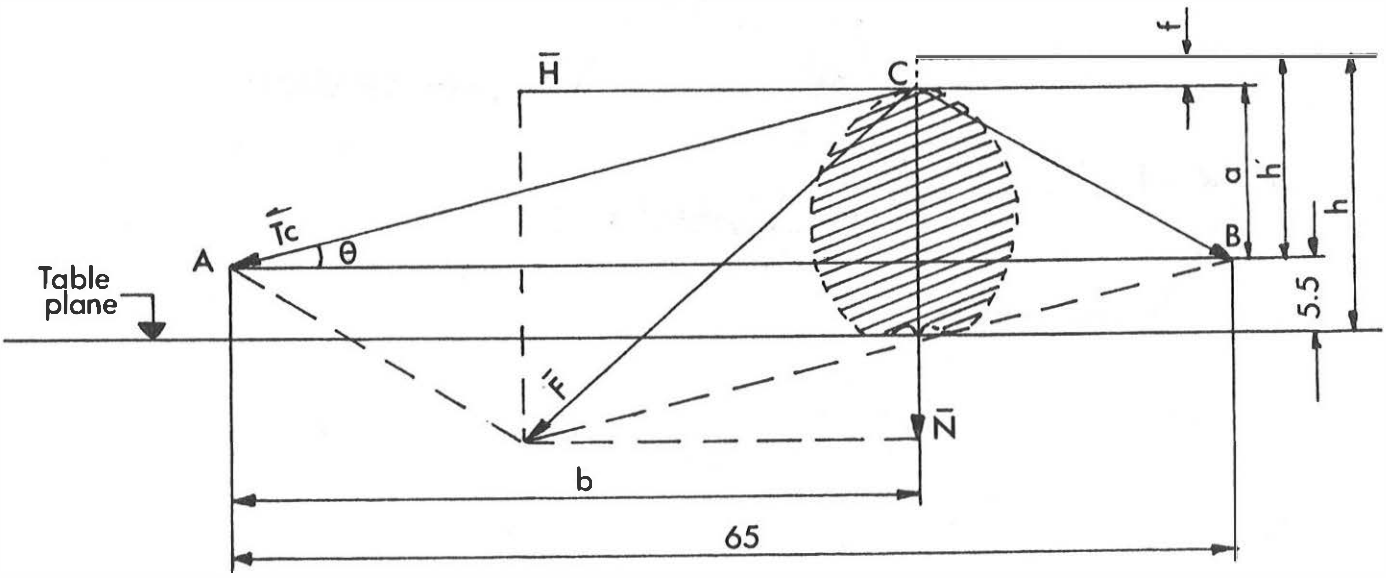


Fig.9 : Parallelogram of forces.

Point C is the contact point of the chest with the belt. Point A represents the first guide pulley. The belt tension Tc is given by a load transducer ; with the help of the parallelogram of forces ACBD, we know exactly the direction and intensity of the component CA represented by the vector Tc, the direction of the component CB which resultant is also known. This resultant can be resolved into force H and into a normal force N applied to the center of the chest C.

We can easily find the value of N which is dependent upon the belt tension and the angle θ between the belt and the table. This equation may be written under the following form :

$$N = 2\ Tc\ \sin\theta$$

The results are filled in the column N of the tables 1-4.

C- <u>Study of the thoracic rigidity</u> :

The static force applied to the chest has been studied by Patrick (1966) according to the deflexion. This author has applied on human cadavers forces exceding 408 Kg (900 Lb) for a contact surface of 193 cm2 (25-30 in2) and on volunteers, forces

of 204 Kg (300-400 Lb) for the same contact surface. The load - deflexion curve gives an average slope of 71 Kg/cm (390 Lb/in) for the human cadaver.
Our own results have shown that this slope was a little weaker, i.e. 78 Kg/cm (see Fig. 3 of the 2nd trial).
This divergence can be explained by the difference of the experimental protocol : as a matter of fact, Patrick has not used the "belt" as static form, but a metal weight or an hydraulic machine. This force is thus more "concentrated" than the one of the belt and the resulting deflexion is more important (the slope being weaker). The divergence of these results can also be explained by the individual variations of the mechanical properties of the studies subjects.
Experiments in static and dynamic have been carried out, with the help of an"impactor", for a mechanical study of the cardio-thoracic injury by Beckman (1972). The alive monkey thoracic rigidity has been evaluated at 2,42 Kg/cm (28 Lb/2,1 in) for the static study : "the impactor" consisting in its end of a round metal piece, with a diameter of 7,62 cm (3 inch) which was in contact with the chest.

The results of Beckman are rather close to ours (4,5 Kg/cm).

We have found that the effort/deflection variation (see fig.3) is a linear function for all our tests. For loads exceding about 30Kg corresponding to a deflection of 4,5 cm, the chests of the monkeys present a permanent deformation.

A comparative study of the chest rigidity between human and animal shows that this one is different : the average slope is of 78Kg/cm for human cadaver and of 6,6 Kg/cm for dead baboons.
This phenomenon could be explained by the fact that they have not the same mechanical properties, namely for example : the human ribs surface is twice more important than the one of animals; their sizes and shapes (justified by the connection height-length of the chest) are also different. On the other hand, the chest consists of three elements that are very heterogeneous materials : skeleton, muscle and viscera. These elements are playing a different part towards the force applied experimentally on the anterior face of the chest, and, consequently, towards the force opposed to the one before, i.e. the table. This manysided problem is not part of our study for the moment.

We can also see, in figure 3, that slopes of 4th, 5th, 6th trials are weaker than those of 8th, 9th and 10th trials. The first series of tests is corresponding to alive monkeys, except for the 6th trial for which the monkey has been killed by an overdose of "PENTOBARBITAL SODIQUE" and put, one hour later, through the experiment.
The results show that in the second series, the normal force is more important of 100% as against the one of the first series, and this for a flexion of 4,5 cm.

On the other hand, Beckman (1970) has carried out the same tests, but on embalmed monkeys. He has ascertained that the chest of the embalmed monkey is tenser than the one of an anaesthetized alive monkey. The effort for the embalmed monkey is more important of 132% as against the effort of the anaesthetized monkey, this for a deflexion of 3,75 cm (1,5 inch).

This phenomenon can find a physiological explanation :

After the death of the primate, muscles and organs lose their elasticity and this more especially as the death is more distant in the time : this is what is observed in comparing the results obtained with alive monkeys (1st series of tests) and with dead monkeys (2nd series of tests). The alive animals can thus sustain a more important deflexion.

Now, the results of the 6th trial are in contradiction to this verification : this seems due to the fact that the experiments carried out on the corresponding animal have been done very nearly after its death (one hour), muscles and organs having not lost their entire elasticity.

Other tests, carried out within comparable experimental conditions, could perhaps enable us to classify these results with those obtained with alive animals.

D- Absorbed Energy :

If we study the energy absorbed by the chest, we obtain curves of the same form, represented in figure 10 :

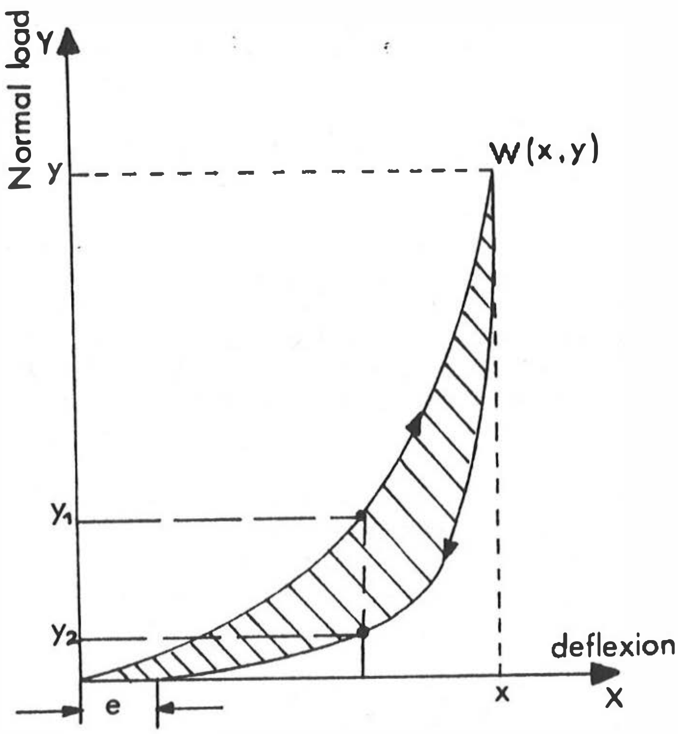


Fig.10 : Normal Force according to the chest deflexion (hysteresis cycle)

It can be observed that the curves of the normal load (y) as a function of the deflexion (x), do not superpose themselves when up and down. "e" represents the permanent deformation we discussed before. The hatched surface represents the work wasting which can be considered as the energy absorbed by the torso, which can be represented under the following mathematical form :

$$a = y1\ dx - y2\ dx$$

This surface has been calculated. We have drawn the "up and down" curves with a step x = 2 mm. The top of the curve, W (x, y) has been estimated (x - the flexion, y - the normal force).
The "belt work" value represents the sum "x"."y" of the values "x" and "y". The surface of this work "A" is represented in figures 5 and 6. As the absorbed energy surface "a" has been measured, we can therefore determine the value of the energy absorbed on chest with the following equation :

$$E = \frac{a.W}{A} \text{ (kg.cm)}$$

On the other hand, the 5th, 9th and 10th tests values are represented in figure 11 according to the jack pressure. We have deduced therefrom that the absorbed energy is a linear function of the jack pressure (i.e. a linear function of the normal force), and that the curves slope become weaker when a 4 or 5 Bars pressure is reached.

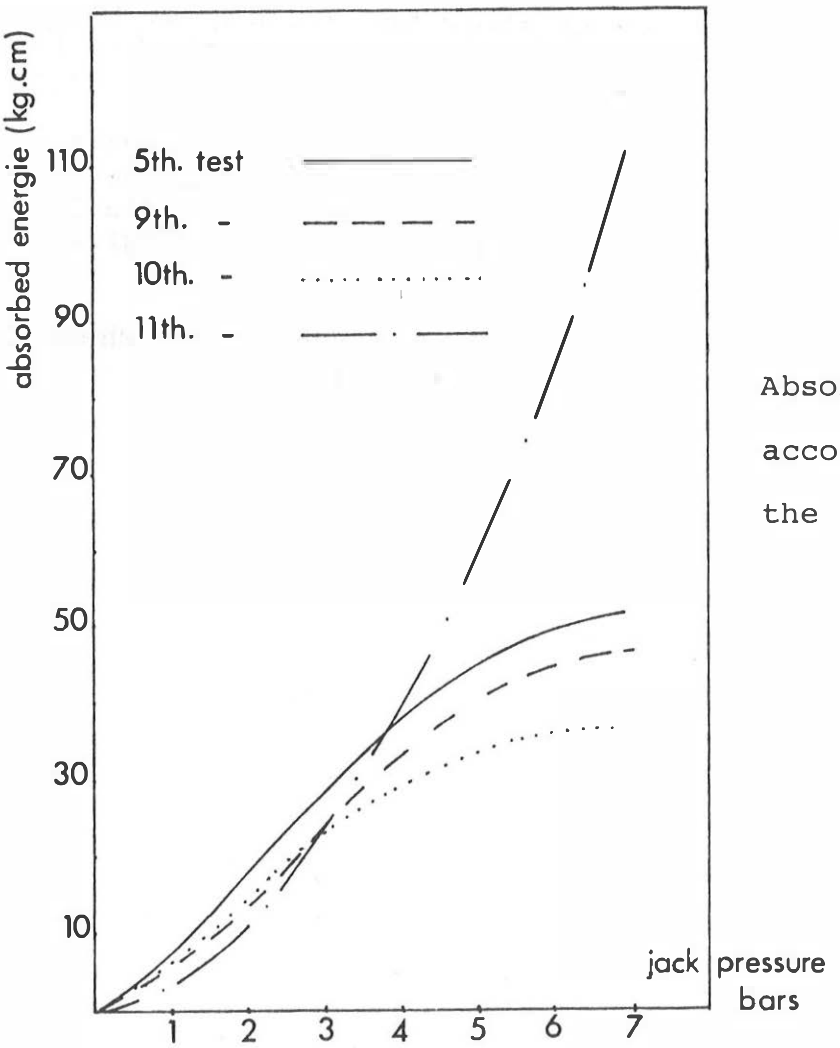


Fig.11 :

Absorbed energy according to the jack pressure.

The chest elasticity decrease as the normal force increase. The absorbed energy on chest become weaker and weaker.

In comparing the curves of figure 11, we find that the slope of the 5th trial (for alive monkey) is abrupter than the one of the 9th and 10th trials (for dead monkeys).The absorbed energy values are respectively of 51.79, 45.97 and 36.34 kg.cm for the 5th, 9th and 10th trials, always corresponding to 7 Bars.
As a result we can see that the absorbed energy by the chest of alive baboon is greater than the one absorbed by the chest of a dead baboon.

CONCLUSION :

1) The normal forces in terms of the chest deflexion are represented by a linear function. The middle slope has been estimated at 78 kg/cm for human cadaver, at 9 kg/cm for animal cadaver and at 4,5 kg/cm for alive monkey. On the other hand, the middle slope obtained for every test with alive or dead monkeys was of about 6,6 kg/cm.

2) The human thoracic rigidity is greater than the one of the animal.

3) The dead monkey thoracic rigidity is 100% more important as against the one of alive monkey and this for a flexion of 4,5 cm.

4) The absorbed energy on chest according to the applied force is represented by a linear function, the slope of which becomes weaker as the force increases, and particularly, when this one reaches 4 or 5 Bars (normal force : about 30 kg) for the monkey.

5) The absorbed energy on alive monkey chest is greater than the one observed on dead monkey chest.