TOLERANCE LIMITS AND MECHANICAL CHARACTERISTICS OF THE HUMAN THORAX IN FRONTAL AND SIDE IMPACT AND TRANSPOSITION OF THESE CHARACTERISTICS INTO PROTECTION CRITERIA

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In order to ensure the protection of vehicle occupants during occurrence of frontal and side impact collisions, several requirements must be satisfied.

. It is necessary to know the human tolerance limits, i.e. the physical parameter(s) that are most reliably correlated with the injuries sustained, and also to know the value of this parameter (or these parameters) corresponding to an acceptable injury severity which will be considered as the critical limit for human tolerance.

. Independently from the matter of human tolerance, in order to design protective apparatus and to assess its effectiveness, it is necessary to have a test impact dummy whose dynamic behavior is sufficiently similar to that of the human individual. This dummy should make it possible to verify conformity with the protection criteria, i.e. the findings of the measurements performed on this dummy should remain below the previously determined tolerance limits.

. The authors of this report had in view to compile a summary of the mechanical and biomechanical data pertaining to the human thorax collected from unembalmed, instrument-equipped cadavers during occurrence of frontal impact(for three-point seat belt wearers)and during occurrence of side impacts(for free falls onto unprepared surfaces or surfaces covered with shock-absorbent material, or during reconstitutions and simulations of real world accidents).

METHODOLOGY -

The test subjects were the unembalmed cadavers of individuals whose deaths had occurred fewer than four days previous to the onset of the test session. They were meanwhile conserved in a cold room (approximately 2°c) and were removed several hours prior to testing.

1. Test conditions - By and large, the violence of the frontal and side impacts was chosen so as to be as representative as possible of the severest real world accidents against which vehicle occupants are to be protected.

Case of side impacts : Side impacts can be grouped into two categories, as follows :

- Free falls : The human cadavers were released to fall sideways from various heights (from between 0.5 and 3 meters) onto flat, rigid surfaces that were either unprepared or had been covered with shock-absorbent materials.

They were made to fall upon their right or left sides so as to point up possible abdominal injuries (liver, spleen, etc...).

Simulations or reconstitutions of real-world accidents - The human subjects were seated at the level of the impacted zone of the vehicle that had been struck laterally. Prior to collision, the striking vehicles had velocities of from 45 to 73 kilometers per hour, depending on the tests.

Parts of the findings from these sundry tests have been written up in published reports (1 to 4). In this paper, we are presenting a summary of these findings.

Case of frontal impacts : Frontal-impact tests were performed in passenger compartments placed on sleds (sled tests). For these tests, the sled's pulse of deceleration as a function of time was simulated by braking tubes installed on the sled's forward part. Impact velocities ranged from 50 to 65 kilometers per hour depending on the tests, and sled stopping-distances were between 600mm and 900mm.

The body-retention device for these tests was a three-point seat-belt fitted with a belt retractor-blocker.

The cadavers were positioned in the right-front passenger seat or in the driver's seat. For certain tests, the seat-back was altered to accommodate the film-shooting apparatus for recording thoracic deflection over time. The films shot additionally enabled reliable evaluation of the thorax's relative position in relation to the shoulder webbing (chest strap), necessary for calculation of the force applied perpendicularly to the thorax. These data were used for the dynamic characterization of the human thorax for this type of retention.

2. Preparation of subjects - Preparation of subjects was appreciably the same for both frontal and side impacts, and it can be summarized as follows :

Case of side-impacts : The human subjects were equipped with a rigid metal rod that passed through the thorax along the median transverse plane between the fourth and fifth ribs. This rod, which was secured to the impacted part of the thorax, was fitted with guide marks designed to enable film recording of the deflection of the impacted thorax and half-thorax over time. For additional details, see reports (1) - (2).

For tests involving simulation or reconstitution of real-world accidents, only the material on whole-thorax deflection is available.

Case of frontal-impacts : The intrathoracic rod, which enabled film recording of the thorax over time, traversed the thorax along the subject's median sagittal plane. Its front tip was under the belt, in contact with the sternum. Its rear tip protruded some 20 to 30 centimeters beyond the subject's back, between the 4th and 7th dorsal vertebrae, depending on the anthropometry of the cadaver used. For additional details concerning this procedure, see report (5).

3. Anthropometric measurements - After every test the subjects were x-rayed, and then autopsied. Rib fragments were collected for the purpose of improved interpretation of findings, and also in order to fix the level of the physical parameters corresponding to the tolerance limits of living individuals by means of a skeleton characterization of the test subjects compared with that of living individuals exposed to accident risks.

The methods employed have already been described in reports (6)-(7).The latest developments will be submitted at the next STAPP Car Crash Conference(8).

4. Acceleration measurements - All the subjects were equipped with instruments i.e. with a tri-axial acceleration transducer attached at the level of the 4th and 7th dorsal vertebrae. In addition, whenever possible, we equipped the subjects in accordance with the so-called 12 acceleration method. This method was developed in the United States by the University of Michigan, and it has been described in several papers (9), to which the reader may refer for further details.

This method may be summarized as follows : The thoraxes of the human cadavers were equipped in the following manner :

. With a tri-axial acceleration transducer attached at T1 and T12.
. With four unidirectional acceleration transducers attached to the upper and lower parts of the sternum and the outermost parts of the 8th left and right ribs. The sensitive parts of these transducers were longitudinal in relation to the subjects.
. With two unidirectional acceleration transducers attached to the outermost parts of the medium arcs of the 4th left anf right ribs. The sensitive part of these transducers was transversal in relation to the human subjects.

Altogether, for these tests, 18 accelerations were measured on the periphery of the thorax.

The procedure used for these measurements was in conformity with the requirements of norm SAE J 211b for the T4 and T7 measurements, and as defined by report (9) for the other transducers.

TOLERANCE LIMITS OF THE HUMAN THORAX -

Previous reports (1 to 4) have shown that the maximum (or the value applied during 3ms) of the acceleration measured at T4 was by itself insufficient to fully account for the severity of thoracic injuries.

It may be that an analysis of the full set of data yielded by the instrumentation described above (18 accelerations measured on the periphery of the thorax) will make it possible, by taking into account the subjects' skeleton quality and their physical size characteristics, to establish a predictive function for thoracic injuries, which, it should be recalled, are essentially rib fractures.

For our immediate purposes, for both side and frontal impacts, we shall endeavour to correlate the occurrence of injuries with those physical parameters that are most frequently used to define the tolerance limits of the human thorax.

Skeleton quality of test subjects - This point is fundamental, and it may be summarized as follows :

Knowledge of the relative "resistance" of the subjects' skeletons enables a more finely detailed interpretation of the findings. To this end, intact parts of ribs are collected after every test and are characterized by means of mechanical flexion and shearing tests, as well as by morphometrical data (rib section and mineralization). These methods have been written up in several reports (6)-(7); they enable us to eliminate from the analysis those subjects whose bone resistance is abnormally weak, a fact that would tend to slant the interpretation of findings. The latest method of evaluation of the influence of interindividual variations utilizes factorial analysis (8). This method enabled definition of a B.C.F. (Bone Condition Factor) parameter that is representative of the skeleton quality of each individual subject. It was possible to make comparisons with the data for real world accident victims, since rib fragments were collected from individuals who had met sudden deaths without the occurrence of any alteration in their skeleton qualities. Comparisons between the data from the ribs of the test subjects and the data concerning the accident risk exposed population then made it possible to conclude as to the significance of the injuries that occurred during the tests.

In addition, knowledge of this relationship between the skeleton quality of the test subjects and that of live individuals enables definition of the level of the physical parameter(s) corresponding to the thoracic tolerance limits of the accident risk exposed human individuals.

THORACIC TOLERANCE LIMITS IN SIDE IMPACTS -

We shall deal, successively, with the following : with the BLUR parameter defined by Robbins (9), which is calculated from the transverse acceleration measured on the 4th rib located on the impacted side; with the "AVERAGE POWER" parameter used by Morgan (10), which is calculated from the transverse acceleration measured on the 4th dorsal vertebra; and with the relative deflection of the impacted whole and half thorax, used by Tarrière and Walfisch (1 to 3).

The BLUR parameter - The BLUR is calculated with the formula defined in reference : (9).

The findings are shown in Figure 1, in which will be seen that there is no simple correlation between BLUR and thoracic injuries, and that for a given BLUR value, a subject can be uninjured or can have incurred extremely severe injuries depending on his skeleton quality, even under closely similar conditions of impact. (This was the case in tests 191, 194 and 195 ; tests 192 and 193 ; and tests 196, 197 and 198.)

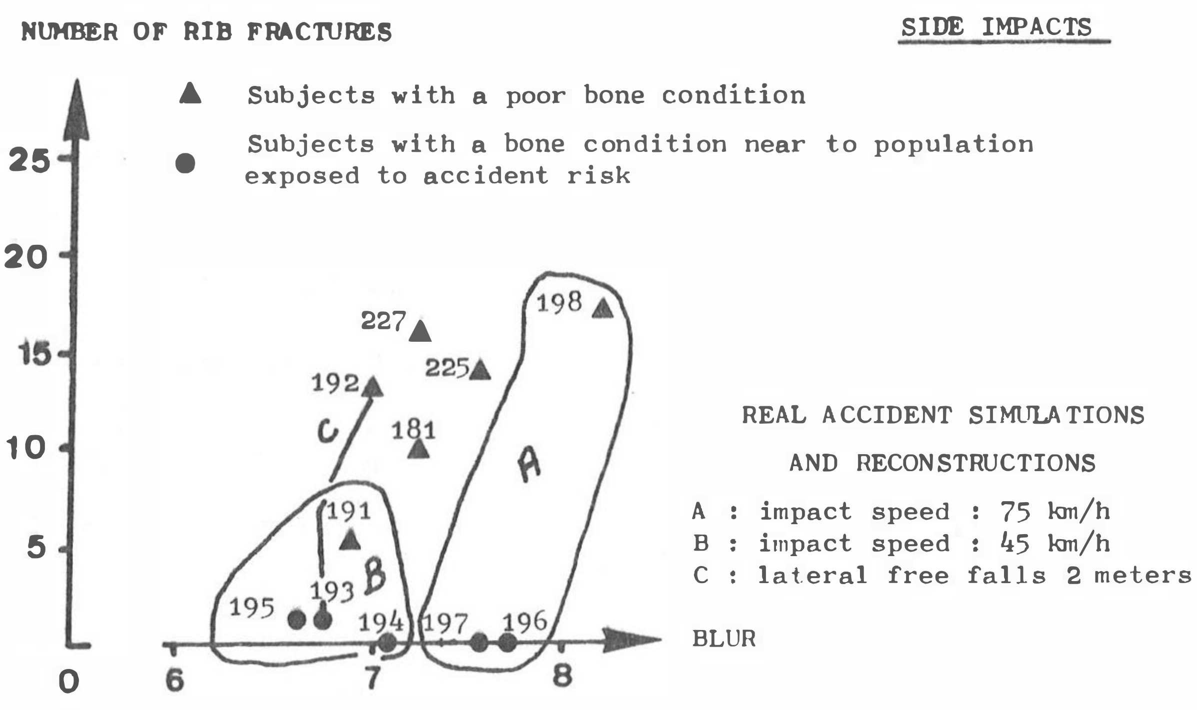

FIG: -1- NUMBER OF RIB FRACTURES VERSUS THE BLUR.

In addition,it will be seen (Figure 2) that BLUR enjoys a rather high correlation with the impact velocity of the side panel against the thorax (r=0,69 - N = 10). This is not surprising if we refer to its definition.

BLUR hence emerges more as an indicator of the variation in velocity of the surface that impacts the thorax than as an indicator of impact violence for the thorax.

These findings were obtained on the basis of ten tests with human subjects, including two free falls against paddings and eight simulations of real world accidents.

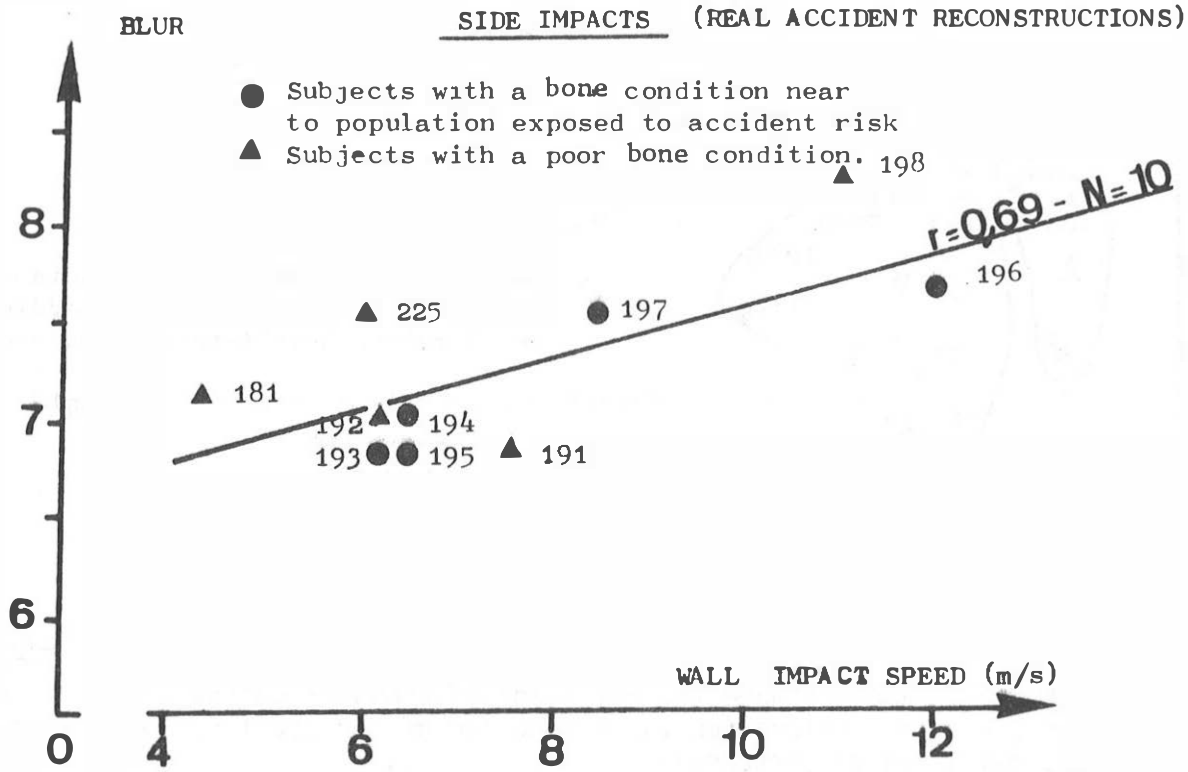

FIG: -2- BLUR VERSUS THE IMPACT SPEED OF THE WALL AGAINST THE THORAX.

"AVERAGE POWER"parameter - This parameter is calculated here by the following formula :

$$\frac{1}{T}\int_0^T \gamma(t) * \left[\int_0^t \gamma(u).du\right].dt$$

If we analyze Figure 3, showing the number of rib fractures as a function of AVERAGE POWER, we can get the same findings as with the BLUR, i.e.that there is no simple correlation between "AVERAGE POWER" and the thoracic injuries sustained,even if we consider separately those subjects that have closely similar skeleton qualities. It can also be noted that for a given "AVERAGE POWER",the human subjects incur a greater number of injuries in direct ratio to the poorer quality of their bone conditions.

In fact, if we group the tests performed under given sets of conditions (Figure 3), it emerges that, like "BLUR" at a lesser level,"AVERAGE POWER" is more an indicator of test conditions than an indicator of thorax impact violence.

This finding was yielded on the basis of 19 tests involving free falls,performed under the conditions described in the methodology section.

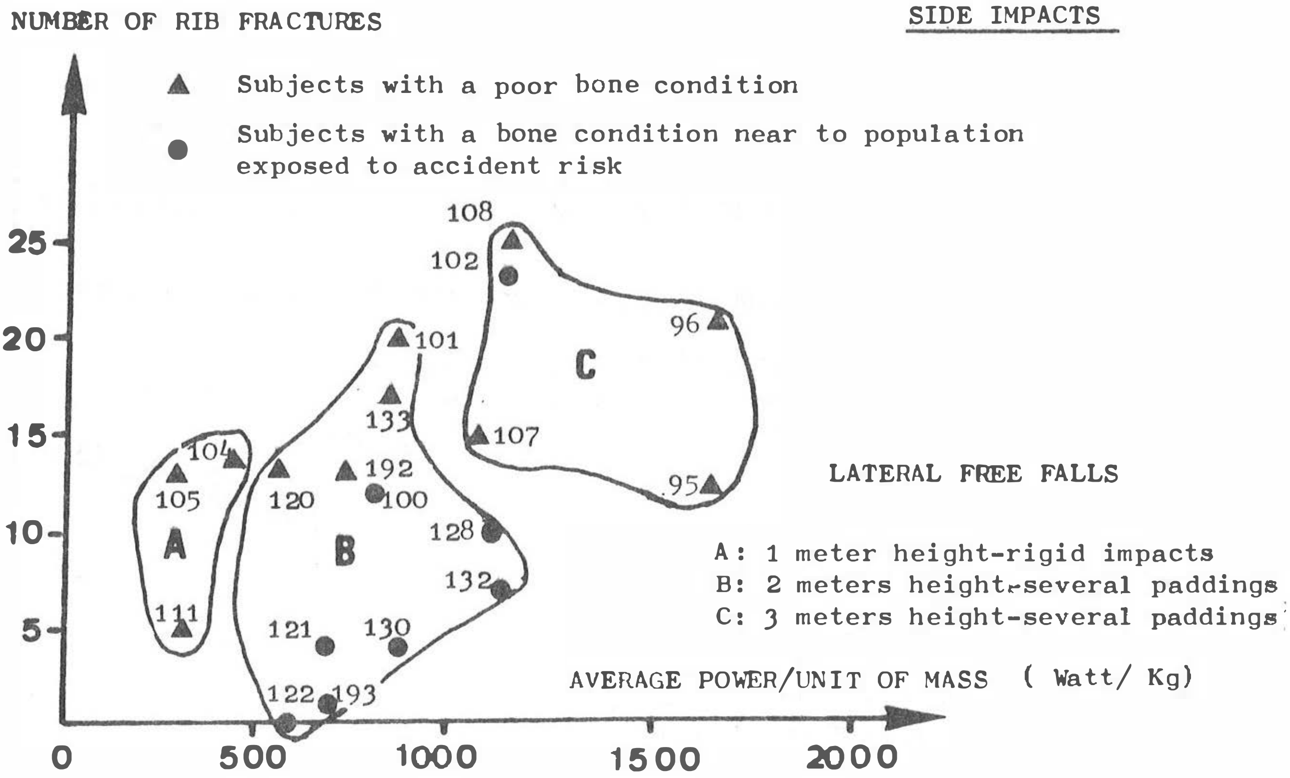

FIG: -3- NUMBER OF RIB FRACTURES VERSUS THE "AVERAGE POWER"

The last two parameters analyzed were the deflection of the impacted whole thorax and the deflection of the impacted half thorax. As compared with the preceding ones, these parameters have the advantage of considering the thorax as a whole rather than the acceleration (or a function of the acceleration)measured at one point (on a rib or vertebra).

Figure 4 indicates, on its abscissa, the relative deflection of the whole thorax (in percentage) and, on its ordinate, the number of rib fractures; this Figure shows that there is a fairly high correlation between these two parameters (R = 0,82 - N = 24). This finding is based on the data from 24 tests performed with human subjects under widely differing conditions of impact: 15 free falls and nine real world accident simulations and reconstructions.

It emerges from this finding that the relative deflection of the whole thorax is a reliable indicator of the gravity of thoracic injuries, whatever the test conditions and whatever the bone characteristics or anthropometrical features of the test subjects.

It then becomes possible to define the tolerance limits of the human thorax by analyzing more specifically those subjects whose skeleton quality was closely similar to that of the live individuals. A value of approximately 30 percent of the width of the whole thorax can be considered for the human tolerance limit, if we consider that seven rib fractures correspond to the maximum severity of the "safe" injuries that can be sustained by the human subject. (this number of fractures constitutes the threshold beyond which there is the risk of occurrence of flail chest (A.I.S. = 4) (16).

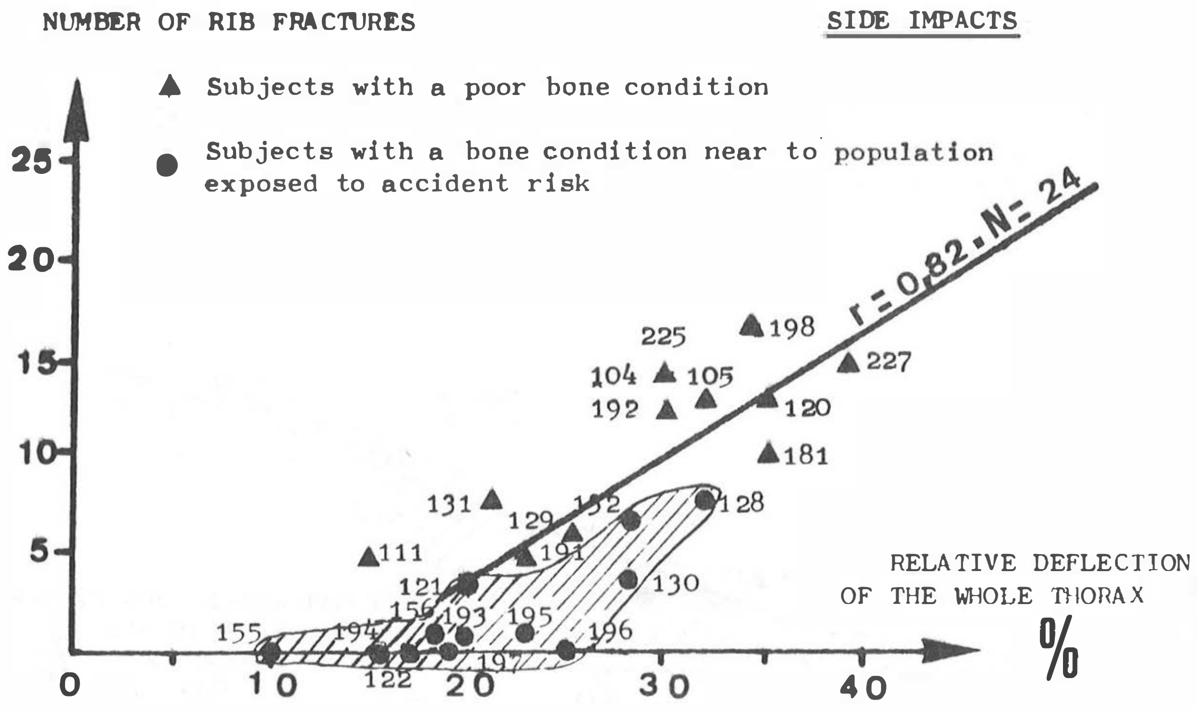

FIG : _4_ NUMBER OF RIB FRACTURES VERSUS THE RELATIVE DEFLECTION OF THE WHOLE THORAX

Remarks:_We chose to present the findings here by using the number of rib fractures as an indicator of thoracic injury severity. Identical conclusions were reached by considering the number of fractured ribs or the thoracic AIS.

- Analysis of Figure 4 also shows that it is possible to classify the subjects into two groups according to their skeleton quality, and that for a given injury severity, the thorax of a subject whose bone resistance is representative of that of the accident-risk-exposed-individuals can deflect 20% to 25% more than that of a subject having "poor" bone resistance.

The last parameter used was the relative deflection of the impacted half thorax. The findings are shown in Figure 5, where, on the abscissa, we have the relative deflection of the impacted half thorax and, on the ordinate, the number of rib fractures.

It will be seen that, as previously, there is a strong correlation between this parameter and the severity of thoracic injury (r=0,84-N=15), whatever the test conditions and whatever the skeleton quality and anthropometrical characteristics of the test subjects.

Proceeding as above, it is possible to fix the level of this parameter corresponding to the human tolerance limit by more specifically analyzing the findings acquired with those subjects whose bone characteristics showed that they had skeletal resistances representative of those of the accident risk exposed live individuals.

It then emerges (Figure 5) that a relative deflection of the impacted half thorax close to 35% can be considered as the critical limit for the human thorax tolerance.

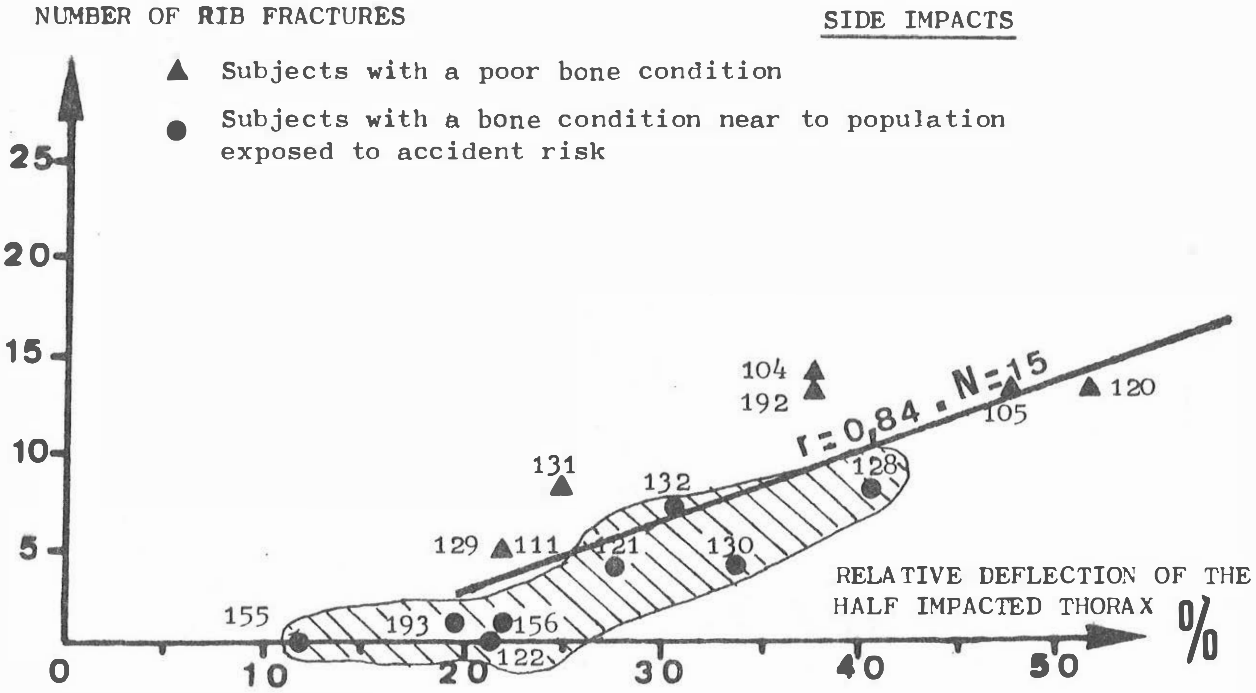

FIG: _5_ NUMBER OF RIB FRACTURES VERSUS THE RELATIVE DEFLECTION OF THE HALF IMPACTED THORAX

This is a highly significant finding for consideration, since the impacted half thorax is the most extensively deformed part of the thorax, the seat of the greatest number of rib fractures. In addition, it is the part of the thorax that is in contact with the vehicle's side panel, whose dynamic behavior (notably the ascending part of the force/deflection characteristic) must consequently be given first consideration for the protection, or the simulation, of the human thorax.

MECHANICAL CHARACTERISTICS OF THE HUMAN THORAX IN SIDE-IMPACT COLLISIONS -

Independently from the matter of the human tolerance limit, it is necessary to characterize the dynamic behavior of the human thorax in order to have satisfactory specifications for the designing of the dummy's thorax. To this end, in the performance of the free falls described above, we endeavoured to define the "force" characteristics on the basis of the relative deflection of the impacted half thorax, The curves obtained are shown in Figure 6 , where the force applied to the thorax is normalized as if the subjects had all weighed 75[x] kilograms . This transformation stems from the consideration of the size analysis (11).

Figure 6 shows that the ascending parts of the curves display but slight scatter and that they are hence not influenced by test conditions or by the subjects' skeleton qualities (for a given impact violence, the lesser the subject's resistance, the greater his deflection, the result being an increase in the number of rib fractures.)

These considerations enabled definition of a corridor of "normalized force /relative deflection" of the impacted half thorax (Figure 6). Since then,this zone has been used for the purpose of defining specifications for the APROD dummy[xx] (12,13,14), with which a protection criterion was defined that makes direct use of the findings previously acquired pertaining to human tolerance limits, i.e. maximum relative deflection of the half thorax = 35 percent of its half width. This datum, measured on the outside of the thorax, was transposed to the APROD dummy for the purpose of defining a protection criterion.

This protection criterion is based on the measurement of the internal deplacement of the dummy's piston . Experimentally, we found that it is linked to external deflection by the following equation :

Internal deflection (mm) = external deflection (mm) - 10 mm

This fixes the level of this criterion at the value of 42.5mm(52.5mm[xxx] -10mm).

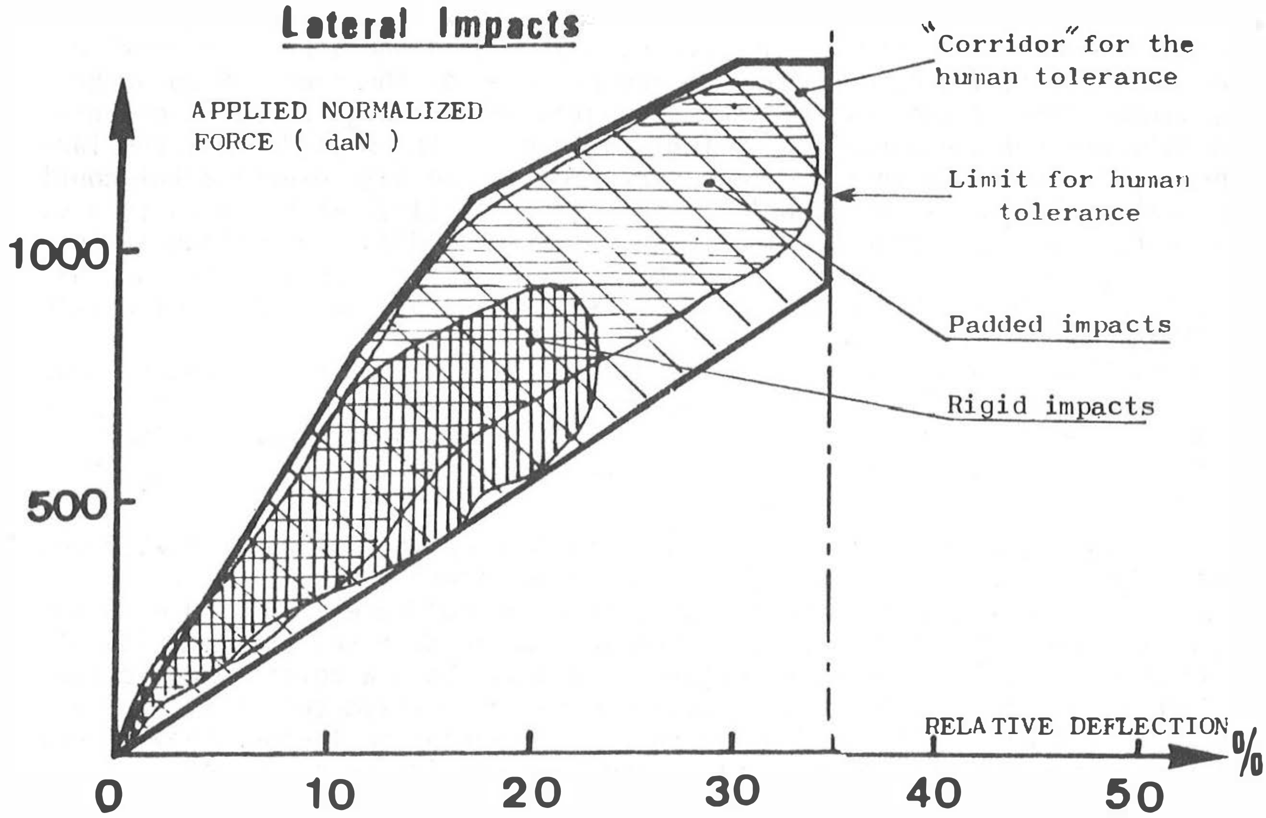

FIG: 6 FORCE/DEFLECTION CHARACTERISTICS OF THE HALF IMPACTED THORAX.

x Normalized force (75kg subject) = Measured force $\times \left(\frac{75}{\text{mass of the subject}}\right)^{\frac{2}{3}}$.

xx Dummy designed as part of the work performed under contracts with the European Economic Community and the French government (via the intermediary of the Transportation Research Institute). Its latest development has proven highly satisfactory from the standpoint of the simulation of the dynamic behavior of the human thorax during occurrence of side impact.

xxx 52.5 mm corresponds to 35 percent of the half width of the APROD dummy's thorax.

TOLERANCE OF THE HUMAN THORAX RESTRAINED BY A THREE-POINT SEAT BELT IN FRONTAL IMPACT.

The bibliographical data pertaining to the impact tolerance of the human thorax have frequently been yielded through tests involving impacts of a disk against the sternum. But, as reported by Fayon (5) further to the static testing of volunteer subjects, thoracic behavior differs depending on whether the forces are exerted on the thorax with a disk or whether they are exerted with a seat belt.

More recent publications are based on investigations involving effort measured at shoulder level (5,15). A synthesis of these investigations was presented by Eppinger (11) at the sixth E.S.V. conference; in this study, the efforts had been normalized as if all the subjects weighed 75 kilograms. A certain correlation emerged between thoracic injury severity and normalized effort measured in the strap at shoulder level. For a given effort applied perpendicularly to the thorax, the effort measured in the strap can vary to an extremely wide degree depending on the position of the chest strap anchoring points. One of the reasons that accounted for the high correlation between injuries and the normalized effort measured at the shoulder was the large proportion of tests that had been performed in the same experimental configuration (seat and position of belt anchoring points (15)). With a view to assigning a more general range of significance to the findings, attention in the following report will be devoted to the resulting effort applied perpendicularly to the thorax, obtained from analysis by means of films of the thorax's relative positions with regard to the seat-belt.

We shall also endeavour to establish a correlation between thoracic injury severity and the physical parameters emerging from the 18 accelerations measured on the periphery of the thorax, as well as the relative anteroposterior deflection obtained via the experimental setup described in the chapter on methodology.

Relative anteroposterior deflection - Maximum deflection was reliably measured in four tests whose findings are shown in Figure 7.

Because of their small number, these tests do not make it possible to define a relationship between relative thoracic deflection and the severity of the injuries sustained. However, Figure 7 suggests that a relative deflection of close to 30 percent of its thickness should be approximately that of the tolerance of a belt-restrained human thorax in frontal collision. (Any injury that does not cause occurence of flail chest is considered as "safe").

Normalized effort - The analysis involved 29 subjects. If, like Eppinger (11), we consider the normalized effort measured in the chest strap at the shoulder level, the correlation coefficient that links this parameter to the number of rib fractures is 0.68.

This correlation is improved if we use the maximum normalized resulting effort applied perpendicularly to the thorax and the number of rib fractures; $r = 0.73$ for the same subjects. Figure 8 illustrates this finding.

In this Figure, it will be seen that all the subjects located farthest from the regression line, in the direction of greater injury severity for a given thorax applied effort, are subjects whose skeleton qualities were not representative of those of individuals exposed to accident risk (excessive fragility).

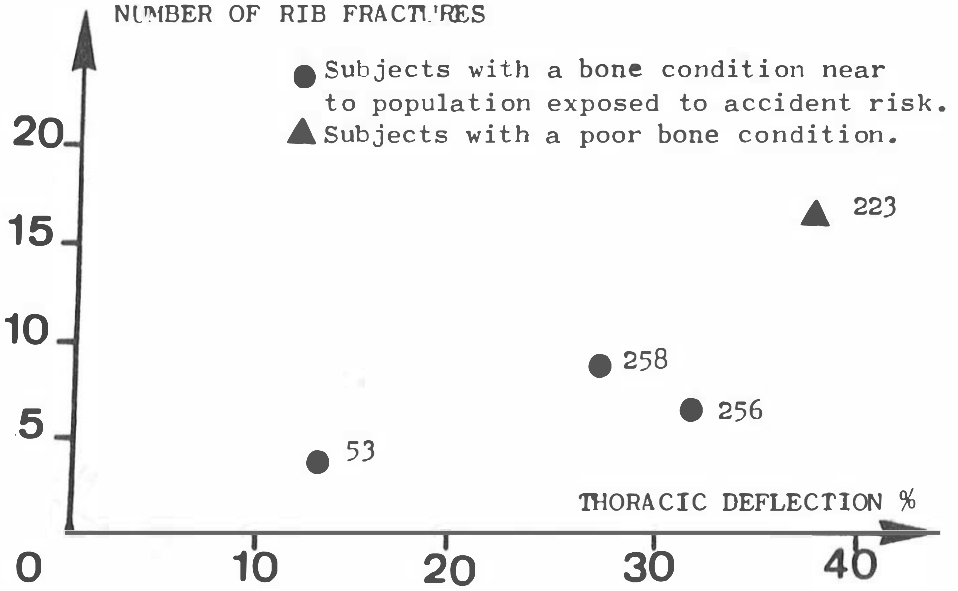

FIG: _7_ NUMBER OF RIB FRACTURES VERSUS THORACIC DEFLECTION
FRONTAL COLLISIONS-3 POINT SEAT BELT WEARERS.

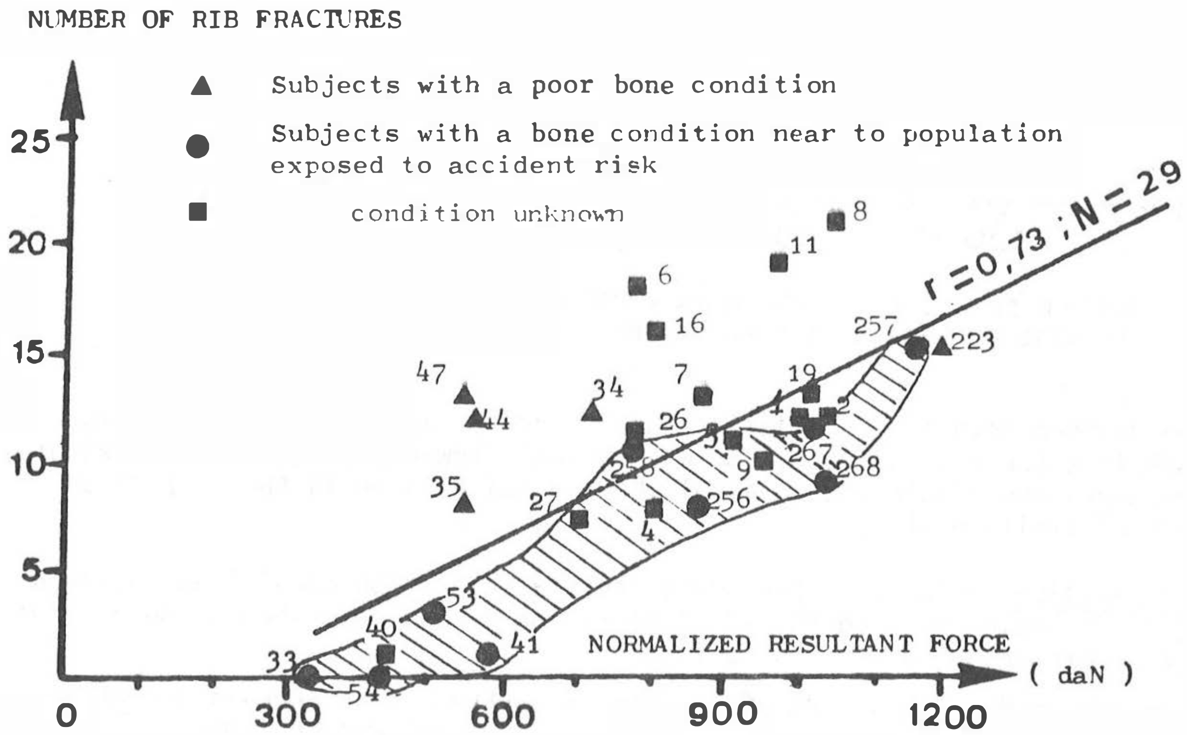

FIG: _8_ NUMBER OF RIB FRACTURES VERSUS THE NORMALIZED RESULTANT FORCE
FRONTAL COLLISIONS: 3 POINT SEAT BELT WEARERS.

In the light of these findings, therefore, it would appear that the maximum normalized resulting effort is a reliable indicator of thoracic injury severity. In consequence, it is possible to evaluate the maximum level of this human thorax tolerance parameter by analyzing more particularly the findings for subjects who displayed skeleton qualities closely similar to those of the live individuals (Figure 9 , r = 0.94, - N = 9) .

It is then seen that a normalized resulting effort of approximately 850 daN perceptibly corresponds to the human thorax tolerance of a man weighing 75 kilograms restrained during frontal impact by a three-point seat belt,

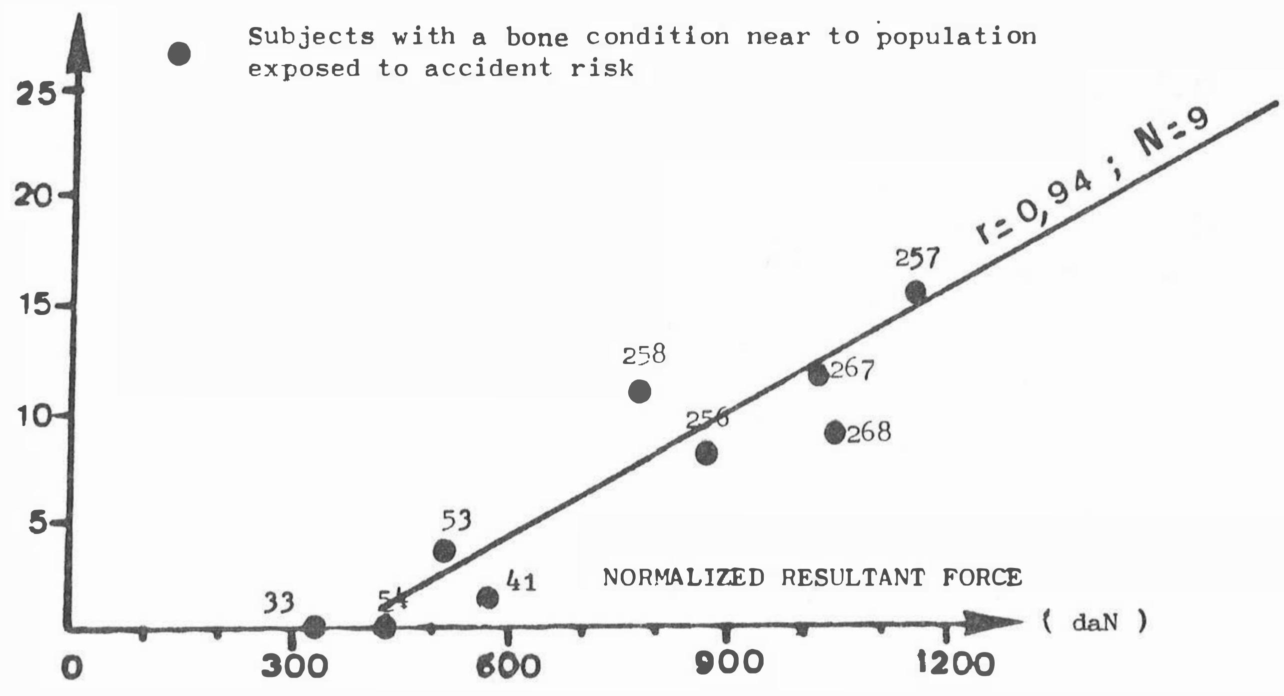

FIG: 9 NUMBER OF RIB FRACTURES VERSUS THE NORMALIZED RESULTANT FORCE FRONTAL COLLISIONS : 3 POINT SEAT BELT WEARERS.

The maximum severity of injuries considered as safe for human subjects was such that the associated A.I.S. was strictly lower than 4; seven to eight rib fractures constitute the threshold beyond which there is the risk of occurrence of flail chest.

Accelerations - Analysis performed under acceleration conditions involved 18 tests, for which we used the 12 acceleration method described by Robbins(9).

The parameters used were as follows :

- Parameter B — Logarithm of an integral taken over a specified number of the maximum points of an acceleration signal.
- Parameter Q — The maximum value of the first integral of the acceleration trace (velocity-like).
- Parameter QQ — The maximum value of the second integral of the acceleration trace.

(VI090 — The time interval between 10% and 90% of Q.)

- Parameter RQT; Q divided by VI090 .

As in the case of side-impact collision, we also used expressions homogeneous with a power :

. Average power defined by the following equation :

$$AVP1 = \frac{1}{T_2 - T_1} \int_{T_1}^{T_2} \underbrace{\gamma.(t) * \left[\int_{T_1}^{t} \gamma.(u) . du \right]}_{PO} . dt$$

. Peak power, which is the maximum of the PO function, above.

. Average power defined by the equation $AVP2 = \frac{0,5\ Q^2}{V1090}$

Q is in meter per second
V1090 is in second.

This expression was used by Morgan (10) at the eighth E.S.V. conference.

For all parameters defined above, and for all the possible accelerations, it emerged that only the various expressions of mechanical power, calculated on the basis of the resulting accelerations measured for the 12th dorsal vertebra, were sufficiently well-correlated with the injuries observed. This was notably the case for the parameter $AVP2 = \frac{0,5\ Q^2}{V1090}$, shown in Figure 10.

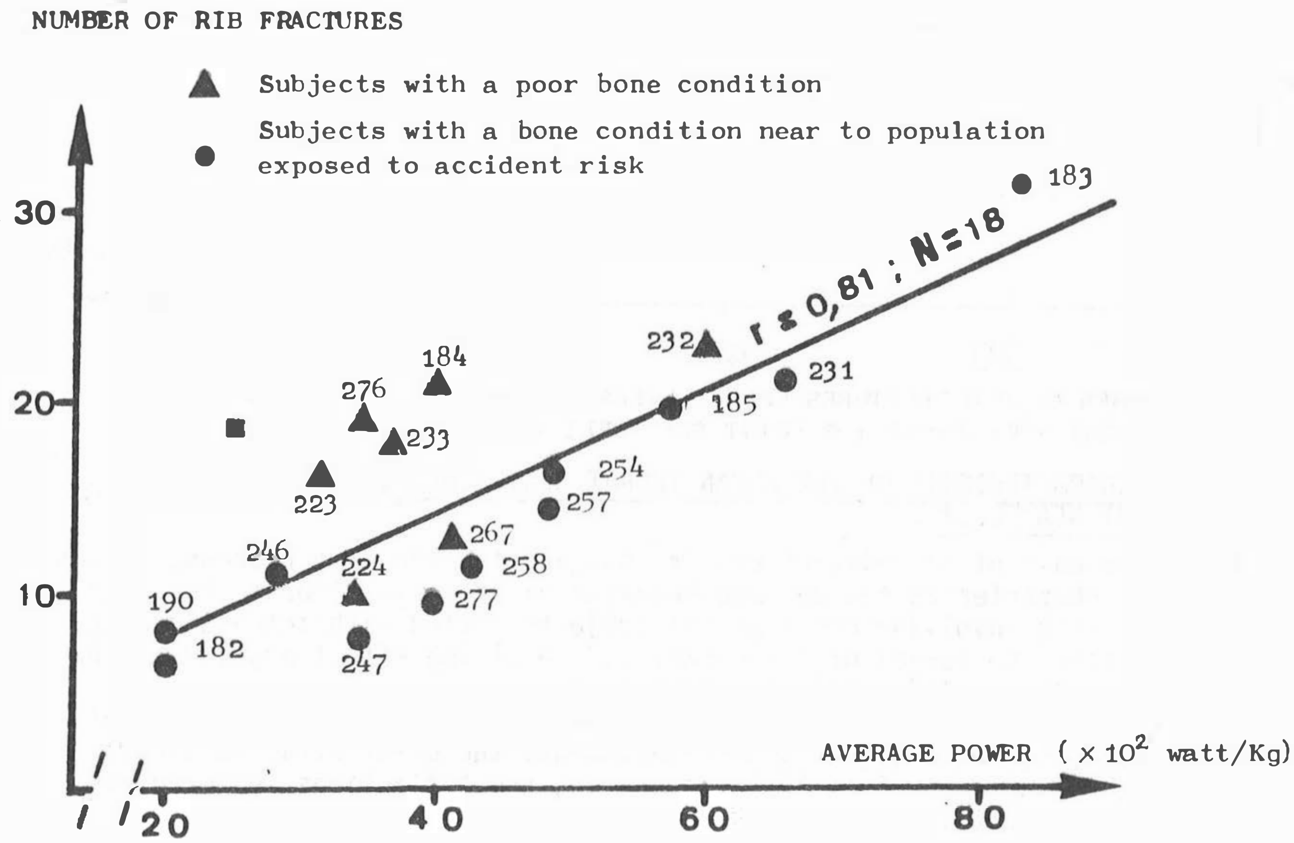

FIG: 10. NUMBER OF RIB FRACTURES VERSUS AVERAGE POWER ON T12
FRONTAL COLLISIONS : 3 POINT SEAT BELT WEARERS.

This correlation is improved if we only consider the subjects whose bone conditions were representative of those of living persons exposed to accident risks (Figure 11).

Figure 11 suggests that an "Average Power" of close(30.10^2 watts/kg) should be approximately that of the tolerance of a belt restrained human thorax in frontal collision.

Only the data from the so-called 12 acceleration method have been analyzed in the above, because the findings for the 4th and 7th dorsal vertebrae were not yet available.

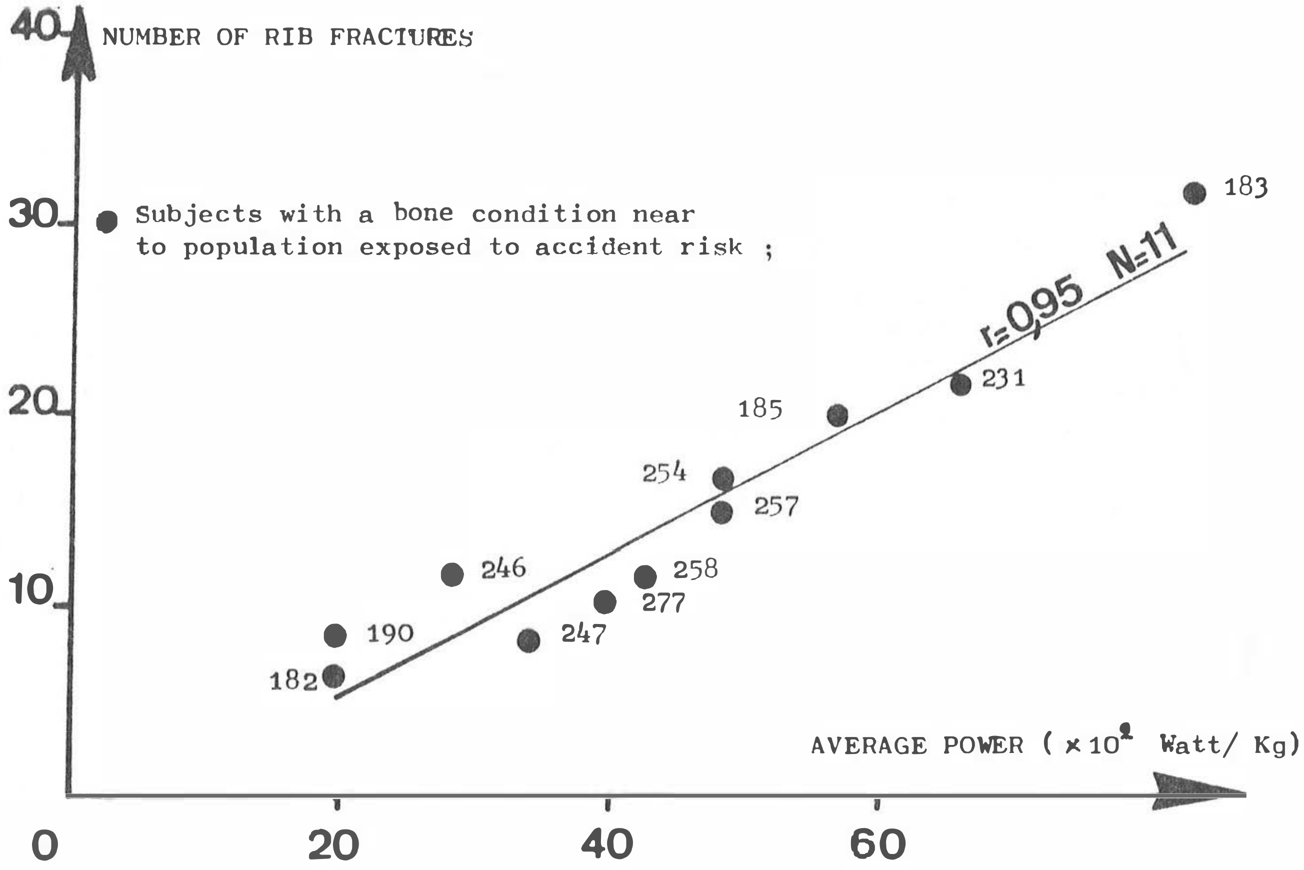

FIG: _11_ NUMBER OF RIB FRACTURES VERSUS AVERAGE POWER ON T12
FRONTAL COLLISIONS : 3 POINT SEAT BELT WEARERS.

MECHANICAL CHARACTERISTIC OF THE HUMAN THORAX RESTRAINED IN FRONTAL IMPACT BY A THREE-POINT SEAT BELT .

As in the case of side-impact collisions, and for the same reasons, it was necessary to characterize the dynamic behavior of the human thorax. For this purpose, in tests involving experimental subjects fitted with intra-thoracic rods, we plotted the curves of the normalized resulting effort applied on the basis of its relative deflection (Figure 12).

It will be recalled that the deflection is obtained from films, and that, for certain tests, beginning at a certain moment, the chest strap no longer presses at the rod level. From that instant on, the deflections measured are no longer representative of thoracic deflection at the place at which the measurement is made. This is the case for tests 257 and 267 (Figure 12),for which we plotted only the reliable part of the curve.

Frontal collisions

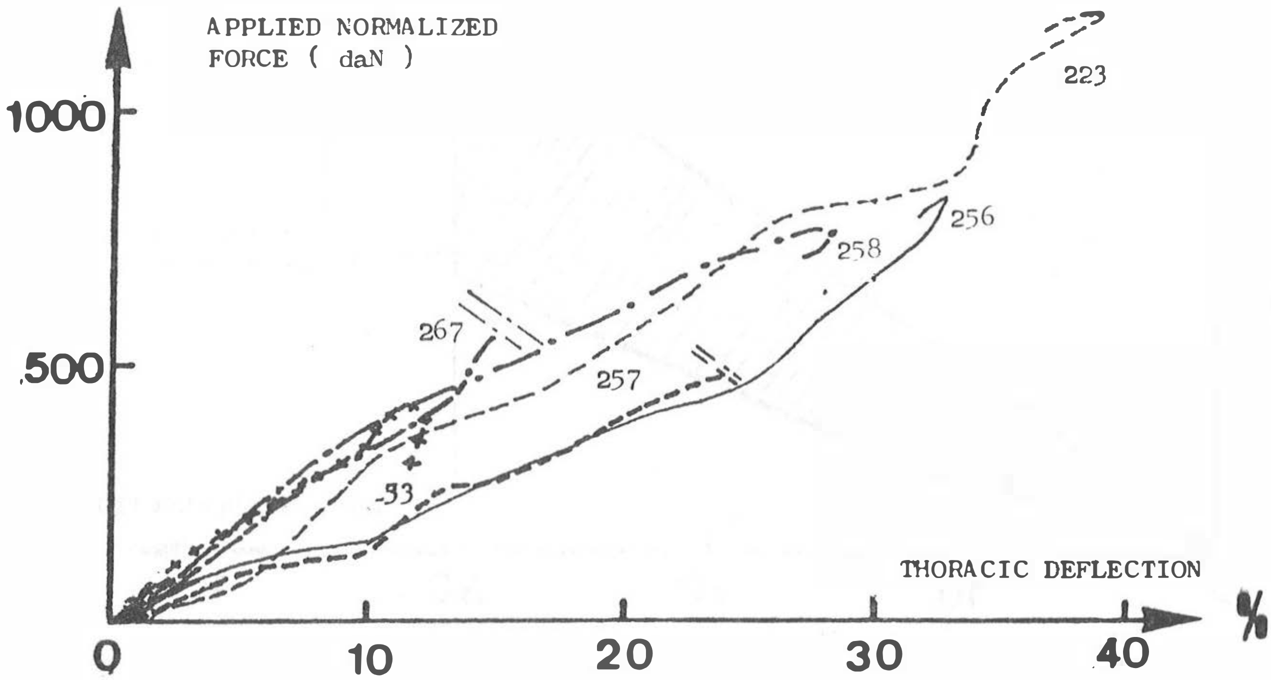

FIG: 12 FORCE/DEFLECTION CHARACTERISTICS OF THE THORAX FOR 3 POINT SEAT BELT WEARERS.

In this Figure, it will be seen that, under the conditions of the tests performed (velocity variations ranging from 50 to 65 kph), the ascending portions of the curves are fairly similar whatever the test conditions and whatever the cadaver's skeleton quality (subjects 256 and 258 displayed skeletal qualities that were quite comparable to those of the young live persons).

These findings, which require a further work, enabled definition of a "Normalized resulting effort/Relative deflection" corridor, in which will have to be situated the dynamic characteristic of the thorax of a suitable dummy in the case involving restraint by a three-point seat belt in frontal impact.

This corridor is depicted in Figure 13. Its lower and upper limits correspond to the envelope of the ascending portions of the curves plotted from the various cadavers used. In addition, the levels of resulting effort and of relative deflection corresponding to the "safe" limits for the human thorax previously established for this type of restraint are also shown in this Figure.

The thoracic stiffness appeared higher in lateral direction than in A.P. direction; that is no surprising according to the rib cage shape.

In addition, in frontal impact the rigidity of the human thorax defined above is far lesser than that of the PART 572 dummy defined in norm 208. (Under different test conditions) .

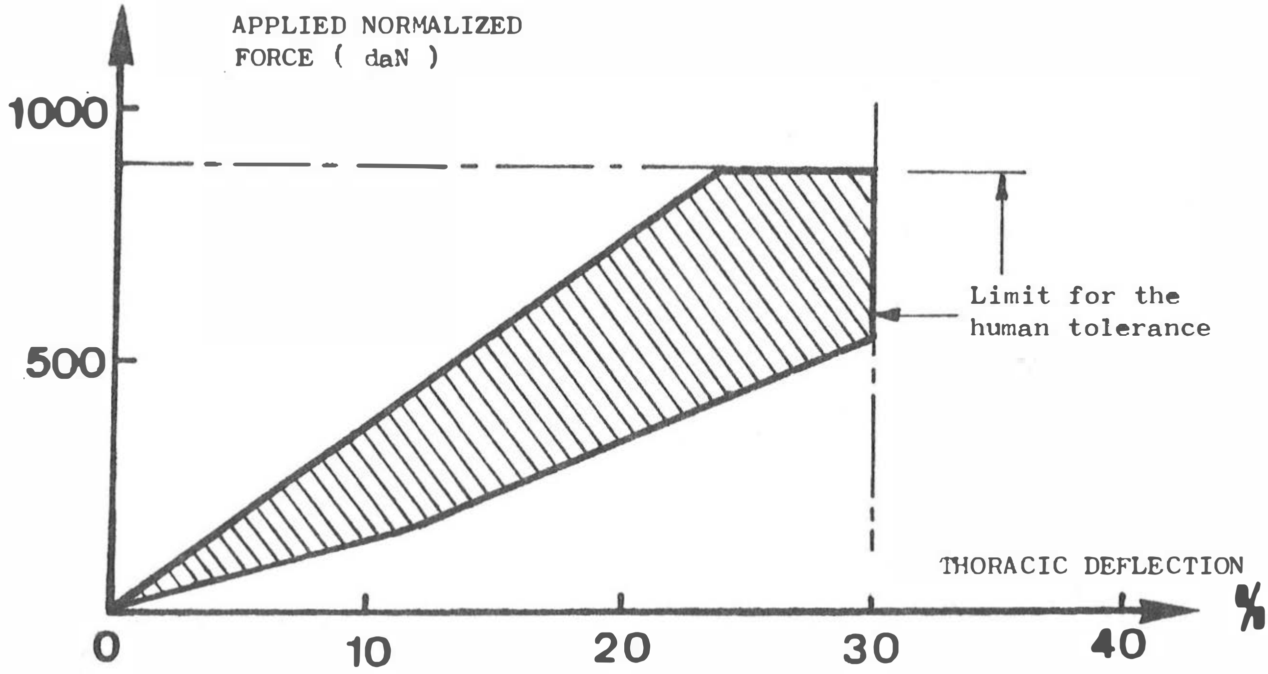

FIG:-13-"CORRIDOR"OF FORCE/DEFLECTION CHARACTERISTICS OF THE THORAX
FRONTAL COLLISIONS: 3 POINT SEAT BELT WEARERS.

CONCLUSIONS .

1. For side-impact collisions, data have been obtained concerning the tolerances of the human thorax. These data show that the relative deflection of the impacted half-thorax (and whole thorax) is a far better indicator of thoracic injury severity than the parameters derived from measurement of accelerations on its periphery (notably, "blur" and "average power", which emerge more clearly as indicators of impact violence.)

It also appeared indispensable to take the test subjects'skeleton quality into consideration for the purpose of defining the thorax tolerances of live human individuals.

A value corresponding to 35% of the relative deflection of the half-thorax can be considered as a limit for its tolerance, if we consider particularly those subjects whose skeleton qualities were comparable to those of the live individuals exposed to accident risk.

We also obtained dynamic characteristics of "Effort/Relative deflection", which enabled the designing of the "APROD" dummy, whose dynamic behavior is closely similar to that of the human being.

A protection criterion corresponding to this dummy was defined by transposing the above-stated critical admissible value into a measurement of internal deflection on this dummy.

2. For frontal collisions involving restraint with a three-point seat belt.
By analysing more particularly those subjects who displayed representative skeletal quality, we obtained thorax-tolerance data, as follows :

For deflection, it would appear that a value of 30% approximates that of the tolerance of the human thorax.

The resulting effort is a reliable indicator of thoracic injury severity; a value of approximately 850 daN can be considered for the tolerance of a man weighing 75 kilograms.

With respect to accelerations, it emerges that the "average power" obtained on the basis of the accelerations measured on the 12th dorsal vertebra was correctly linked to the occurence of the injuries observed. Since the position of T12 is fairly low on the spinal column, there are grounds for contemplating the use of a chest protection criterion based on acceleration measured at the level of T7. The findings for T7 will perhaps enable greater ease of transposition to an impact-test dummy, and should be presumptively more meaningful.

The "Effort/Deflection" characteristics obtained enabled definition of a corridor in which should be located the dynamic characteristic of the thorax flexibility of a dummy in frontal-impact texting. It will then be possible to define the protection criterion related to such a dummy.

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Findings and opinions reported here are those of the authors.

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