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STUDY OF IN THE FIELD ROLL OVER ACCIDENTS AND COMPARISON WITH ROLL OVER CRASH TESTS

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1 - INTRODUCTION

First, the notion of turning over must be defined. It is advisable to call turning over any reversal of the vehicle, either turn around or transverse or combining the two motions. The turning over can be limited to a simple upsetting (rotation of a quarter of round) or to be going on, the vehicle making one or several rolls.

This type of accidents, in spite of a relatively important frequency (about 10 % of accidents) is little studied, doubtlessly because it involves a very problematical aspect and that it seems difficult to individualize a lesional typology of turning over, at reverse of the various other types of impacts.

The motion of an overturning vehicle spreads energy dissipation over a very long time than during a shock against an obstacle, even if at the origin of the turning over, there was initially a shock against an obstacle. But the motion of a free body inside the tipping vehicle is influenced by so many factors that it is not really predictable.

The lesions of occupants are subjected to the same uncertainty and one sets out uninjured of several rolls, when a small overturning would be severely resented by another.

The litterature is little prolix about this subject. The majority of authors notes however that the mortality is high in that type of accident, all the more that there is an initial impact (1). But particularly, all accidentology studies insist on the high frequency of ejections during overturning, and are in agreement for recognizing the ejection as an aggravating factor. PATEL and GOT (2) state that overturnings constitute generally 10 % of the shocks.

Among those, 25,5 % of occupants were ejected and one on two of them dies of his injuries. CAMPELL (3) insists also on the eminently baneful role of ejection for any type of accident, but remarks that this mechanism is most often linked to overturning.

The overturning problem, if it is little often studied into its entity (most time, that type of accident is described during a more overall study) has meanwhile interested searchers, who have tried to carry out a mathematical model.

2 - SAMPLE CHARACTERISTICS

This study covers 1 053 light vehicles, involved in traffic accidents, studied in bidisciplinary accident investigation, in the Rhône-Alpes area and in the Salon-de-Provence area.

These accidents involved 1 669 occupants. This sample was divided into two groups : on one hand the vehicle having undergone a rollover, on the other hand, vehicles involved in other types of impact excepted bumps with pedestrians of two wheeled vehicles.

In the first group, only overturning accidents without primary or secondary major shock were taken into account. Therefore, it is well the overturning mechanism which is at origin of lesions. All vehicles taken into account are light vehicles. 111 vehicles were retained according to these criteria. They involved 218 occupants.

The group of accidents other than overturning concerns 942 vehicles and 1451 peoples.

Among the 218 peoples involved in overturning, 29 worn a safety belt. 76 persons were ejected. In the 2nd group, among the 1 451 involved persons, 254 were belted and 171 were ejected.

3 - FACTORS CHARACTERIZING THESE ACCIDENTS

3.1. Weight of vehicles

It could be expected to find in the weight of vehicles a variable influencing on the existence or not of an overturning.

In fact, the weight distribution is appreciably identical in the two samples : accidents with overturning, accidents without overturning.

One remarks a light decrease of overturnings frequency for categories less than 700 kg, and from 700 to 800 kg, categories corresponding more often to French vehicles with front wheel drive, with large clearance springing.

3.2. Number of shocks

One of the selection criteria of the sample is the absence of a major shock other than overturning. In spite of that, a number of vehicles undergo either a small initial shock (against a kerb, for example) or bumps during the rolls (against trees, milestones, etc...)

In the sample of vehicles having undergone other types of bumps, one finds that 79,3 % of vehicles have undergone a single impact, 19,3 % have undergone at least two shocks. In 1,3 % of instances, it was not possible to precise the number of shocks.

3.3. State of the carriageway

The state of the carriageway does not appear, on that sample, as having a prominent role in the origin of overturnings :

	Overturnings	Other
Dry carriageway	71,4 %	76,2 %
Wet carriageway	27,6 %	19,6 %
Snow or frost	1 %	0,7 %
Gravels	0 %	0;5 %

Distribution according to the state of carriageway

If effectively, the "wet carriageway" factor increases appreciably the risk of overturning, one does not find again the influence of graveled carriageway the low frequency of these conditions in the geographical situation of this study.

3.4. Plane layout roads

The following table shows the significant influence of the roadway layout on the type of accident. The "intersection outside bend" is a great provider of overturnings. The bends negotiated at too high a speed entailed a beginning of road leaving outside the bend and at the time when, on the side of road leaving, the wheels are contacting the shoulder, the difference of ground adhesion, associated with a reflex steering deflexion, can entail an overturning towards outside. One founds also road leavings without skidding, the overturning coming then from the tipping down, outside the road bed.

Intersections are more often generating shocks between vehicles, which are sometimes followed by overturnings, but these accidents have not been taken into account, for the primary shock is always the strongest.

Straightline roadways are the seat of numerous overturnings, and there, only an error of driving can explain these accidents :

	Overturnings	Other
Intersection	6,3 %	32,7 %
Straight line	41, 4 %	43,2 %
Intersection outside bend	52,3 %	24,1 %

Distribution according to the plane layout

3.5. Category of road

The highway traffic promotes overturning accidents, since more than a quarter of these accidents occurs on highways, when only a eight of other accidents is found on this type of network.

The speed, the shoulders problem, but also the bump on guardrails promote, in fact, the occuring of overturnings.

Reversedly, the urban ways seem little proper to this kind of accident.

	Overturning	Other
Highway	26,9 %	16,6 %
National Road Outside Agglomeration	37 %	39,2 %
Country Roads	28,7 %	26,8 %
Urban	7,4 %	21;4 %

Distribution according to roads categories

3.6. Locations

In connection with the two previous paragraphs, one finds that 90 % of accidents with overturning occur outside agglomeration. This appears as logical, since the notion of high speed, the shoulders problems and the presence of curved layouts are obviously the fact of traffic ways outside agglomeration.

4. SEVERITY AND DISTRIBUTION OF LESIONS

4.1. Overall severity

The severity index of injuries (AIS) was used for quantifying the severity of occupants injuries, on one hand those involved in an overturning accident, on another hand those having undergone different accidents.

Considering the overall AIS for all occupied places, one achieves the following distribution :

AIS	Overturnings	Other
O	18,8 %	21,5 %
1	28,8 %	26,3 %
2	17,4 %	15,7 %
3	12,5 %	14,9 %
4	2,2 %	6, %
5	2,9 %	3, 3 %
6 and more	17,4 %	12, 3 %

°° One remarks that overturnings generate more mean lesions (AIS 1 and 2) and less severe lesions (AIS 3-4-5)° than accidents without overturning.

But it must be well stated that there is also in the "overturning" r sample less uninjuried and clearly more fatalities. This difference can be explaines by the ejection frequency in overturning, which, we shall see that more in detail, generates a little situation of "all or nothing", that is a less distributed risk as for other mechanisms of lesions with either minimal lesions of fatal ejections, the ejection severity depending not or little, in the fact, of the vehicle but of the environment.

If one carry out at finer comparison, by separating front occupants of rear occupants, in overturning, one finds several elements on the curve 1.

For front occupants, the severity rate in overturning and in other types of accidents, is very nearby up to AIS 3, with, however, a little less injured and a little more light injred in AIS overturnings (the curves are crossing between AIS 3 and AIS 2).

Severely injured people are less frequent in overturnings, and this is observed by a flatter curve. Then, the slope suddenly uprights again in connection with the high mortality rate.

At level of rear occupants, in the two categories, one finds a percentage of uninjured people clearly higher than that of front seats. As for front seats, this rate is slightly lower for rear passengers in overturning. Up to AIS 4, occupants in overturning are less represented than in other shocks. But for AIS 5 and up values (very severely injured and dead persons) the slope of the curve is very higher in overturning.

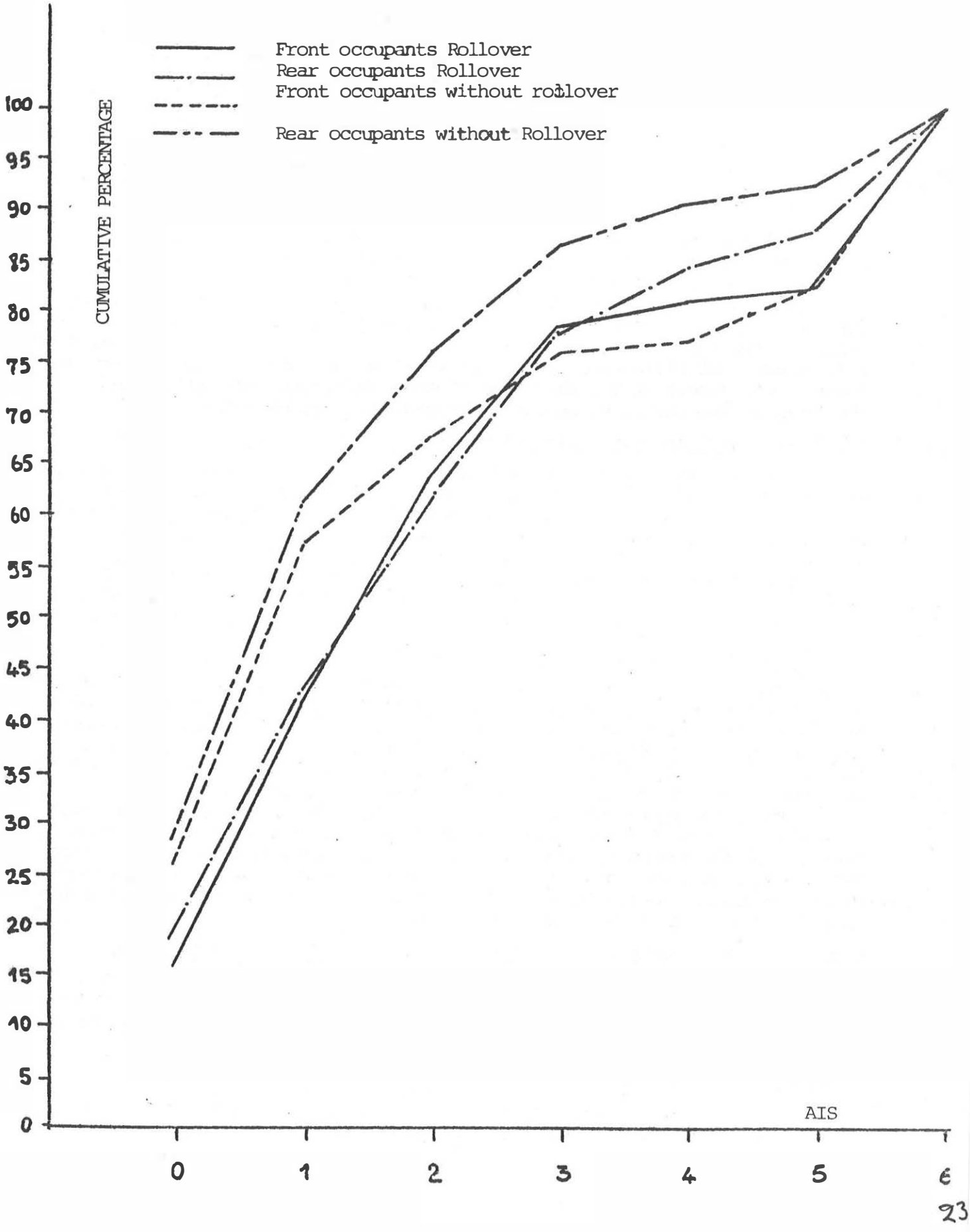
The curve representing the overall severity injuries of rear passengers without overturning corresponds to the less injured persons category, which is currently admitted.

4.2. Ejection

It is conventional to admit (4) that overturning promote the ejection, and that the latter constitutes an aggravating factor in this type of accident.

4.2.1. Ejection frequency

Considering, in following tables the ejection distribution in function of occupied places, one finds on one hand that the ejection rate is multiplied by 3 or 4 in overturning. On another hand, in overturning accidents, it is the rear occupants who have the greatest risk to be ejected. This figures must be blended, for a part of rear occupants were belted. Also, if we relate the risk to unbelted occupants, the ejection rate at front seats turns form 30,9% to 38,3 %, value neighbouring the ejection percentage of rear seats.


Front occupants Rollover
Rear occupants Rollover
Front occupants without rollover
Rear occupants without Rollover
CUMULATIVE PERCENTAGE
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
AIS
0
1
2
3
4
5
6

	Overturnings			Other		
	Nbre	Ejected	Belted	Nbre	Ejected	Belted
Front	149	46 (30,9%)	29 (19,5%)	1082	124 (11,5%)	254 (23,5%)
Rear	69	30 (43,5%)	-	369	37 (10 %)	-
Total		76 (34,9%)	29	1451	161 (11 %)	254

Other elements can interfere with the ejection risk : particularly for the driver, it seems that the presence of the steering wheel and steering column limits the exit possibilities on left hand side.

The ejection rate in the other types of shock is, at reverse, higher for front occupants. This is all the more true if one considers only not belted occupants. The ejection risk at front seats being then 50 % higher than rear seats, that difference can be explained by the large representation of front shocks (about 72 %), this type of shock deforming more particularly the front of the car body, promotes the opening of front doors.

4.2.2. Severity associated with ejection

For belt estimating the importance of ejection on lesions severity, one has carried out 4 graphical representations of distribution concerning the front occupants, involved in an overturning, the rear occupants of that same type of accident, then front occupants having undergone other types of accidents, finally the rear ocuupants of the same sample.

Each graphical representation comprises a cumulative frequency curve AIS with ejection and without ejection, and for front occupants, one has separated a curve combining belted occupants.

Graphic of front occupants in overturning

One finds a glance that there is no uninjuried person ejected. Then the category of lightly injured persons is significantly less represented. The mean slope of the curve corresponding to severely injured persons is higher than the two other, in spite of an inflection AIS 4 level, probably due to the smallness of the category. Reversedly, the number of dead persons is high as shown by the sudden upgrading of the curve as its end.

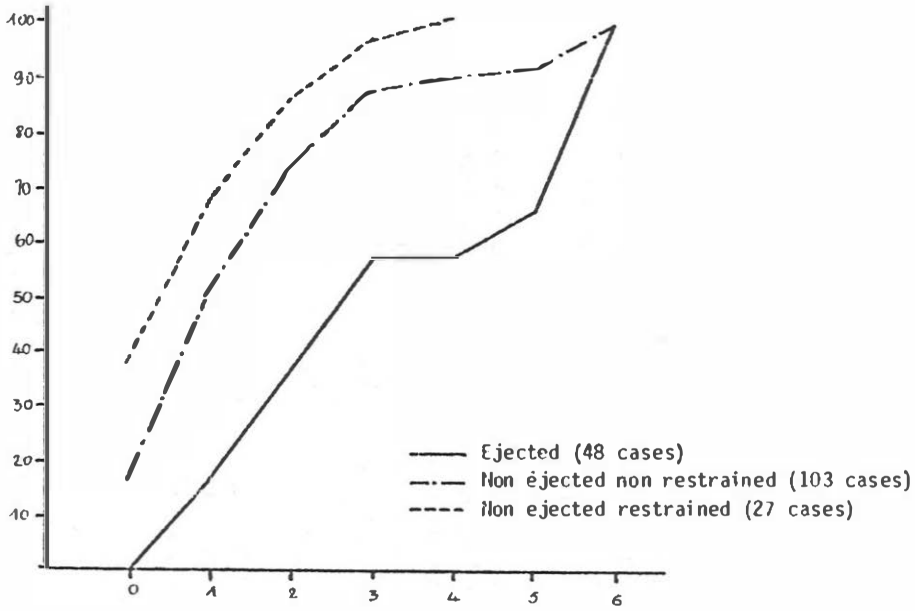
The curve representing the unjected, unbelted occupants category is, in the whole, less severely affected. Up to AIS 2 the slope is higher than that of ejected occupants, uninjured and slightly injured persons being more represented, when for major values, the curve is significantly less increasing. Belted occupants undergo less severe lesions. One does not find an AIS higher than 4 and 37 % of occupants are uninjured.

Graphic of front occupants involved in accidents other than overturnings

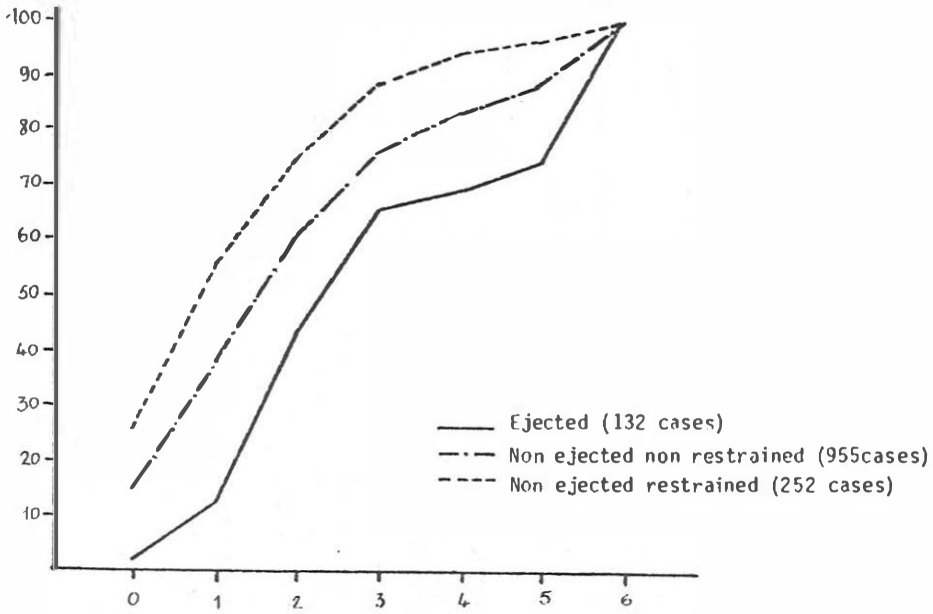
The same phenomena as previously are observed, but at a lesser degree, the gap between the three curves being smaller. One states the belt efficiency particularly at the level of high AIS, where the gap clearly increases in relation with the curves of unbelted occupants.

Graphics of rear occupants in overturning and without overturning

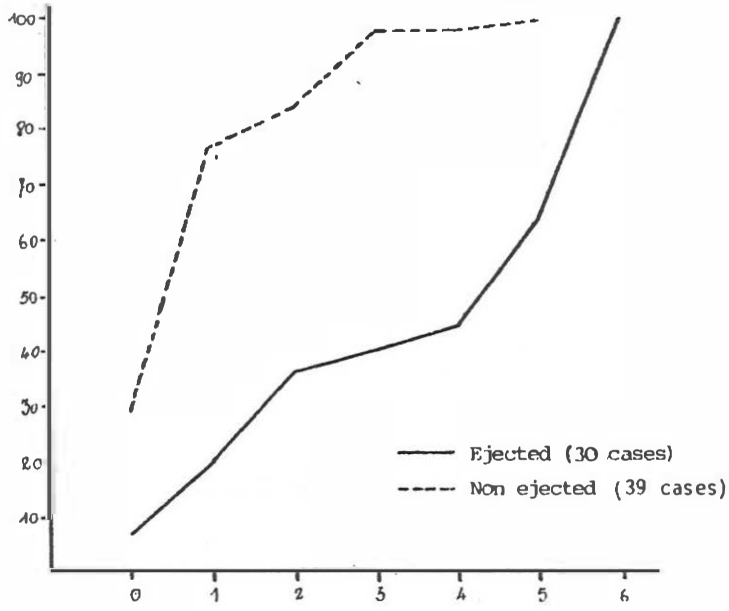
One finds in the aggregate a severity clearly higher of ejected occupants particularly in overturning where curves are very far one of the other.



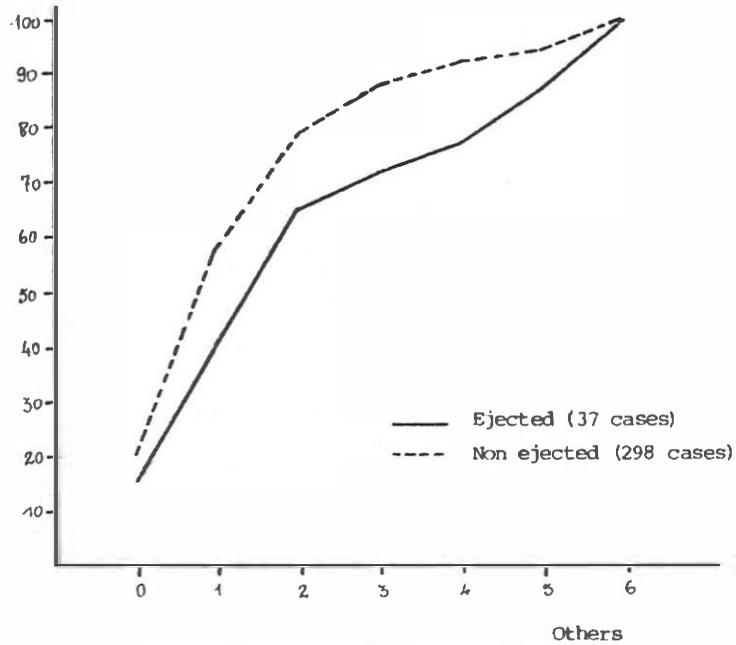
ROLLOVER



OVERALL SEVERITY OF FRONT OCCUPANT



Rollover



Others

Overall severity of rear occupants

4.2.3. Compared mortality of two samples

	Overturnings (218 occupants)		Others (1451 occupants)		Total (1669 occupants)	
	Ejected	Unejected	Ejected	Unejected	Ejected	Unejected
Nbre Occup	76	142	161	1290	237	1432
%	34,9	65,1	11	89	14,2	85,8
Nbre killed	29	9	37	142	66	151
%	38,2	6,3	23	11	27,8	10,5
TOTAL killed %	17,4		12,3		217	

Frequency and mortality rate

In the aggregate, the mortality rate in overturning is perceptibly superior at that stated for the others types of shocks.

This may seem paradoxical because the overturning is a slow phenomenon; not generating high strenghts at occupants level at reverse of forehead or lateral shock. Analysing more in detail the talble, we found that this high mortality is essentially due to the ejection particularly frequent in this type of shock.

In fact, for the occupants, subjected to an overturning but unjected, the mortality rate is little high and clearly lesser than the average rate of the sample (about twice lower).

Reversedly, when there is ejection, the risk to be killed during an overturning is considerable, this rate varying from 6 to 1 between ejected and unjected.

For the other types of shock, the ejection remains an aggravating factor, even if its influence is lesser. The risk to be killed is multiplied by 2 the ejection. One must remember here that the recruitment mode of this study has its origin at the hospital. The thing is, therefore, accidents are more severe than the average, which explains a very high rate of killed.

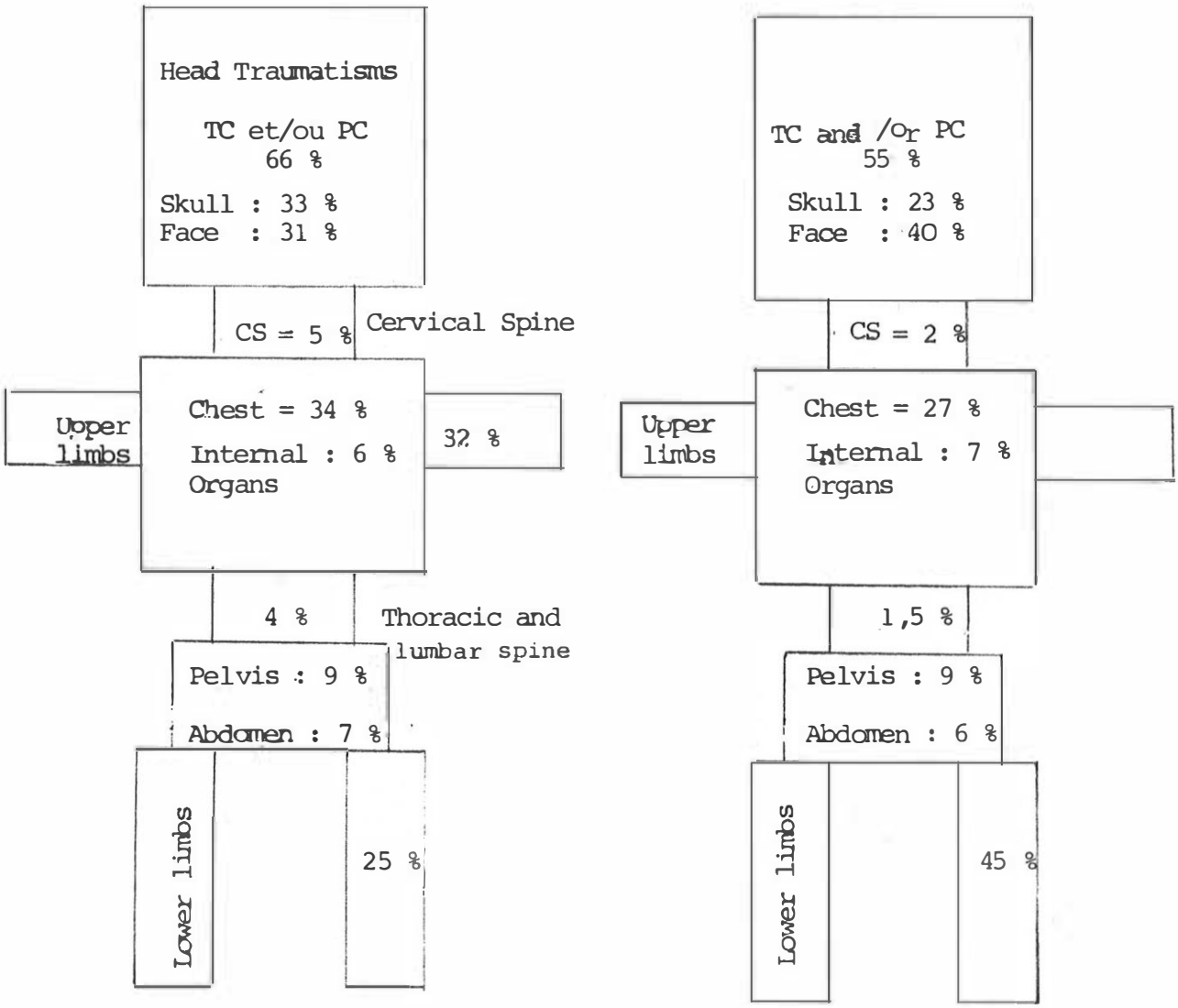
5 - DISTRIBUTION OF LESIONS

By establishing a diagram representing the number of lesions by body segment in the two cases, with and without overturning, we find that the typology of accidents having undergone an overturning is significantly different of the other and on some points, significant of that type of accidents.

First, we state an average lesions number by individuals a little higher (2,5 lesions by injured peoples). This is undoubtebly explained by the disorderly and continued motions of occupants during a roll, when they hit different parts of the car.

On the other hand, cranial lesions (fractures or wounds so that head traumatisms with or without loss of consciousness are higher in overturning. Two mechanisms may be evoked : the knock of the head against the roof at the time, doubtlessly, when the car passes on the roof and the bump of the head by the deformed roof. We shall see, in the chapter "vehicle" that the deformations of the roof are more often less important, but in some cases, particularly during overturning with falling below, the roof collapses till to take stay on the car body. These cases are very severe, and often correspond to

Injuries numbers for 100 occupants



true crashing of the skull.

We shall also see that it is difficult to establish a relation between the localized deformation of the roof and the lesion of the passenger, because the very variable cinematic of occupants is often impossible to precise.

But we otherwise can think, that a certain number of cranial lesions are dut to other elements of the car and to recall the role of the ejection which increases the risk of cranial lesions, the environment presenting itself in a form of strong and rigid obstacles.

Face lesions are contrarily significantly lesser than in other types of shocK. Effectively, in other shocks, the percentage of head on impacts is high and often associated with a shock with scattering of the windscreen.

In overturning, the complexity of the movement avoids more often the contact with the windscreen which, though broken in 50 % of cases, mainly because the deformation of the roof. Injuries observed are for 1/3 of the cases due to ejection, but this is not characteristic of this type of accident since the ejection occurs only in 1/3 of the case in overturning. Many traces are found again inside the car at the level of relieves (sun-visor, roof-light) but severe lesions (others than injuries) are rare (8 % of the face lesions).

At the level of upper limbs the overturnings create an important number of lesions but generally, these are wounds, often during ejection but also against the wall of the car body.

We find inversely, that the lesions of lower limbs are less frequent in overturnings. In fact, we avoid lesions said of the dashboard; and it concerns mainly wounds.

The lesions of the abdomen and pelvis have an almost identical frequency in the two samples with very comparable lesions : essentially breaking of pelvis branches, breaking of the spleen frequent enough without it be possible to precise among the movements which inflict an overturning to car occupants, those at the origin of these lesions.

On the other hand, 2 types of injuries are more frequent in overturning : on the one hand thoracic lesions, on the other hand lesions of the spine.

Thoracic lesions

Severe lesions of this segment are essentially appeared in the sample of ejected (rib fractures, sternum fractures, flail chest) so reaches of intrathoracic visceras).

It is difficult to explain the genesis of these lesions because we do not find the crossings of ejected by other cars. It seems that the thing is a remote ejection at achieving a fall on the back with lesions of costal desinsertion or remote fractures at distance a little similar to motor accidents.

Amongst the belted occupants involved in an overturning, no one has undergone thoracic lesion, the dissipation of energy being too long for generating efforts on the belt.

The lesions of the spine

Their frequency is clearly higher in accidents with overturning : in fact, cumulating cervical, thoracic and lumbar spine of this rachidian axis, so 3 persons only on 100 suffer from this type of injuries in other types of shock.

It is more often lesions by compression occuring to physiologic curves level. We can evoke the possibility of telescoping of the whole body, the head being stayed on the roof during the passage on the roof.

It is more difficult to explain these lesions in ejection. They are undoubtebly motions of excessive flection and the lesions concern especially the lumbar hinge.

Only one cervical lesion is observed with a belt : a dislocation without neurologic trouble. We can therefore think that the pelvis restraint avoids the telescoping against the roof, evidently in the extent where this one deforms lightly.

6 - The vehicle

The sample of this study includes 111 cars involved in overturning and 944 involved in other types (frontal, lateral, rear).

The deformations of cars essentially are characterized by two factors : The VDI, sign of external deformation, and the VIDI, sign of internal deformation.

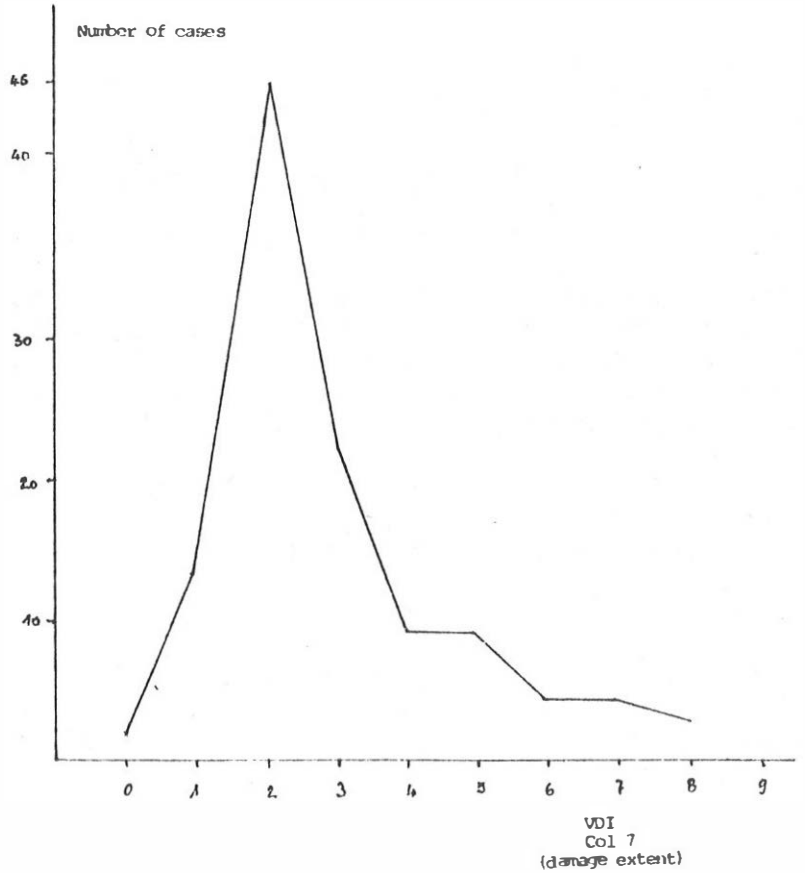
6.1. Outside deformations

All cars involved in overturning have the value 00 for the first figures of the VDI. In fact, this value includes selection criteria taken in account to constitute the sub card-index of accidents in overturning. The last figure classifies by increasing order the importance of deformations undergone during the shock. The values of this figure cannot be compared for different types of shock deformated structures and deformations orientations are different. Meanwhile for a same type of shock it is possible to study the distribution of the values of this index (col. 7 of the VDI). This distribution is represented on the figure below. The value of each case is linked to the roof driving, the value 5 corresponding to a driving in reaching the belt of the car.

From this distribution, we can note that in more than half cases (60 on 111) and so the upper structure of cars be less resistant, the drivings in are less important (lower or equal at 2/5 of the distance comprised between the roof and the belt line,. (line which runs approximately by the bottom of the windscreen the bottom of lateral and rear windows)

This may be explained by the fact that differently of other shocks, the overturning is a long shock, therefore the accelerations undergone by the car, and strenghts exerced on surfaces in touch with the soil are low.

On the other hand, in 10 % of deformations cases are very important (index values 6,7,8) the eight of the car being reduced at less than half of its value. In these cases, the overturning is associated at setting out of the carriageway entailing a fall downards the road and a "landing" on the roof.



Other shocks (944 cars)	361 (38,2 %)	326 (34,5 %)	129 (17,3 %)	129 (17,3 %)

1) of which 26 cars with 2 doors
2) of which 198 cars with 2 doors

Opening of doors during the shock

Opened during the shock	59 (53 %)	46 (41,4 %)	33 (38,8 %)	26 (30,6 %)
Remained closed				
normal opening	15 (13,5 %)	12 (10,8 %)	16 (18,6 %)	13 (15,3 %)
difficult to open	14 (12,6 %)	17 (15,3 %)	8 (9,3 %)	9 (10,6 %)
blocked up	22 (19,8 %)	35 (31,5 %)	26 (30,2 %)	34 (39,5 %)
unknown	1	2	2	3
Total	111	111	85	85
No doors	0	0	26	26

We can note also that front doors are more frequently opened than back doors. The overturning is generally not only a transverse rotation of the car, but this rotation is associated with rocking towards the front, and the front part of the car body is more often affected than the back doors and their great inertia can increase the opening risk.prevents a subsequent opening. This phenomenon is elsewhere confirmed by the following table. In fact, the right hand doors are more often blocked than the left hand doors.

	Front Left	Front Right	Rear Left	Rear Right
Overturnings (111 vehicles)	50 (53%)	46 (41,4%)	33 (38,8%)	26 (30,6%)
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Unknown	1	2	2	3
Total	111	111	85	85
No doors	0	0	26	26

Doors state in rollover

One can also state that door situation in rollover open more frequently than rear doors.

The overturning, generally, is not only a transverse rotation of the vehicle, but that rotation is associated to a tipping towards the front, and by this fact, the front part of the car body is more often affected than the rear part. Moreover, the front doors are of greater size than rear doors, and their great inertia can increase the risk of opening.

CONCLUSION

This study on overturning accidents has enabled to determine the mechanism of injuries in that type of shock.

The overall severity of overturning accidents is closely associated with the ejection of occupants, this ejection multiplying by 6 the risk to be killed in overturning.

The ejection is associated with a frequent opening of doors, while the vehicle deformations, are often little important. By simples arrangements, it would be possible to prevent the opening of the doors (5) during an overturning, which would clearly reduce the severity of this type of accident.

The wearing of the safety belt protects the occupants in overturning, On one hand, it prevents the ejection, but also, when comparying with unbelted and unjected occupants, one notes that the wearing of the belt reduces the severity of lesions, by preventing the disorderly motions inside the car body, and therefore shocks with the walls during an overturning.

The roof collapsing is always baneful, and occurs even for little violence of shocks particularly when the shock is dissymetrical.

Overturnings are associated to a specific lesional typology. The occupant involved in an overturning has, in the whole, more cranial lesions, rachis lesions, thoracic lesions and also of the upper limbs. One states that lesions having an interference with the survival possibility are increased in an overturning, which explains the high rate of deaths.

In car racing, overturning is frequent but scarcely severe. The protection measures taken increase much the safety in this type of shock, for one prevents ejection by the wearing of a retaining system, the roof collapsing by the safety archs, and the head is protected by wearing a helmet.

Some of these measures applied to current cars would enable to significantly decrease the hazard associated with overturning.