INTRA-CRANIAL INJURIES ASSOCIATED WITH UNCONSCIOUSNESS IN TWO-WHEELER ACCIDENTS

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In France, in traffic accidents one fourth of fatalities and one third of severe injured are two-wheelers. Among these, motor-cycles represent three-fourths and bicycles one fourth as concerns fatalities and respectively 5/6 and 1/6 as concerns severe injured (1) (see Figure 1). Head injuries are the most severe and constitute the major cause of death.

This paper analyzes 39 cases of traumatic coma subsequent to two-wheel accidents ; 20 two-wheelers were helmeted and 19 were not. All the patients were admitted to the neurological intensive care unit of the Neurological hospital in Lyons.

DESCRIPTION OF THE POPULATION

This population is taken from 118 cases of all kinds of accidents with traumatic coma. All the injured have shown troubles of consciousness immediately or shortly after the accident, lasting more than 24 hours and have been coded AIS 5. For all these cases the head injury was the most severe : the main associated injuries are listed in Table 1 which indicates that the most severe injuries to other body segments were not beyond AIS 3 (3 femur fractures, 3 lung contusions, 1 vertebral fracture, 1 injury of the popliteal artery). On the other hand, 18 injured two-wheelers had no other injury than to the head except superficial abrasions of AIS 1. These selection criteria made the population characterized by a severe head injury with a sufficiently long lasting unconsciousness and by rather moderate injuries to the other segments with the aim to avoid that a severe injury in addition to the head one significantly increased the whole severity. In this way it can be assumed that the patients' state as well as fatalities are exclusively resultant from the injury to the head.

It has to be underlined that the cases studied in this paper are not representative of head injuries in two-wheel accidents on the whole because minor head injuries as well as polytrauma with severe injuries to other body segments have not been included. Moreover, this sample is composed of hospitalized people ; hence their distribution related to head injury typology is likely different from that of injured people who died immediately on the accident site or during their transportation to hospital.

Age varies from 9 to 64, the average being 23.8 and the median 22. Figure 2 shows the distribution related to age groups : 26 out of the 39 cases (i.e. 67 %) are between 15 and 29 years old. Within this age range, which corresponds to the greatest motorcycle use, there are 85 % of helmeted injured of the sample.

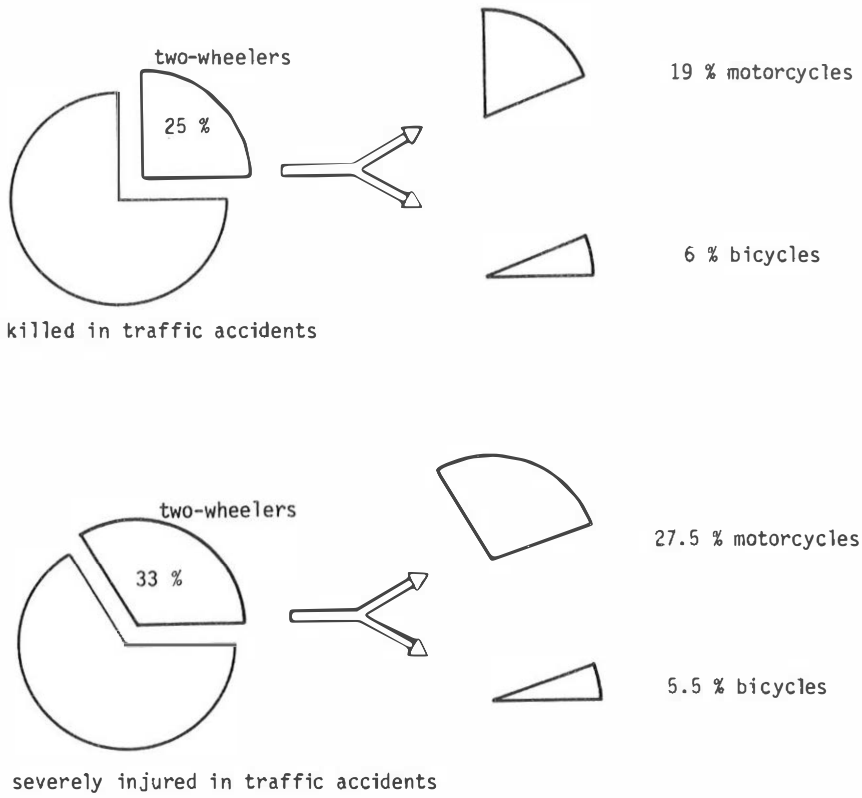

Figure 1 : Proportion of killed and severely injured two-wheelers in traffic accidents in France

INJURIES	AIS 1	AIS 2	AIS 3
Superficial abrasions or contusions	12		
Rib fractures	3	1	
Clavicle fracture		6	
Fractures or dislocations of limbs		10	3
Spine fractures		2	1
Pelvic fracture		1	
Lung contusions			3
Popliteal artery laceration			1

Table 1 : Injuries of the other body segments

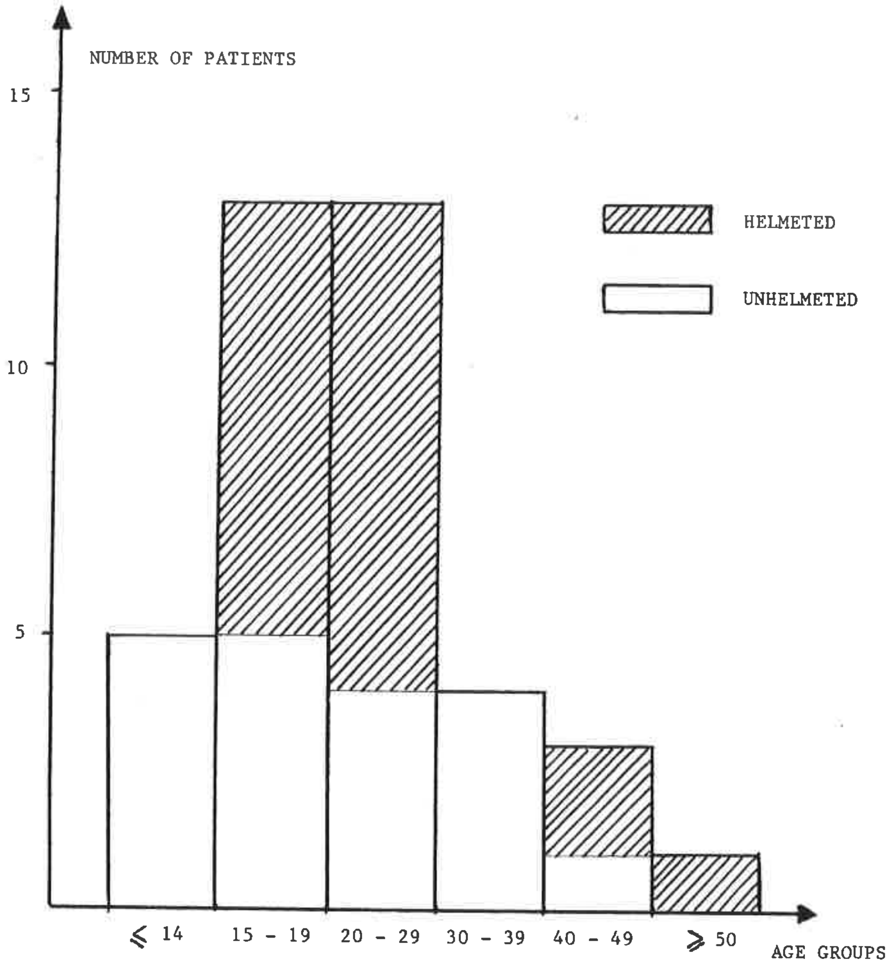

Figure 2 : Distribution of patients in age groups

Though the number of cases is not large enough to result in strong statistically validated conclusions, it can give some trends which are to be further investigated by means of additional cases and experimental data.

METHODOLOGY

All the patients have had a clinical examination made by physicians of mobile emergency units on the accident site or during their transportation. Then they have been periodically examined in the intensive care unit and even after in other units or rehabilitation facilities. These successive examinations made it possible to follow the course of injuries and to know the outcome.

The state of consciousness and its variation at successive examinations have been particularly considered. Two scales have been used jointly : the Glasgow Coma Scale (GCS), which is widely known, and a scale used for more than 20 years in Lyons (which quotes perceptivity, unspecific reactivity, pain reactivity and vegetative reactivity). It is important to monitor any variation of consciousness (either improvement or impairment) to make assumptions about physiopathological mechanisms underlying the comatose state.

From the external examination of patients, indices of the location of impact on the head may be discovered in order to establish relationsphips between the impact area and the location of possible brain lesions. Through a comprehensive neurological examination, some signs of localization may be related to possible focal brain injuries. Some routine investigations such as skull radiography, computed tomography and electroencephalography have been carried out for all patients on admission and sometimes again later on. Other examinations such as intracranial pressure recordings, cerebral angiography and brain evoked potentials have been performed in some patients only.

CLASSIFICATION OF HEAD INJURIES

1) Bone fractures

They can be divided into :

- facial fractures involving the maxillary, the nasal bone, the zygomatic bone and the mandible
- skull fractures either of the vault or of the base.

2) Intra-cranial injuries

They can be either vascular or parenchymatous and also either focal or diffuse.

- Among vascular lesions, there are extra-dural hematomae, sub-dural hematomae, sub-arachnoidian hemorrhages, intra-cerebral hematomae and intra-ventricular hemorrhages.
- Focal lesions of the nervous tissue are mainly brain contusions which may be either coup contusions or contre-coup contusions depending on their location related to the impact area on the head.
- Diffuse brain injuries are of two kinds :

. small diffuse petechial hemorrhages inside the nervous tissue; according to ZIMMERMAN (2), they occur rather at the level of the corpus callosum, the upper cerebellar peduncles, the internal capsule, the junction of the gray and the white matter. Sub-arachnoidian hemorrhages are very often associated and intra-ventricular hemorrhages are found in one-third of cases.

. stretching and rupture of fibers in the white matter have been described for more than 20 years (3) in microscopic examinations of brain sections from autopsies. Due to their small size, these lesions cannot be described without microscopy. However, experimental studies on animals (4) have show they are always present when there are petechial hemorrhages ; they may even exist without petechial hemorrhages. Nevertheless, when no post-mortem examination is carried out, diffuse injuries are difficult to diagnose ; sometimes signs of micro-hemorrhages may be seen at the C.T. scan. In the other cases, these injuries have to be supported by clinical data.

According to GENNARELLI (5), two kinds of diffuse injuries, different by the rate of stretching of nervous fibers and by the severity of resulting symptoms can be distinguished :

- the diffuse injury is considered "to be primary traumatic unconsciousness, unassociated with mass lesions, lasting more than 24 hours and not associated with persistent continuing decerebrate posturing".
- the diffuse white matter shearing injury (DWSI) is considered to be "primary traumatic unconsciousness of more than one day, with either C.T. evidence of corpus callosum hemorrhagic lesions, or by persisting decerebration and prolonged coma not due to intracranial masses or intracranial hypertension".

In fact, these two kinds of diffuse injuries are different only in their degree and not in their nature nor in their producing mechanism. It seems that there is a continuous relationship between the importance of the mechanical input signal and the injury severity. This segmentation has therefore been dropped out.

CONCEPT OF BEST DIAGNOSIS

C.T. scan gives images of injuries. Clinical examinations, electro-encephalography, intra-cranial pressure indicate signs of disfunctioning. It is important to establish relationships between structural damage and functional impairments. The C.T. scan is a first-rate means of investigation, which has greatly facilitated the diagnosis in a large number of cases. However, it has to be borne in mind that it overlooks some severe lesions and that, besides, it may show various lesions in the same patient. All other available criteria have then to be considered to define which injury may explain the patient's state in the likeliest way. Even if this point may seem obvious to physicians, it is necessary to underline that it is important to make the best diagnosis and to say that all injuries are not equivalent in terms of severity. As an example, a small hemispheric contusion together with a limited swelling and a normal intra-cranial pressure cannot explain a decerebration syndrome whereas a diffuse injury not visible on the scan can do it.

RESULTS

Figures 3, 4 and 5 indicate the types of injuries as well as the best diagnosis for the whole sample, helmeted and non-helmeted riders respectively. These two groups (helmeted and non-helmeted) being quite of the same size (respectively 20 and 19), they can be compared directly without establishing percentages.

In all cases, the diffuse injury ranks first without difference between helmeted and non-helmeted riders.

As expected, the rate of skull fractures for the non-helmeted group is twice that of the other group.

Although they are pretty numerous (in 21 % of cases) coup contusions have been taken as best diagnosis only 3 times, whether they were minor or associated with more severe injuries.

In helmeted riders, contre-coup contusion ranks second as best diagnosis, while in non-helmeted riders the second prevailing injury is extra-dural hematoma.

Table 2 shows outcomes for the various best diagnoses. On the whole death rate is 38.5 % and 23 % of patients have a severe outcome (vegetative or severely disabilitated) ; only 25.5 % recovered fully or with very light sequelae. Diffuse injury alone accounts for 40 % of fatalities (and also for 45 % of severe outcomes). Four injuries (diffuse injury, extra-dural hematoma, intra-cerebral hematoma and contre-coup contusion) account for 87 % of fatalities.

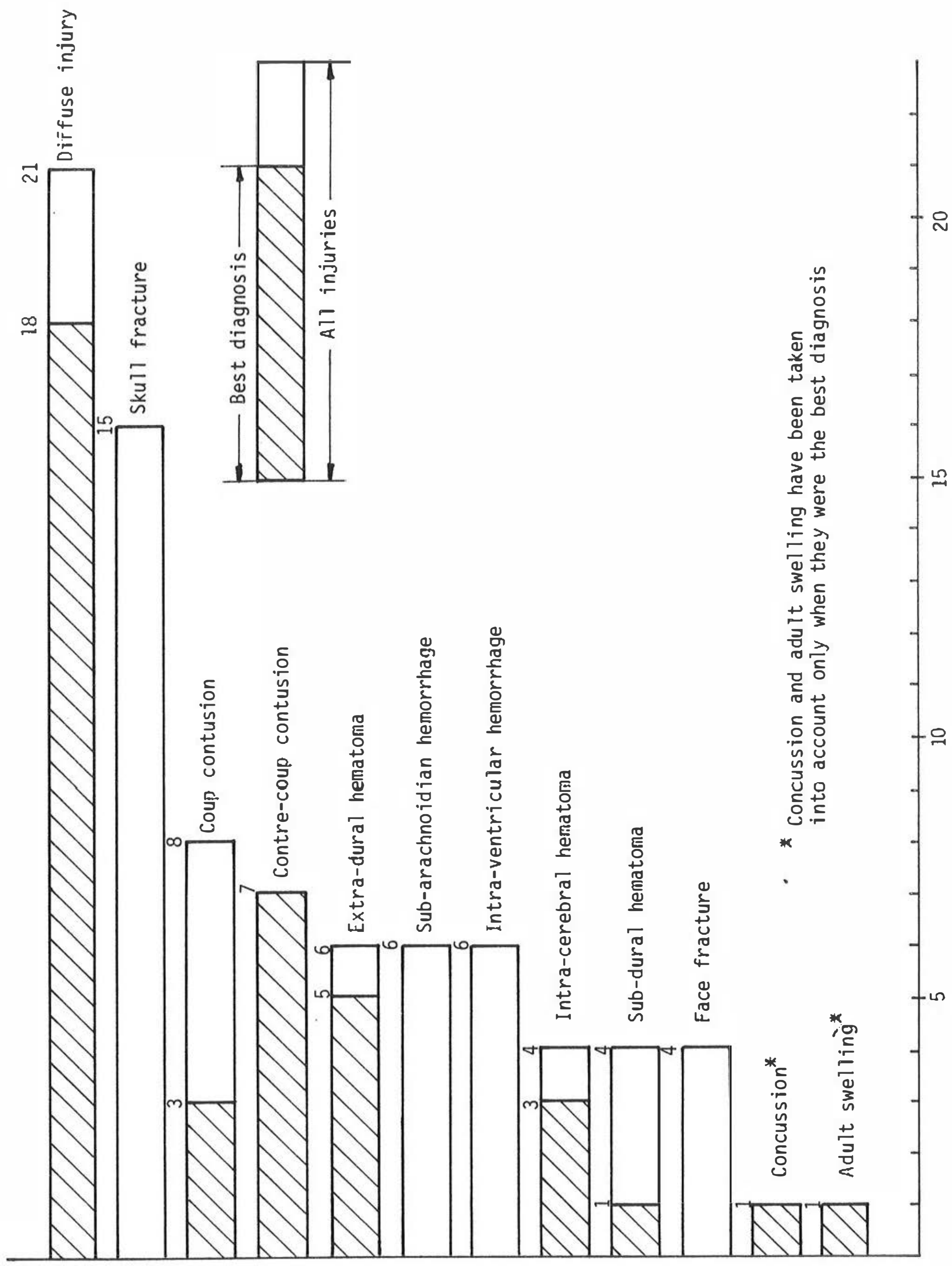

Figure 3 : Injury distribution in the whole population of two-wheelers (39 cases)

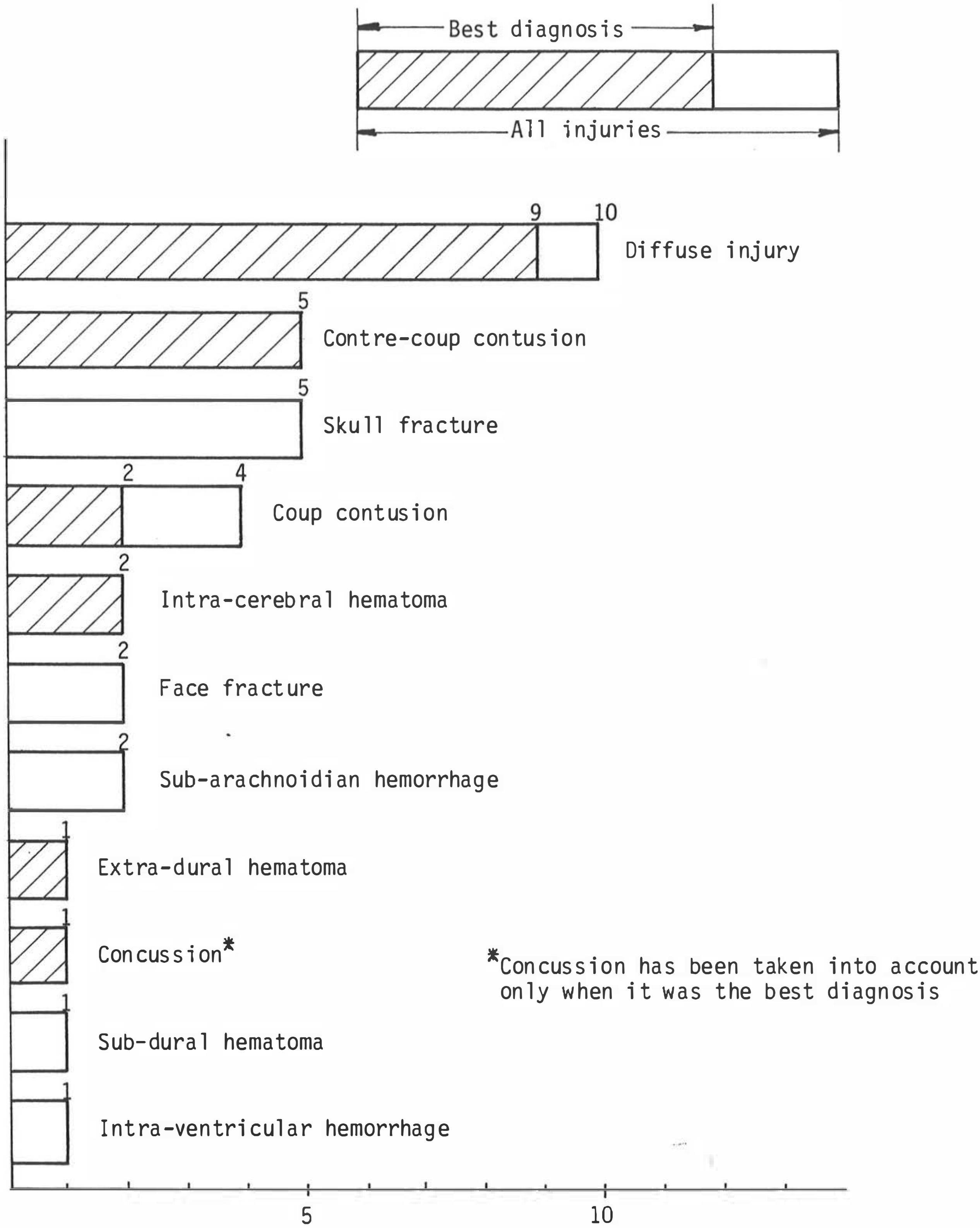

Figure 4 : Injury distribution in helmeted two-wheelers (20 cases)

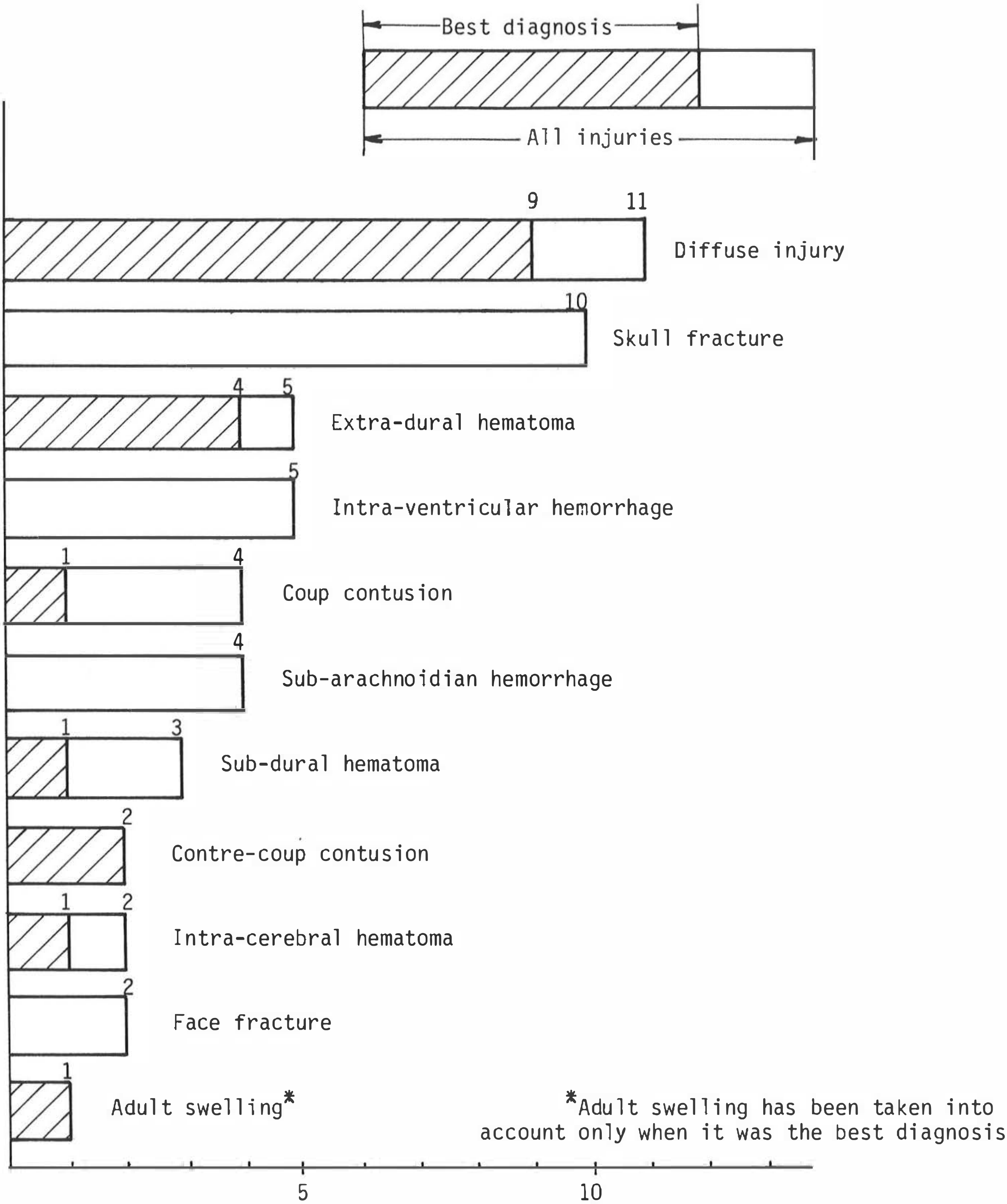

Figure 5 : Injury distribution in unhelmeted two-wheelers (19 cases)

▨ Helmeted □ Unhelmeted	OUTCOME				TOTAL (BEST DIAGNOSIS)	MORTALITY INDEX *
	FATAL	SEVERE	MODERATE	GOOD		
DIFFUSE INJURY	6	4	4	4	18	1538
CONTRE-COUP CONTUSION	2	2	1	2	7	513
EXTRA-DURAL HEMATOMA	3	1	0	1	5	769
COUP CONTUSION	1	1	0	1	3	256
INTRA-CEREBRAL HEMATOMA	2	1	0	0	3	513
SUB-DURAL HEMATOMA	1	0	0	0	1	256
CONCUSSION	0	0	0	1	1	0
ADULT SWELLING	0	0	0	1	1	0
TOTAL ▨	5	4	4	7	20	
TOTAL	15	9	5	10	39	3845
TOTAL □	10 (38.5%)	5 (23%)	1 (13%)	3 (25.5%)	19 (100%)	

* Mortality index indicates the number of death per 10 000 patients.

Table 2 : Distribution of best diagnosis and outcomes

DISCUSSION

1) Effect of a skull fracture

Among the 15 skull fractures which were recorded (i.e. 38.5 % of cases), 13 were fractures of the vault and 2 fractures of the base. Table 3 shows that on the whole, the death rate is nearly the same with or without a skull fracture. In fact, if a distinction is made between helmeted and non-helmeted riders, it seems that the presence of a skull fracture slightly increases the death rate among non-helmeted riders and decreases it among helmeted ones.

	Proportion of skull fractures	Death rate	Death rate with fractures	Death rate without fracture
Whole sample	38.5 %	38.5 %	40 %	37.5 %
Helmeted	25 %	25 %	0 %	33 %
Non helmeted	52.5 %	52.5 %	60 %	45 %

Table 3 : Effect of skull fractures on the death rate

Experiments without head impact have shown that it is possible to produce sub-dural hematomae and diffuse injuries without any fracture (6). It is the same for contre-coup contusions, but in this case they do not have the same topography (7). Moreover, impact forces necessary to produce a skull fracture are known and they vary depending on the impact localization (8). Consequences of head impact can be schematized as shown on Figure 6 :

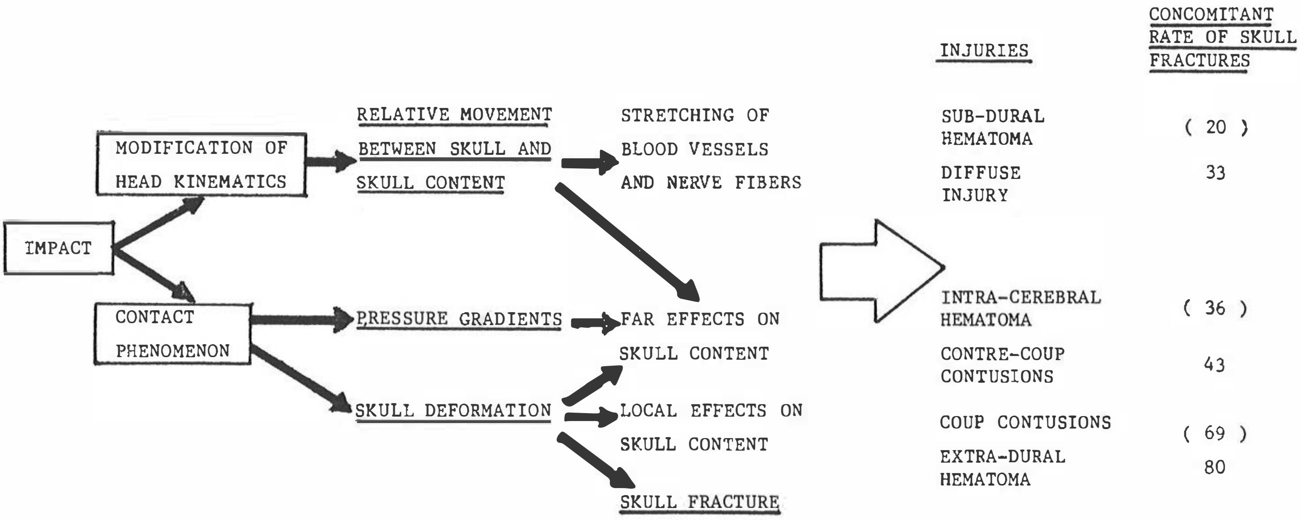

Figure 6 : Proposed mechanisms of injury

if these mechanisms for explaining injury occurrence are admitted, the fracture appears only as a phenomenon concomitant with other injuries. Since a fracture needs a certain amount of energy, it is an indicator of the impact violence and the presence of a skull fracture, to some extent, may indicate a certain probability of brain injury. However, this probability must be the higher as the intra-cranial injury mechanism is closer to the one which is able to produce a fracture. So, the fracture rate associated with intra-cranial injuries must increase from the top to the bottom of the diagram of Figure 6 ; this is shown on the right column (when the number of cases was under 5 as best diagnoses, the skull fracture rate corresponding to a larger sample including pedestrians, car accidents and falls has been indicated between brackets).

This chart indicating injury mechanisms allows to explain results of Tables 2 and 3 : by absorbing energy, the helmet lowers the contact phenomenon and the fracture rate and then, the death rate is zero in case of fracture among helmeted riders (Table 3) and there is no fatalities from injuries associated with the mechanism of skull deformation among helmeted riders (Table 2).

2) Effect of a face fracture

Four face fractures were recorded (2 among helmeted riders and 2 among unhelmeted ones). One was associated with a fracture of the skull base in a helmeted rider ; another one was associated with a parietal fracture of the vault in a non-helmeted rider. All these 4 fractures were mandibular ; the death rate of these 4 cases has been 50 %.

Three out of these 4 fractures were associated with a diffuse injury, the fourth one with a contre-coup contusion.

The chart of Figure 6 explains that a facial impact violent enough to produce a fracture and to induce a high torque around the articulation of the head on the vertebral column must then lead to levels of angular acceleration likely to result in a diffuse injury and possibly a contre-coup contusion.

3) Effect of the helmet

The helmet provides an obvious beneficial effect since it divides the death rate by two (see Table 2) and it slightly reduces the number of severe sequelae.

Its effect is twofold :

- first, as mentioned above, it cancels fatal injuries associated with skull deformation (while they represent 40 % of unhelmeted fatal cases). When an injury of such a kind occurs in a helmeted rider, it means that the helmet was not strong enough, compared to the violence of the impact, to provide a satisfactory protection : for instance, only one case of extra-dural hematoma was recorded in a helmeted rider whose helmet was broken during the impact ; however it must have had an effect (though a limited one) since the patient recovered after surgery without sequelae.

- secondly, the helmet may have a minor effect on the severity of diffuse injuries (but not on their number) by lowering the peak rotational acceleration while it is being deformed. This latter effect is less obvious than the former one and should be assessed from a larger sample.

Currently used helmets do not however offer an absolute protection since 25 % of helmeted users have been killed and 20 % have recovered with severe sequelae. Research work should be carried out with the purpose of improving the performance of helmets.

4) Effect of age

The effect of age is difficult to estimate with a small sample because many other factors interfere : the types of vehicles and their maximum velocity and the percentage of helmeted riders are not the same in the various age groups.

The distribution of outcomes in the various age groups is given on Figure 7. It seems that the age group 20-29 is a turning group showing a balanced distribution between fatalities, severe sequelae, moderate sequelae and recovery without sequelae. Before the age of 20, the sequelae rate is low (16 %), the death rate is high (56 %) and the rate of recovery without sequelae is mean (28 %). After the age of 29, death rate and rate of recovery without sequelae are low (respectively 25 % and 12.5 %), the rate of sequelae, all being severe, is very high (62.5 %). Then it seems that from the age of 30, fatalities are few but good recoveries are unusual.

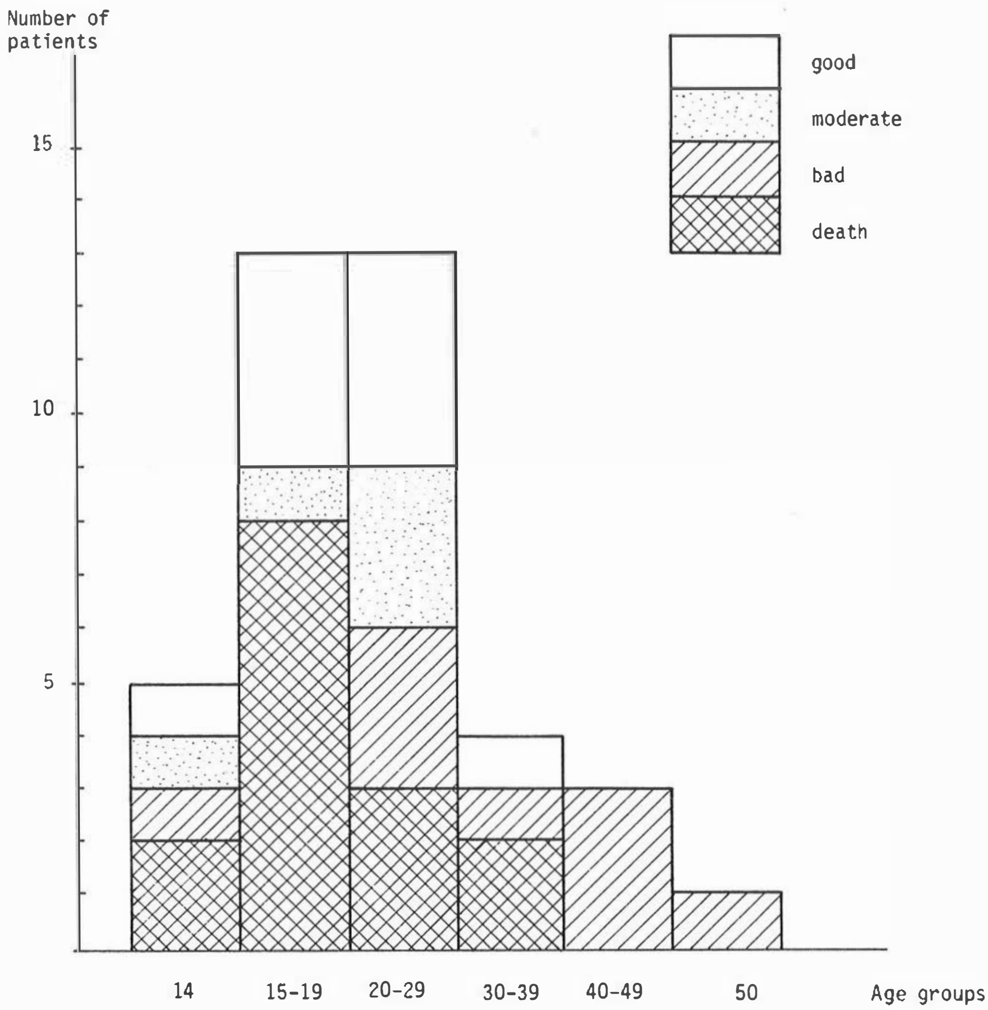

Figure 7 : Outcome distribution relating to age groups

5) Effect of accident types

An attempt was made to distinguish spontaneous falls to the ground from impacts against a vehicle. So, 12 cases of falls to the ground and 16 cases of impact against a vehicle have been identified ; in the remaining 11 cases, the accident type was not correctly identified.

No significant difference relating to the outcome could be found between these two sub-samples. The only difference recorded is the highest percentage of diffuse injuries and moreover the greatest severity of these injuries in cases of impact against a vehicle (see Table 4). This feature may be explained by the sudden stopping generating high accelerations opposed to cases of spontaneous falls during which either the speed is low or the rider skids on to the ground and stops less roughly.

	OUTCOME				TOTAL NUMBERS OF DIFFUSE INJURIES
	FATAL	BAD	MODERATE	GOOD	
Ground impact alone (12 cases)	0	1	1	2	4
Vehicle impact (16 cases)	4 *	3 * *	0	1	8
Unknown (11 cases)	2	0	3	1	6
TOTAL (39 cases)	6	4	4	4	18

* 67% of fatal diffuse injuries

* * 75% of diffuse injuries leading to severe disabilities

Table 4 : Numbers of diffuse injuries and resultant outcomes for the different types of accident

6) Comparisons of two-wheelers with other comatose patients

Our study presently covers 118 cases of traumatic unconsciousness, out of which 108 result from traffic accidents (34 car accidents and 35 pedestrian accidents in addition to the 39 cases of this paper) and 10 result from falls, assaults or sporting accidents. Table 5 compares the outcomes in these various categories. It is noted that there is no significant difference on the whole, except that pedestrians have the highest death rate among traffic accidents and car passengers the lowest. When considering two categories of outcomes only, i.e. bad outcomes (fatalities and severe sequelae) and good outcomes (full recoveries and moderate sequelae), it is noted they are quite evenly distributed whatever the group of injured is, with an average percentage of bad outcomes of

62.5 % varying from 60 to 67 % only.

	OUTCOME				
	FATAL	BAD	MODERATE	GOOD	TOTAL
2-WHEEL ACCIDENTS (39 cases)	38.5	23	13	25.5	100
-Helmeted	25	20	20	35	100
-Unhelmeted	52.5	26.5	5	16	100
CAR ACCIDENTS (34 cases)	35	32	12	21	100
PEDESTRIAN ACCIDENTS (35 cases)	54	6	11	29	100
NON TRAFFIC ACCIDENTS (10 cases)	60	-	10	30	100
WHOLE SAMPLE (118 cases)	44	18.5	12	25.5	100

Table 5 : outcome comparison of two-wheelers with other patient groups having a traumatic unconsciousness

On the other hand, if helmeted two wheelers and unhelmeted ones are considered separately, it is obvious that helmeted riders have a far better prognosis than other groups of injured ; reversely, non-helmeted riders reach 79 % of bad outcomes, which constitutes the worst prognosis. This shows how the wearing of helmet has a beneficial effect on brain injuries.

7) Consequences in terms of protection

When considering the chart of Table 6, injuries can be classified in 3 main categories from their mechanism of occurrence :

- injuries resulting from an angular acceleration (4) (7),
- injuries which have an intricated mechanism (angular acceleration, pressure gradient, skull deformation) whose prevailing factor is not clearly known,
- injuries which are subsequent to the local effect of the contact phenomenon.

Table 6 shows the respective part of the various mechanisms in the determination of different possible outcomes. It is clear that, whilst the helmet ensures protection against the local effect of the contact phenomenon, it has no action on the other mechanisms. The fact that injuries of "intricated mechanism" type are prevailing in helmeted riders (hence, relatively well protected against the contact phenomenon) indicates that the modification of head kinematics seems to be the main mechanism to produce these injuries.

		BEST DIAGNOSIS	OUTCOME FATAL	SEVERE	MODERATE	GOOD
ANGULAR ACCELERATION (Diffuse inj. S.D.H. Concussion)	Helmeted	50	40	25	75	57
	Unhelmeted	53	50	60	100	33
INTRICATED MECHANISM (Contre-coup C. I.C.H.)	Helmeted	35	60	50	25	14
	Unhelmeted	16	10	20	-	33
LOCAL EFFECT OF CONTACT (Coup Contus. E.D.H.)	Helmeted	15	-	25	-	29
	Unhelmeted	26	40	20	-	-
OTHER (Swelling)	Helmeted	-	-	-	-	-
	Unhelmeted	5	-	-	-	33

Table 6 : Prevailing mechanisms for helmeted and unhelmeted 2-wheelers (% of all the best diagnoses and of each outcome in each group)

To improve the overall protection of two-wheelers, two types of measures may be put forward from the previous results :

- to make helmet wearing compulsory for all two-wheelers, which would allow to reduce fatalities of one-third in cases of severe traumatic unconsciousness.

To reduce costs and to obtain a good acceptability from bicyclists, it would be advisable to propose a simpler and lighter helmet, as suggested by ALDMAN (9). In fact, data from this study and from others (10) as well indicate that most cranial impacts are located on the periphery and not on the top of the skull. A ring-shaped protective padding around the head could afford bicyclists a protection nearly as good as a complete helmet would do, but without its drawbacks (9).

- in a second step, to further develop protection, devices which limit head angular acceleration during an impact must be designed. This is much more difficult to achieve since such devices should be effective whatever the site and the direction of the impact on the head are.

CONCLUSION

From this study, which has to be carried on to confirm its results on a larger population, it is possible to draw some conclusions which, shall it be reminded, are valid only within the limits of representativeness of this sample (it does not include immediate death nor delayed unconsciousness) :

- the death rate is twice for unhelmeted riders than for helmeted ones,

- the helmet mainly eliminates fatal head injuries related to the contact phenomenon, i.e. extra-dural hematoma and coup contusion,

- the skull fracture has only a minor action on the occurrence of injury to the intra-cranial content ; however, it is an indication of the impact violence, and hence it is often associated with the local effect of the contact phenomenon,

- facial impacts may produce facial fractures but simultaneously they may induce high head angular accelerations,

- the outcome depends on patients' age in the sense that only one patient over 30 has totally recovered without sequelae,

- brain diffuse injuries account for 46 % of all best diagnoses and are altogether more frequent and more severe in accidents with impact against another vehicle than in cases of spontaneous falls to the ground,

- on the whole, compared to the other cases of traumatic unconsciousness, helmeted two-wheelers have the best prognosis while unhelmeted ones have the worst,

- a better protection can be achieved by taking two successive steps : to bring the helmet wearing into general use even for bicyclists, then to design head protective devices which limit the angular acceleration during an impact.

ACKNOWLEDGEMENTS

This work was sponsored by the French Ministry of Transportation, Direction des Routes et de la Circulation Routière, and by E.E.C. The authors are grateful for these supports. They also want to thank the staff of the Hospital Pierre Wertheimer in Lyons, and especially Dr. Artru and Dr. Duquesnel for their efficient assistance.

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