INJURY MECHANISMS AND MOTORCYCLE DESIGN

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The theme for the Second International Congress on Automotive Safety in July, 1973 was Motorcycle Safety (1). A number of papers were presented there, with further motorcycle papers being presented at the AAAM meetings; yet the mechanism and frequency of injury seem little changed during the last three years. The sad expenditure of our young males is not limited to the United States; similar problems and accident statistics are to be found in both Australia (2 and 3) and England (4); in fact, less than 7% of motorcycle fatalities involved females, and over 70% of the fatalities were caused by head injuries. In over two-thirds of the accidents, the motorcycle collided with another vehicle, and in over 50%, the other vehicle was assessed to be more responsible for the collision.

DESCRIPTION OF THE UCSD COLLISION STUDY

There were 127 motorcycle occupants, of which 27 were passengers (Figure 1). Two motorcycles carried three occupants each. One operator stayed on his motorcycle after ejecting his passenger. Not every specific injury is listed in this study. Instead, each body region was given an overall rating. Certain body regions were grouped together; e.g., the brain, face and head. Injured occupants were classified according to the American Medical Association Abbreviated Injury Scale (AIS).

MOTORCYCLE OCCUPANT COLLISION CLASSIFICATION

Non-ejected Occupants were those who, after the impact, came to rest in the impact area near their motorcycles. They were not ejected in their original direction of travel, but tended to remain within ten to fifteen feet of the impact area. The majority of these collisions were motorcycle frontal impacts, usually into the sides of the cars, and some into the front or rear of an opposing vehicle. (Figures 2 and 3.)

Ejected Occupants were those who were thrown from their motorcycles in their pre-crash direction during the collision. Generally, these occupants were airborne for more than ten feet. Most of these cases involved motorcycles that struck the sides of cars. Although the occupant was ejected, the motorcycles came to rest in the vicinity of the impact area.

Deflected Occupants were those whose paths were changed from their original direction during the collision. These included cases of cars striking the sides of the motorcycles, as well as glancing impacts by the motorcycle with the front or rear corner or bumper of cars. Usually, the motorcycles, as well as the occupants, were deflected and came to rest some distance both from the point of impact and from the point of rest of the car.

INJURY SEVERITY

Non-ejected Occupants. Eighty-three percent received severe to fatal injuries. This classification generally sustained the most extensive injury pattern, which included severe to fatal lesions to at least two body regions, and nearly 20% sustained more than one fatal lesion. Depending on the amount of pitching, the occupant will strike the vehicle with his knees and then with his head. His upper torso will usually contact the upper surface last. The car's rain gutter was frequently impacted by the head. (Fig. 4).

Ejected Occupants. Eighty percent of these occupants received severe to fatal injuries, of which 22% sustained fatal injuries. The type of ejection included occupants who struck the front or rear mudguards of cars and were ejected over the bonnets or boots. The overall injury severity appeared dependent on whether the occupants struck the ground initially with their heads or their feet. There was a definite body rotation or somersault during this airborne phase. A passenger would "ramp" over the now loaded body of the operator and was often ejected a longer distance. Other operators lost control on slippery roads and the motorcycles were overturned. When the head was not injured, these occupants generally received moderate or less injuries, consisting of abrasions and road burns.

Deflected Occupants. Eighty-four percent received severe to fatal injuries, of which 16% had fatal lesions. The deflected occupant usually underwent non-symmetrical body impacts, and frequently sustained a severe leg injury as the operator attempted to avoid but struck the car with a glancing blow, crushing or partially traumatically amputating his leg as the retarding force was transmitted. Head injuries generally appeared to be less.

INJURED BODY REGIONS AND OCCUPANT CLASSIFICATION

Most occupants received injuries to more than one body region, several to most body regions. The total percentage of occupants having a body region injured in each classification is listed, and subdivided into severe to fatal, and minor to moderate injury levels. (Fig. 5).

The non-ejected occupants sustained the highest number of head injury involvement, 92%, of which 53% were severe to fatal. The ejected occupant sustained a slightly lower head involvement because occasionally his feet took the initial landing impact before he rolled along the ground. However, it should be noted that both for non-ejected and ejected occupants, when there is head injury, serious head injuries occur at 58% for both groups. The head involvement with deflected occupants is much lower. Some of the 28% of non-ejected occupants who received fatal head injuries and sustained closed blunt head injury without skull fracture, died due to diffuse brain contusion and swelling.

Arm injuries were involved in about 47% of the non-ejected and ejected occupants, and about 15% were severe or worse. Their arm injury impacts against the car or pavement were about the same. Only 2% of the deflected occupants had serious arm injuries.

Thirty-one percent of the non-ejected occupants had severe or worse thoracic injuries; both the ejected and deflected occupants had lower involvements due to less direct trauma to this region. In a frontal impact the non-ejected's knees and head strike the vehicle first, then the chest is loaded. No heart damage was noted in this clinical study, but consideration has to be given to the young age of the motorcyclists. Only one person was over 45 years of age. There was one fatal aortic laceration.

It is interesting to note that the leg involvement causing serious injuries with the ejected occupants was 37%, compared to 33% for the non-ejected. This further supports the contention that some of the ejected occupants initially impacted the ground with their feet. Furthermore, where there is leg injury, serious injuries occur at the rate of 51% for the ejected, compared with 40% for the non-ejected. However, the highest level of 93% was associated with deflected occupants, of which 70% received severe leg injuries. These involved multiple factures of the femur, tibia and fibula, as well as partially and traumatically amputated legs. Some of the worse injuries were associated with operators who were leaning their bikes, attempting to turn and avoid the front or rear of a car. They impacted the vehicle's corner and then were cut by the edge of the mudguard or bumper. The deflected occupants were subjected to lateral forces which tend to rip or tear the lower leg, involving comminuted fractures and loss of soft tissue, frequently requiring both bone and skin grafting. Generally, when leg injuries were severe, a permanent degree of disability was present. Considerable convalescence and medical management was required.

The highest abdomen involvement, 31%, occurred to the non-ejected group, of which 23% received severe injuries. The mechanism of these injuries was due to the direct frontal impact. Some of the occupants had survivable liver lacerations; one had bladder contusions, secondary to a pelvic fracture.

Motorcycle Spills. There were 12 operators whose motorcycles struck potholes or kerbs, or became dynamically unstable. The occupants were propelled from their motorcycles and were classified in the Ejected group. In this group, only 40% sustained severe head injuries because the operator sustains a lower vertical velocity and subsequent deceleration during high speed spills. The human body appears to be sufficiently resilient to slide and roll without life-threatening injury, if the head can be protected.

Head Protection. Twenty-three percent were using helmets. (Fig. 6). Almost all of the helmets conformed to the American National Institute Z90.1. 1966 Standard. Twenty percent in this study had their helmets "fail" during the accident. In four of the cases the strap or strap connector failed and the occupant lost his helmet. In one case the helmet was later found in pieces. In another case the plastic visor broke and jagged edges severely lacerated the victim about his eyes. Darkened plastic visors can also precipitate accidents. One operator failed to see road signs at night and ran off the road.

Forty-three percent of the occupants not wearing a helmet sustained severe to fatal head injuries. Of the persons whose helmets were intact after the collision, only 11% received severe to serious head injury. These occurred during high speed impacts. Several of the helmeted occupants sustained moderate concussion, but no evidence of skull fracture.

Genitalia Injury. There were six male occupants who sustained injuries to the perineum, scrotum, testicles or penis. All were operating the motorcycles and were involved in Ejected and Non-ejected collisions. Three were carrying passengers, which may have increased the chance of this type of injury. Three different manufacturers' motorcycles were involved. The width and height of the tank relative to the seat affected the injury pattern. Particularly important were the filler cap location and the front fork instrument cluster.

Collision Location. In the 93 collisions involving a motorcycle and another vehicle, 69% were at intersections in which 67% involved the other vehicle turning left across the path of the approaching motorcycle. The majority of the vehicle drivers interviewed said that they looked but did not see the motorcycle until impact, or just before impact. Due to the severity of the injuries to the motorcyclists, they were not interviewed at the scene, but subsequently some claimed not to have had sufficient time to brake, whilst others claimed to have used only the rear brake.

When the distance between the point of rest and point of impact, length of skid-marks, etc. were evaluated, many of the motorcycles were estimated to have been travelling well in excess of the posted speed. This has a triply detrimental effect on impact speed. Besides the initial pre-braking speed being higher, the speed reduction at this higher speed range over a given braking distance is diminished, and the reaction distance is increased, thereby reducing the braking distance available.

SUMMARY

Field studies of motorcycle accidents provide the only method to obtain base line injury data, and to set up realistic parameters for future controlled collisions. This clinical, in-depth study reveals definite predictable injury patterns associated with occupant kinematic motion and helmet use. Although limited in number, certain conclusions are indicated by this study of injury production. (5).

Ejected occupants can sustain the same level of head injury as the non-ejected occupant, but less frequently, due to striking the pavement with another portion of the body first. Non-ejected occupants will often sustain two or more fatal lesions from very high deceleration encountered by direct frontal body contact with the sides of vehicles. Impacts to the front, side front, side rear of a car generally eject occupants over the bonnet or trunk. Deflected occupants either have a leg crushed or torn as the motorcycle is slightly retarded by the collision as it passed by the front or rear of the car. This injury mechanism can also occur during a sideswipe collision. They experience the worst leg injuries, but the head and upper torso are not injured as frequently or as severely.

The non-helmeted occupants who experienced severe to fatal injuries were four times as many as helmeted occupants. Nearly 60% of the accidents were caused by cars turning into the path of a motorcycle. However, there is a tendency for motorcycle operators to react late to emergency situations; in part, this could be due to wind against unprotected eyes at speeds of 30 to 40 mph. In a few cases the operator deliberately "laid down the bike"; in other cases the sliding bike deposited the operator on the pavement. The occupant, astride the sliding bike and impacting the lower portion of the fender or bumper, did not mitigate the injuries. One in eight persons had no licence to operate a motorcycle and half of these had no licence at all.

A number of gas tanks were bowed in by the inside of the thigh during side impacts; however, genitalia injuries were associated with frontal impacts. In the majority of collisions, fuel was spilled from the gas tanks. One of these cycles caught fire.

RECOMMENDATIONS

Safety for motorcyclists, except for helmets, has been sadly unexplored. There have been no significant improvements since the early days of the belt-driven motorcycle. These recommendations are based on the specific injury patterns and accident causation found in the different types of collisions.

1. A space-frame concept with a deflecting rail would protect the legs of deflected occupants. The rail should not be wider at the bottom than at seat level. A further side rail should be attached behind the rear seat, above the motorcycle's centre of gravity, to prevent the motorcycle from loading or resting on the rider if the machine becomes overturned.
2. At night, a single motorcycle headlight is often misinterpreted by the car driver as a background light. A double headlight system with at least an 18 cm. (7 inches headlight diameter) space between them might be sufficient to alert the car driver of an approaching motorcycle.
3. The gas tank/seat junction should be smooth and without a hump. The gas tank filler cap should be non-injury-producing and should not open during impact, spilling fuel on riders who subsequently can receive second- and third-degree burns. The steering head and instrument cluster should be mounted lower than is the current practice. This would reduce some of the genitalia injuries associated with ejected and non-ejected occupants. Non-leak gas tank valves and filler caps would reduce gas spillage and fires.
4. The initial impact height on the motorcycle is half the wheel diameter for frontal collisions. This does not allow the motorcycle to be used effectively in restraining the occupant. Impact forces acting on the front of the bike tend to somersault it. (Fig. 7). A light-weight, energy-absorbing structure fixed to the forks, but located directly above the front wheel, could house the headlight and air bag, and limit the forward impact pitch. The air bag concept would have worked very well on non-ejected occupants. Currently the air bag would be of less benefit to the passenger who tends to ramp up the back of the operator. Ejected operators would be partly restrained by the air bag.
5. Motorcycles with limited forward pitch could employ a knee energy-absorbing device to limit forward motion. The operator who initially slides forward in a seated position during frontal impacts would be partly restrained.
6. Riders should be encouraged to wear approved helmets, suitable gloves, goggles, clothing and boots, as well as a light-weight fluorescent jacket, to increase their visibility to the motorist. In the daytime they should use dipped headlights.
7. In controlled situations, the motorcycle is manoeuvrable, but in unexpected panic situations, the average motorcyclist cannot swerve his motorcycle as fast as an equally competent automobile driver, due to the distance travelled before the motor-

cycle is leaning over sufficiently to make a tight turn. Many motorcyclists were scared of using the front brake for fear of going over the top of the handlebars or locking the front wheel. Front disc brakes have helped give more feel, but even now the fear persists. Unlike a car, it is essential to keep the front wheel rolling to maintain stability; hence an efficient anti-skid system for the front wheel, with suitable driver education, would reduce impact speeds and injuries. Defensive riding, with earlier reaction by the motorcyclists, would also reduce accident severity. The education should also include practical demonstrations that motorcycles being braked can stop sooner than those that slide after being laid down.

8. Helmets should be made lighter, more comfortable, and designed for better ventilation and hearing. It appears that the head impact force is not the same in all directions. Further clinical studies are required to establish more appropriate helmet parameters, optimum design and testing.

9. If the fronts of cars are made more contoured to reduce pedestrian injuries, this would also help to reduce injuries to deflected occupants.

10. Lorries should have under-run guards along the sides as well as on the rear, to prevent motorcycle under-ride, with the rider's upper torso being exposed to an abrupt halt by the side of the vehicle.

REFERENCES

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3. Messiter, G.F., An Assessment of Measures to reduce Cyclist and Motorcyclist Accidents, December 1972.
4. Road Accidents in Great Britain. Department of the Environment, Government's Statistical Service.
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COLLISION DATA

UCSD-TRG MOTORCYCLE STUDY

100	Operators
27	Passengers
25	Motorcycles with passengers
126	Injured, including fatalities
31	Fatalities

Figure 1.

OCCUPANT KINEMATIC CLASSIFICATION

UCSD-TRG MOTORCYCLE STUDY

	Number	Percent
Non-ejected	36	29
Ejected	46	36
Deflected	44	35
	126	100%

Figure 2.

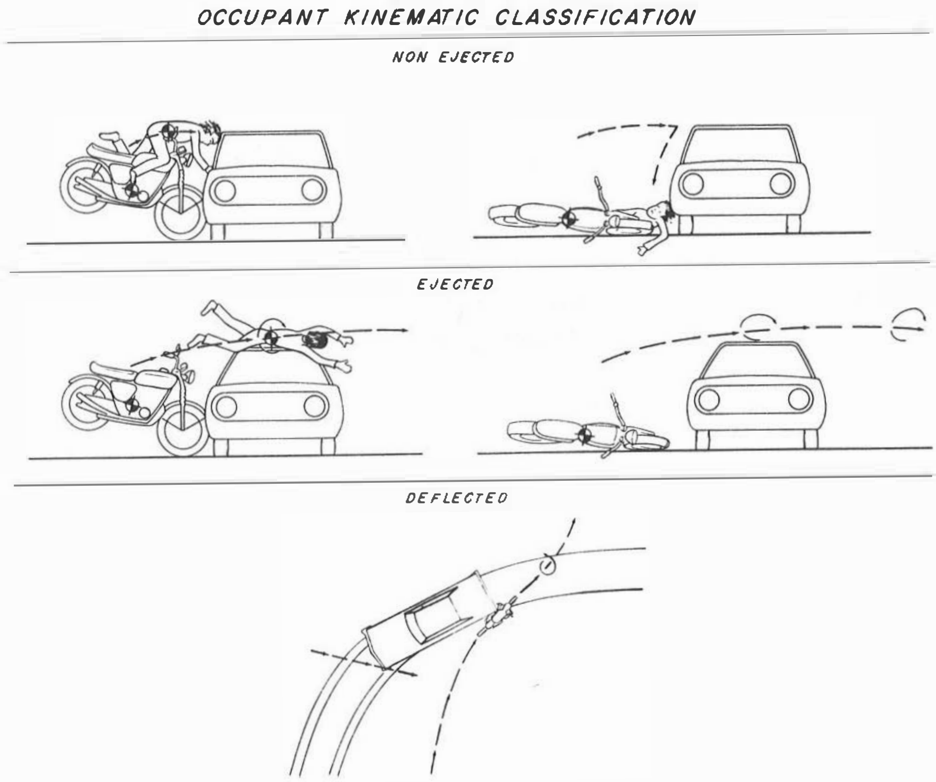

Figure 3.

INJURY SEVERITY FOR NON-EJECTED,
EJECTED AND DEFLECTED OCCUPANTS

UCSD-TRG MOTORCYCLE STUDY

INJURY SEVERITY	00	01	02	03	04	05	06 (Fatal)	07 (Fatal)	08 (Fatal)	09 (Fatal)	Percent *
36 Non-ejected			6	(7	7	2	7	2	4	1)	(83 %)
46 Ejected			9	(12	11	4	7	1		2)	(80 %)
44 Deflected		1	6	(16	12	2	7			)	(84%)

* Percentages reflect the numbers in brackets.

Figure 4.

PERCENTAGE OF BODY REGIONS INJURED

UCSD - TRG MOTORCYCLE STUDY

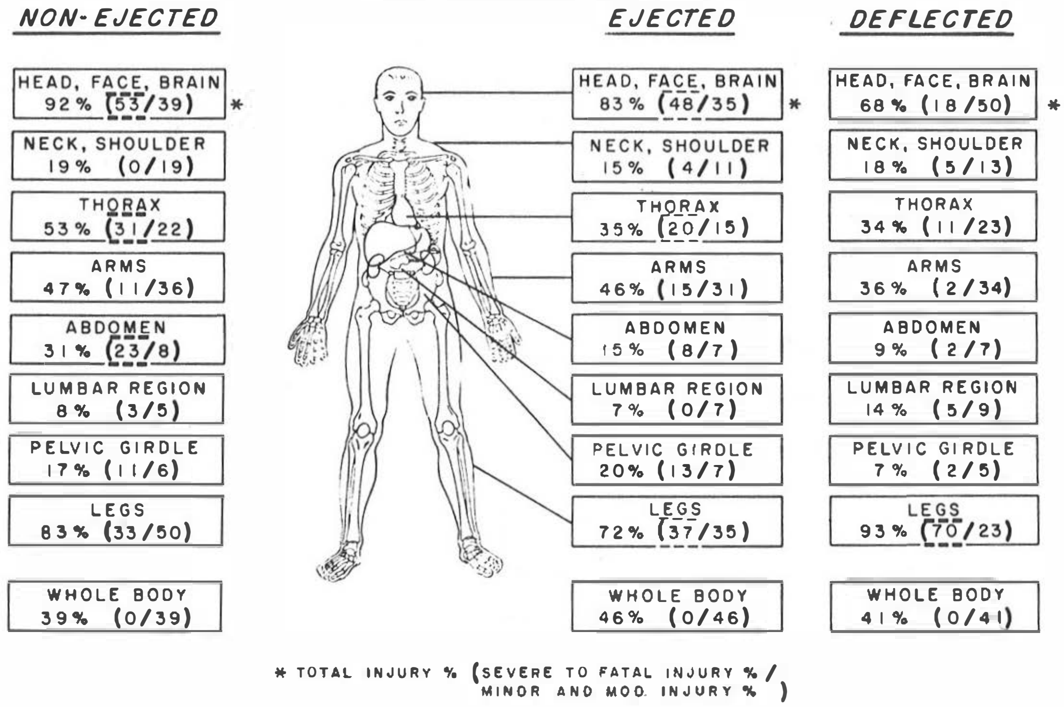

Figure 5.

HEAD INJURY SEVERITY

UCSD-TRG MOTORCYCLE STUDY

INJURY SEVERITY	00	01	02	03	04	05	Fatal 06	Percent *
103 No helmet	15	11	33	(12	7	7	18)	(43%)
19 Helmet	10	4	3	(	1	1	)	(11%)
5 Failed helmet		1		(1		1	2)	(80%)

*Percentages reflect the numbers in brackets.

Figure 6.

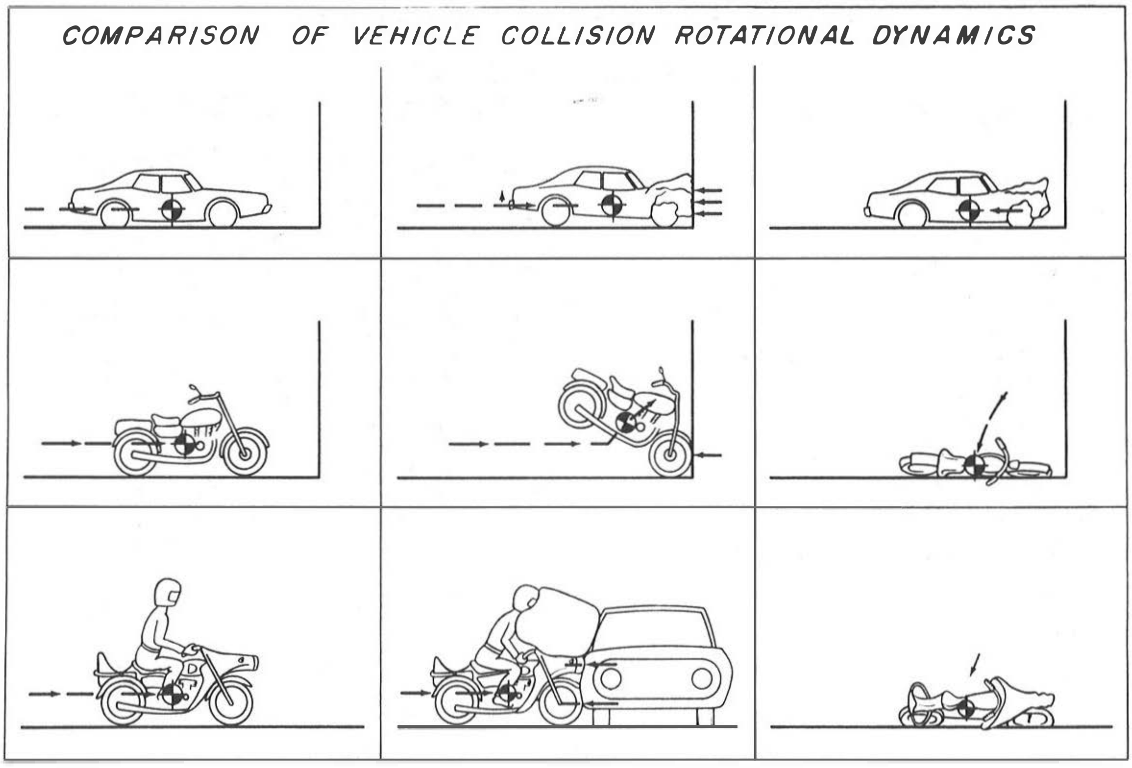

Figure 7.

AMERICAN MEDICAL ASSOCIATION
ABBREVIATED INJURY SCALE

Severity Code	Severity Category
00	None
01	Minor
02	Non-dangerous, moderate
03	Non-dangerous, severe
04	Dangerous, serious
05	Dangerous, critical
06	Fatal lesions in one region
07	Fatal lesions in one region, severe in one region
08	Fatal lesions in two regions
09	Fatal lesions in three or more regions

Figure 8.