AFTER HELMETS - IS THERE ANYTHING ELSE?

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PREFACE

Helmets remain the primary protective device available to motorcyclists. Their effectiveness in reducing the incidence and severity of head injuries has been clearly demonstrated in a number of field accident studies. Increasing attention is now being given to the potential and design of other protective devices: In particular, leg shields or guards and protective clothing.

This paper is a review and evaluation of the development and current status of such protective features. Special attention is given to the difficulties of interpolating existing motorcycle accident data for the development and evaluation of such features.

INTRODUCTION

The excitement of motorcycling and the availability of relatively low cost, highly responsive machines, have made motorcycles a popular form of transport throughout the world, especially for young males. The use of motorcycles as a form of transport is however, tarnished by the associated high accident rate (1). Their use (typically by inexperienced young riders) is compounded by the vulnerability of the exposed rider and the high injury probability.

Accident figures show that per kilometer driven, motorcycle riders are between 10 to 20 times more likely to be involved in injury-producing accidents than car occupants.

Fundamental to the development of injury protective devices is the need to understand the nature of the problem. This includes the characteristics of the motorcycle accident, the location and severity of injuries and under what circumstances which injuries occur. A number of motorcycle accident studies have been conducted which provide data on these matters (2-9). A summary of their main findings follows.

ACCIDENT TYPES

Motorcycle accidents fall into two main categories: collisions with another vehicle (multi-vehicle accidents) and accidents involving no other moving vehicle (single-vehicle accidents).

The most frequently occurring multi-vehicle involves the front of the motorcycle striking the front, side or rear of another vehicle. The other vehicle most commonly passing across the path of the approaching motorcycle. Upon impact, the rider continues to move forward to be pitched into or over the opposing vehicle. Depending on the collision configuration, the rider may be ejected over the hood or the trunk of the automobile, or the rider may strike the side of the automobile with their upper torso and head.

Lateral impacts whereby the side of the motorcycle is struck by another vehicle are the second most common type of multi-vehicle accident. The rider's leg is often struck by the impacting vehicle.

The third major type of multi-vehicle accidents are glancing or side-swipe collisions between the motorcycle and another vehicle. In these accidents, the rider's legs will typically be injured on impact with the other vehicle. Depending on the precise collision configuration the rider may again be deflected onto the automobile.

In all cases, following the initial impact, the rider will fall to the ground where he/she may sustain further injuries.

Single vehicle accidents are characterized by the rider losing control of his/her motorcycle and falling from the machine; rider and motorcycle (typically independently) sliding to a stop. Impacts with objects in the rider's path will turn the accident into an injury-producing event. In some cases, the rider may still be seated on the machine when it strikes a fixed/rigid object. It is note-worthy that a large percentage of these accidents are not included in official police-based statistics (1).

PATTERNS OF INJURIES

The injuries suffered by the rider obviously depend on the severity and type of collision and the rider's trajectory. An overview of the nature and severity of injuries sustained by **helmeted** riders show the following:

In minor accidents, the rider's injuries are typically confined to surface abrasions and lacerations to the legs and body.

In moderate to severe accidents, fractures to the arms and legs predominate. Multiple and compound fractures with severe soft tissue damage characterize the more severe impacts. The severity of leg injuries sustained in motorcycle accidents, the excessive bone and soft tissue damage aggravated by contamination, is well established (10-13). Such injuries are characterized by long term treatment and rehabilitation, often with poor end results.

Fatal accidents are typified by multiple serious injuries frequently in more than one body region.

INJURY PROTECTIVE DEVICES

The amelioration of motorcycle accident injuries has been attempted via protective systems attached to the rider and motorcycle. Consideration has also been given to the design of motor vehicles and road environment to reduce the incidence and severity of injury producing impacts. This paper is confined to considering those protective features which form part of the motorcycle/rider unit.

Any protective device must not only be technically feasible, it must be acceptable to the consumer and cost effective. Furthermore, it cannot be developed in isolation. A protective device may be developed to address a specific problem, but ultimately it will be involved in a variety of crash configurations. To this end, the development and evaluation of injury preventive devices depends heavily on the availability of detailed and reliable data from real accidents representative of the general population of motorcycle accidents (14).

The two primary established sources of data, police and medical records, typically provide details on only one aspect of the accident/injury event. In-depth field accident investigations facilitate a better understanding of the collision sequence. These involve a detailed examination of the accident scene, involved vehicles, the riders and their injuries. In this way the riders' movements, contacts and associated injuries, and the use or potential of different protective devices may be examined.

A number of in-depth motorcycle accident studies have been conducted, many to examine the effectiveness of specific injury preventive devices. Pertinent studies are reviewed below.

PROTECTIVE APPAREL

The helmet is the most valuable protective apparel available to motorcyclists. Beyond improved integral facial protection, current helmet designs afford near maximum head protection within the constraints of contemporary rider acceptability and comfort. The benefits of helmets are well documented (15-17).

The potential of protective wear for other parts of the body is less clearly defined.

Hurt, et al, conducted a detailed examination of the injuries sustained by helmeted and unhelmeted motorcycle riders from the results of 900 on-scene in-depth accident investigations (16). They concluded that heavy garments of thick cloth or leather afforded the rider some protection against abrasive injury. Heavy-duty footwear showed a protective role at the moderate and minor injury level. Other researchers including Schuller (18) and Aldman et al (19) have reported similar results.

In a study of 124 motorcycle riders treated for injuries between 1972 and 1974 Feldkamp and Junghanns (20) reported that compound fractures were sustained by unprotected riders three times more frequently than riders with protective clothes. This finding, however, has not been confirmed by other accident studies.

Aldman et al reported on the development and laboratory evaluation of a new motorcycle safety suit (21). The suit, which was introduced in Sweden in 1983, is made from leather with polyurethane foam in the area of the knees, elbows and shoulders. In an analysis of initial accident data, Aldman et al compared the number of fractures sustained by riders wearing and not wearing the safety suit. Only 2 (12%) of the 17 fractures sustained by suited riders were located at areas protected by the energy absorbing foam in the suit. In comparison, 26 (54%) of the 48 fractures sustained by the riders wearing other types of clothing were concentrated in these regions. They confirm that leather clothing reduces the risk of surface abrasions and lacerations diminishing the risk of wounds by at least 50%. Further, they estimate that leather clothing reduces the risk of wound contamination by at least 50%.

In conclusion, protective clothing, specifically leather, reduces the likelihood of abrasions and lacerations. It further affords some protection against contamination of these and more serious wounds; a considerable benefit in the management of long bone fractures.

MOTORCYCLE DESIGN

Design concepts for protective features fitted to the motorcycle cover a broad range of ideas. In one of the more extreme examples, the rider is restrained on a motorcycle fitted with roll cages and fairings (22). The intrinsic form of the motorcycle is lost. Aside from the problem of user acceptability it is unlikely that such a protective surrounding and restraint system would be an effective injury reducing device in all accident configurations.

Other ideas include the fitting of a chest pad restraint. The chest pad yields at a pre-set level thereby slowing the rider and preventing complete rider ejection in frontal impacts (23). This concept has since been exchanged for an airbag frontal impact system. The air bag inflates on impact near the center of the handlebar mounting. The work remains in the experimental stage as part of a frontal impact restraint system development for motorcycle riders being developed at the Transport and Road Research Laboratory (24).

Although initial test results utilizing the chest pad showed the system is effective in reducing the impact energy of the rider in frontal collisions, the consequences of restraining a rider at the point of impact needs to be examined more fully.

LEG PROTECTION

In recent years the potential benefits of leg protective devices has received increasing attention.

In the USC study of 900 motorcycle accidents, Ouellet et al (25) concluded that contemporary motorcycle crash bars of tubular steel appear to reduce the injuries to the ankle and foot region, but that this effect is offset by increasing debilitating injuries to other regions of the extremities.

In a sample of hospital patients, Ross (11) reported fewer leg injuries to motorcyclists on machines fitted with crash bars, however there appears to have been little control on the severity or collision configuration.

Early work in the development of alternative leg protective devices was conducted by Bothwell (26), and Bartol and Livers (27). More recently, research efforts have concentrated on the development and evaluation of leg protective devices specifically to preserve the riders' leg space and to reduce initial impact energy.

Tadokoro et al (28) describe the evaluation of a Crushable Leg Protector, CLP. The CLP consists of a rigid understructure made of steel tubing, covered by and energy absorbing component of aluminum honeycomb and urethane foam. Using a Hybrid II dummy fitted with breakable bakelite upper and lower leg "bones", collision tests were conducted representing angled, broadside and offset collisions with a car. They conclude that whilst the CLP is effective in preserving leg space and thereby reducing the likelihood of lower leg injuries, they express concern that the CLP tends to move the site of the injury into the upper leg and hip region. Furthermore, they report that initial results indicate that the motorcycle rider typically experienced a higher ejection velocity when the motorcycle was fitted with the CLP.

Preliminary results of full scale crash testing conducted at TRRL as part of ongoing research to develop leg protectors, do not agree with the findings of Tadokoro (29, 30). In a description of the results of impact tests with and without their prototype energy absorbing leg protective fairing, Chin et al report that the fairing reduced the energy input into the leg appreciably. They used an OPAT dummy fitted with damage indicating legs made of aluminum honeycomb glued to flat plates. They believe the device has potential to significantly reduce leg injuries without increasing the risk of other types of injuries.

Chin and Macaulay suggest that differences in the design of leg protectors, the nature of the crash tests and certain discrepancies in the interpretation of the data presented by Tadokoro, contribute to the different results.

BIRMINGHAM MOTORCYCLE ACCIDENT STUDY

In 1977 a motorcycle accident study was initiated at the Accident Research Unit, Birmingham, England. Through in-depth accident investigation procedures, data was collected on a sample of 204 fatally injured motorcycle riders and 100 seriously injured riders. The final part of this paper examines the results of this study, specifically in terms of the effectiveness and potential of the protective devices considered above.

THE FATALITIES

The fatal accidents were characterized by serious injuries frequently in more than one body region. The extremely violent nature of the accidents is reflected in the high incidence of severe head injuries sustained by riders whose helmets remained in place. Only three riders were not wearing helmets at the time of the accident but at least 63 of 201 riders lost their helmets at some stage during the accident. Even so, in this sample of high energy collisions, the total loads were frequently beyond the protective capabilities of the helmets. Fatal injuries to the chest and abdomen were the next most frequent. Leg fractures were sustained by 34.5% of the casualties. In 29.9% of these cases there were multiple long bone fractures in the same leg. Fat embolism following leg fracture resulted in the death of 4 riders.

There were 108 (56.3%) multi-vehicle accidents. Direct impacts between the front of the upright motorcycle, and the other vehicle occurred in 58 cases. Not surprisingly, in the single vehicle accident sample of fatalities, collisions with rigid and unforgiving off-road objects predominated. A lamp post, telephone pole or tree was identified as the main impact for 29 riders.

Beyond banning motorcycles, it is difficult to foresee any single protective feature which might have had a significant effect on most of the fatal motorcycle accidents. Even so, consideration can be given to the potential value of frontal and leg protective devices.

It is estimated that the TRRL chest pad or air bag would have been deployed on motorcycles involved in 58 (30.2%) of the fatal accidents. These are accidents where upright motorcycles were involved in frontal collisions with other vehicles or solid objects, and the riders' direction of travel lay between 11 and 1 o'clock. However, it seems probable that the involved closing speed of the impact in many of these fatal accidents may be beyond the likely design limits of the TRRL prototype restraint system.

In the Birmingham fatal accident sample, leg fairings, made of either "fibreglass" or a plastic material were fitted to only 14 (7.3%) motorcycles. There were 35 (18.2%) motorcycles fitted with leg "protective" bars of tubular steel. It was difficult to establish the precise role of these devices, but their protective effectiveness in these severe impacts seemed to be insignificant. In no case was it established that a rider's leg had been trapped between the protective bar and the machine.

It was considered that in 67 (37.0%) of the fatal accidents, energy absorbing leg protection may have protected the riders from potential leg injuries. This is not germane here, however, as most of these riders died from fatal injuries to other body regions. The results do indicate that fitting an energy absorbing and impact resistant leg shield would seem likely to prove beneficial in many motorcycle accidents of lesser severity. Their effect on the trajectory of the rider and the incidence and severity of other injuries is, of course, unclear.

THE SERIOUSLY INJURED RIDERS

A sample of seriously injured motorcycle riders were randomly selected from accident victims who received treatment at hospitals within the rural and urban study areas. In all, 96 accidents involving 100 seriously injured riders were studied in-depth.

The definition of serious was adopted from that used in national road accident statistics, viz.

> "a person who is detained in hospital or with fractures, concussion, internal injuries, crushings, severe cuts and lacerations, severe general shock requiring medical treatment."

The accident sample again reflected the motorcycle accident population with 79% of the riders aged 16-24 years and only 6 female riders, 3 of whom were passengers. All, but two of the riders were helmeted. The representativeness of the sample was examined by comparing them with the total population of seriously injured motorcyclists in the study area. The general characteristics of the riders were similar in terms of age, sex and rider type.

ACCIDENT TYPE FOR SERIOUS ACCIDENT SAMPLE COMPARED TO NATIONAL DATA

	IN-DEPTH STUDY ACCIDENT SAMPLE (N=96)		POLICE SERIOUS ACCIDENT SAMPLE (N=371)	
	N	%	N	%
Single-Vehicle	35	36.5	102	27.5
Multi-Vehicle	61	63.5	269	72.5

The injury pattern of the 100 seriously injured riders show that leg injuries predominate with half of the riders sustaining leg injuries rated AIS ≥ 2. The next most frequently injured body regions were to the head and arms. All injuries were rated following the 1980 Abbreviated Injury Scale (31).

RIDERS WITH INJURIES AIS ≥ 2
SAMPLE OF SERIOUSLY INJURED CASUALTIES (N=100)

	SINGLE-VEHICLE (N=35)		MULTI-VEHICLE (N=65)		TOTAL (N=100)
	N	%	N	%	
Head*	10	28.6	24	36.9	34
Face	2	5.7	3	4.6	5
Neck	1	2.9	2	3.1	3
Arms	15	42.9	18	27.7	33
Chest	3	8.3	3	4.6	6
Abdomen	4	11.4	2	3.1	6
Pelvis	1	2.9	4	6.2	5
Legs	13	37.1	37	59.9	50

* The high incidence of head injuries AIS ≥ 2 is partially a feature of the 1980 AIS coding system more than a true indication of severe head injuries. In 30 of the 34 cases the coded injury was based upon level of consciousness from initial observation. 21 of these casualties described as suffering amnesia (no recollection of crash) or reporting loss of consciousness were rated an AIS 2. Typically this is not substantiated by diagnostic instrumentation .

LEG INJURIES IN SERIOUS ACCIDENT SAMPLE

The location and severity of the leg injuries sustained by the seriously injured motorcyclists was examined for single vehicle and multi-vehicle accidents.

Injuries to the foot and ankle appear to be a more common problem during single vehicle accidents. Whereas, motorcyclists in multi-vehicle accidents sustain more frequent and more severe injuries to the thighs, knees and lower legs. In these accidents, without exception, all major leg injuries resulted from impact with the striking vehicle. This data would support the current emphasis on evaluating the potential of leg protective devices in multi-vehicle crash tests.

DISTRIBUTION OF LEG INJURIES AIS ≥ 2 FOR SERIOUSLY INJURED RIDERS BY ACCIDENT TYPE

	SINGLE-VEHICLE		MULTI-VEHICLE	
	N	%	N	%
Thigh	3	8.6	14	21.5
Knee	1	2.9	11	16.9
Lower Leg	4	11.4	20	30.8
Ankle & Foot	5	14.3	2	3.1

DISTRIBUTION AND SEVERITY OF PELVIC AND LEG INJURIES FOR SERIOUSLY INJURED RIDERS BY ACCIDENT TYPE

		SINGLE-VEHICLE (N=35)			MULTI-VEHICLE (N=65)		
		AIS			AIS		
		1	2	3	1	2	3
Pelvis		0	1	0	0	1	3
Thigh	Surface	1	3	-	10	10	-
	Skeletal	0	0	2	0	0	13
Knee	Surface	8	1	-	17	9	-
	Skeletal	0	1	0	0	5	0
Lower Leg	Surface	2	3	-	11	15	-
	Skeletal	0	3	1	0	6	12
	Internal	0	0	0	0	1	2
Ankle & Foot	Surface	4	3	-	12	2	-
	Skeletal	0	2	2	1	1	1

ROLE OF LEG PROTECTIVE DEVICES

The role of any leg protective devices fitted to the accident motorcycles was evaluated on an individual case basis. Leg fairings were fitted to 15 motorcycles, in 7 cases these were full leg fairings, in the remaining 8 cases they were leg shields. In only 3 cases was the fairing considered beneficial, in each case protecting the rider during initial ground contact.

So called "leg guards" were fitted to 7 motorcycles, in only 1 case to both the front and rear of the motorcycle. No protective value was established for these leg guards. Nine engine ('crash') bars were fitted. In only 1 case may it have had a protective role, by preventing the motorcycle from falling on the rider's lower leg during a motorcycle drop.

Present crash test work in the evaluation of energy-absorbing leg protective devices, such as airbags, concentrates on their response in multi-vehicle collisions; the front of an upright motorcycle typically striking the front or side of a car. An examination of leg injuries sustained by riders in real accidents was undertaken by extracting those cases where an upright motorcycle impacted a car or light van with a direction of travel for the rider of 11, 12 or 1 o'clock. There were 40 such collisions. A breakdown of their leg injuries is presented in the following table.

LEG INJURIES SUSTAINED BY MOTORCYCLISTS IN 11, 12 OR 1 O'CLOCK IMPACTS WITH CARS AND LIGHT VANS (N=40)

		AIS		
		1	2	3
Pelvis		0	1	1
Thigh	Surface	6	5	-
	Skeletal	0	0	7
Knee	Surface	12	8	-
	Skeletal	0	4	0
Lower Leg	Surface	6	11	-
	Skeletal	0	3	9
Ankle & Foot	Surface	9	1	-
	Skeletal	1	1	0

DISCUSSION

In-depth accident studies of real motorcycle accidents has enhanced our understanding of the nature and source of motorcycling injuries. The results of such work have identified specific problem areas for remedial design work, most notably leg injuries.

The likely effectiveness of protective devices and their influence on the trajectory of the rider is less readily ascertained from field accident data. The evaluation of protective design features rests heavily on crash test work.

To date, this work has been restricted by the use of anthropometric test dummies designed originally for an evaluation of car occupant protection. The response of these test dummies may not be appropriate where the precise response of the leg to impact and the trajectory of the dummy is so important. As discussed earlier some attempts to overcome these shortcomings have been made by the fitting of an aluminum honeycomb or bakelite dummy leg, however the retention of a relatively non-compliant test dummy makes the representativeness of the full dummy response questionable.

It is clearly evident from the present study that greater consideration must be given to the development of test devices that can assure both biomechanically faithful kinematic response while at the same time providing a means to monitor for the variety of skeletal and soft tissue injuries that occur to different parts of the lower extremities.

SUMMARY AND CONCLUSIONS

1. Current designs of leg protective devices afford little or no protection.

2. The multiplicity and severity of the injuries suffered by a sample of 204 fatally injured motorcyclists suggests protective features restricted to individual body regions, eg legs, would be of little benefit.

3. A study of 100 seriously injured motorcyclists confirms the high incidence of severe leg injuries sustained by this group of road users.

4. Lower leg, ankle and foot injuries were most common among riders in single vehicle accidents. Injuries to the thigh, knee and lower leg were most frequently sustained by riders in multi-vehicle accidents.

5. In all, 40% of the riders were injured in collisions that approximate those commonly simulated in crash test work to evaluate leg protective devices.

6. Protective features which attenuate the energy of the impact between the rider's legs and the striking vehicle would appear to be beneficial. The effect of such devices on the riders' trajectory is difficult to establish from field data.

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