Protective Helmets and Cranio-Cerebral Trauma in Motorcycle Accidents : a preliminary study

by

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Introduction:

While advances have been made in characterising the types of damage which occur to the brain in head injuries[1,2] and changes of clinical practice have followed this work, there is often little information available about how the injuries occurred. The lack of this information does not hinder clinical management which pursues the injuries found when patients arrive in casualty departments but often knowledge of accident circumstances would give information of value to the doctors responsible for managing the patient and advising their relatives. The careful collection of all information about the nature of an accident and a patient's condition from the accident onwards can be of great assistance in accurately assessing the nature of his condition and will influence management and prognosis.

In addition to improving clinical information and decision taking, careful appraisal of accidents will yield information about hazards which can be modified and about the value of safety features such as design of vehicles and protective items such as clothing and helmets. Many ideas in the design of safety equipment and safety measures have arisen empirically and often introduce unforeseen hazards. This study of the value of motor cyclists' protective helmets has been done in conjunction with the United Kingdom's Department of Transport (Transport and Road Research Laboratory - TRRL). The results of their reconstruction evaluation of helmets are to be presented at this conference. Our studies of the injuries sustained in the same accidents are presented to show the attempts being made to link theoretical considerations with real clinical, radiological and pathological observations.

The principal aims of the combined work are to evaluate the criteria currently used for the design of protective helmets for motorcyclists and to attempt to relate the mechanical factors in accidents to the injuries sustained - particularly to the brain.

Materials:

Motorcycle accidents involving serious injuries or deaths are being studied in the Strathclyde Police region in the West of scotland. This is a large area containing roads in densely populated urban areas, modern motorways and rural roads. Because of the sensitive nature of the information contained in police records and information, including clinical and pathological data, held by the prosecuting authorities, permission has had to be obtained from the Crown Office (Scotland) to use privileged information in accordance with instructions which preserve the legal situation. Clinical records are made available by clinicians in hospitals throughout the region on the basis that the information is likely to lead to improvements in road safety.

Methods:

Accident Data is supplied by Strathclyde Police as soon as possible after the event. Department of Transport Vehicle Inspectors locate and examine the vehicles involved, and the locus of the accident. They prepare scale diagrams which show positions of vehicular collisions, objects which the motorcyclists have struck and where they came to rest. Information about trajectories is often available. Cases are numbered e.g. 009. Individuals are 1/1 if driver or 1/2 if the pillion passenger.

Helmets and clothing are obtained either from hospitals or elsewhere, examined and photographed. Areas of damage and contact information is correlated with the sequence of events established by the police and vehicle inspectors. The helmets are then passed to T.R.R.L. for test rig studies which attempt to reproduce the main impact damage in new helmets of the same types. This work allows calculation of the Head Injury Criterion (HIC)[3] score for the particular helmet and accident, and the HIC value can be considered in relation to the post accident conditions of the individuals. Helmet marks are indicated by the horizontal clock face with 12 o'clock being straight ahead; 9 o'clock the left side. More detail of position is given in the T.R.R.L. paper.

Clinical and Pathological Data includes information from any eye witnesses about an individual's condition at and after the accident. Information about their status during transport to hospital, including any en route treatment is also obtained from ambulance crews. Casualty records and in-patient records are scrutinised for details of injuries observed by clinicians or radiologists (plain x-rays, CT-scans and Nuclear Magnetic Resonance - NMR). Results of examinations and investigations e.g. blood volume and blood gas information are recorded. The data so obtained assists in the interpretation of primary and secondary types of brain damage. If patients survive, their neuro-radiological investigations may give information about the nature and location of any brain injuries or secondary effects.

Pathological Data about verified injuries to the body, limbs, spine and head are obtained from post mortem records. This data is usually concordant with the evidence obtained from clothing examination but gives the data about severity and extent of injuries which form the essence of a study of tolerance of different body tissues and organs to types of physical violence.

Neuropathological data includes information about the spine and spinal cord but for this particular study, the head is examined for external evidence of impacts. These may be bruises, abrasions or lacerations to exposed parts or to parts covered by the helmet. These external injuries along with bruises of the deep aspect of the scalp are considered along with helmet damage to attempt to gain, as accurately as possible, evidence of the direction of the major impact forces sustained.

Neuropathological evaluation of the brain is done partly at the time of the post mortem examination and, more comprehensively after the brain has been fixed in formalin for three weeks. The fixed brain is photographed externally if there are lesions and the cerebral hemispheres are then cut in a standard manner into 1 cm thick coronal slices. At this stage, lesions observed by the naked eye are drawn on prepared line diagrams and, if appropriate, photographed. Microscopic examination follows using standard staining techniques to evaluate the nature, location and severity of primary and secondary damage in the cerebrum, brain stem and cerebellum. Additional information obtained from microscopy is added to the line diagrams started at the naked eye examination of the brain slices.

Such data as can be stored and processed by computer is logged on computer pro formae for further study.

Abbreviated Injury Scaling (A.I.S.) was done on all injuries for entering data on computerised studies using the revised version of the booklet of the American Association of Automotive Engineers.

Results:

The results of the investigations in one accident where both the driver and pillion passenger survived and in six accidents in which there were fatalities will be given individually to show the essential data which has been obtained. This can be considered with the T.R.R.L. paper on helmet testing.

Case 009 1/1 - driver, male, 25 years. Impacts (i) struck central steel crash barrier with off-side, in the 1 o'clock position, lost control and then (ii) fell onto road, curling into a ball and rolling along. Speed at first and second impacts estimated 40 mph. Injuries - joint aches but walked away and was virtually unharmed. Protective clothing - full leather suit. Helmet - full face - few road contact scrapes at rear in 6-7 o'clock positions.

Case 009 (cont'd) 1/2 - pillion passenger, male, 24 years. Impacts (i) struck central steel crash barrier (as 1/1, above) (ii) fell onto road, landing on back. Speed of first and second impacts estimated 40 mph. Injuries: 4 cm diameter bruising over back of head with centre to right of midline; linear occipital fracture (AIS 2), unconscious for 16 hours (AIS 2); posterior fossa extradural haematoma (AIS 4), surgically removed, and dorsal cerebellar subarachnoid haemorrhage. Neuroradiology did not reveal any brain lesions. Discharged home after 10 days and after two months was irritable and had poor concentration. Protective clothing - full leather suit. Helmet - full face - outer shell forced inwards over a 6 cm diameter area with its centre at the 5 o'clock position. The helmet damage corresponded with the position of the skull fracture.

Case Summary: The driver had no injury of consequence, having managed to roll along the road. His protective clothing and helmet protected him adequately. The pillion rider probably followed a similar sequence to the driver after they became detached from the motorcycle. Both landed back down but the pillion rider's impact was heavier on the back of his helmet causing it to buckle inwards in the area in which the skull was fractured. Although unconscious for 16 hours, he recovered. The helmet provided partial protection.

Case 013 1/1 - driver, male 30 years. Impacts: struck central steel crash barrier on motorway with off-side, in the 1 o'clock position, lost control and fell off landing close to barrier after rotating to land on his left side. Speeds at first and second impacts estimated between 60 and 70 mph. Injuries - dislocation of one small joint in hand and fracture of the proximal phalanx of one small toe. No head injury: not unconscious. Protective clothing - not used. Helmet - full face - unmarked.

Case 013 (cont'd) 1/2 - pillion rider, female, 25 years. Impacts as 1/1 (above) but was thrown further from the central reservation and was trapped by head and upper body beneath the engine and gear box of a car travelling in the same direction. Speeds of vehicles, estimated, 60-70 mph. Injuries - crushed head (AIS 6) with comminuted base of skull and facial bone fractures. Brain damage severe with exposure and partial loss of brain tissue at accident site. Transection of right main bronchus (AIS 5); compression fractures of 3rd and 4th thoracic vertebral bodies (AIS 3); fracture of right humerus (AIS 2); fracture of right radius and ulna (AIS 2). Protective clothing - not used. Helmet - full face - became detached after striking ground. Thought to have been wrongly fitting. Helmet thrown across to opposite carriageway and struck by tyre of another vehicle. Road contact scrapes and indentation in 8 o'clock position (as driver) splits running vertically at back, from margin upwards, at 6 o'clock.

Case Summary: The driver and rider probably came off the bike at the same time as it bounced off the central barrier and fell over onto its near side. The pillion passenger was thrown further from the falling motorbike and fell into the path of a vehicle moving in the same direction. Both driver and passenger had evidence of their helmets striking the road at the 8 o'clock position. The pillion passenger's damage in that position was more severe, with indentation as well as scraping. The driver survived with trivial injuries but the passenger died from severe injuries caused by becoming trapped beneath the second vehicle. The driver's helmet protected his head adequately.

Case 016 1/1 (driver only accident) Male, 25 years. Impacts: struck a road sign in 10 o'clock position, became detached from bike then hit road surface three times with helmet's 2 o'clock position. Speed at first impact estimated 70 mph. Injuries - head: diffuse petechial haemorrhages in cerebral white matter (AIS 4): bilateral temporal lobe contusions: tonsillar herniation.

Case 016 1/1 (cont'd) Ruptured left subclavian artery (AIS 4); contusions of left lung; renal cortical haemorrhages (AIS 2); compound fracture of left radius and ulna (AIS 3). He died after a prolonged operation to control severe haemorrhage from his ruptured artery.

Case Summary He had a high speed right frontal impact with a road sign and then a series of left frontal road contacts. He died from haemorrhage. He had bilateral, symmetrical contusions and small white matter haemorrhages.

Case 025 1/1 - Driver, male, 22 years. Impacts: (i) collision with a fallen motorcycle straight ahead then after a trajectory of over 100 feet, landed on back, striking helmet in 7 o'clock position. Speeds at impacts, estimated over 50 mph. Injuries: fracture of right pubic ramus (AIS 2); fractures of right femur - subtrochanteric and supracondylar (AIS 3); fracture of right tibia. No head injury. Protective clothing: not used. Helmet - full face - road scrapes from first contact with road at 6 o'clock position and scrapes at left side - 9 o'clock position from sliding along road.

Case 025 1/2 - Pillion passenger, female, 16 years. Impacts: as for 1/1 above. Injuries: contusions of right temporal and occipital regions of scalp; hinge fracture of base of skull (AIS 4); petechial haemorrhages in brain stem (AIS 5); petechial haemorrhages symmetrically in temporal cortex, unci and thalami (AIS 4). Contusions of both lungs (AIS 4); sub-endocardial haemorrhages (AIS 4); fractured left 8th and 9th ribs (AIS 3). She died at the accident having become unconscious immediately.

Case Summary: The driver and pillion passenger were thrown into a long trajectory landing on their backs. The passenger's helmet had more severe posterior damage suggesting landing from a higher trajectory. The driver had pelvic and lower limb fractures but was protected from head damage by his helmet. The pillion passenger's helmet did not prevent severe skull fracturing and brain damage.

Case 29 1/1 (driver only accident) Male, 28 years. Impacts: (i) collision with car which was in his 7 o'clock position; (ii) after becoming detached from the falling motorcycle he struck his head on a fencing post with the rear of his helmet in the 6.30 position. Speeds at impact estimated at 30-40 mph. Injuries: There were no external scalp injuries and there was no skull fracture. There were small contusions to the upper surfaces of both hemispheres. The right 6th and 7th ribs were fractured (AIS 2); both lungs had tears (AIS 3) and there was also almost complete separation of both upper lung lobes from the lower lobes (AIS 5). There was a fracture of the 3rd thoracic vertebral body (AIS 2) and also of the 6th and 7th thoracic vertebrae with spinal cord compression (AIS 5). There were lacerations of the liver and spleen (AIS 3) and renal bruises (AIS 3). He died at the accident site without recovering consciousness. Protective clothing - not worn. Helmet - full face - concentric rings at rear of helmet at 6.30 o'clock position where the fencing post was struck.

Case Summary: He crossed in front of a car which struck him from behind on the left side. He was thrown from the falling motorcycle and struck a fence post with the back of his helmet, slightly to the left of the midline. He sustained cerebral damage but also had severe thoracic, abdominal and spinal injuries. His helmet may have protected against skull damage and more severe brain damage.

Case 30 1/1 - Driver, male, 24 years. Impacts (i) hit by car coming from behind and to left - 7 o'clock position (ii) hit road surface with left rear of helmet (iii) hit fence-post in 1 o'clock position. Speeds at impacts: estimated speed at collision of vehicles - 50 mph. Injuries: Bruising to right side of forehead (AIS 1); comminuted fractures of orbital plates and ethmoids with fractures of base of skull (AIS 4).

Case 30 1/1 (cont'd) Subarachnoid haemorrhage over entire convex aspect of cerebrum (AIS 3); contusions of both frontal and temporal lobes (AIS 3); petechial haemorrhages in left occipital lobe (AIS 4) and in pons (AIS 5). Lacerations of frontal lobes (AIS 5); lacerations of left optic nerve and both olfactory tracts (AIS 2). Fractures of left 4th to 8th ribs (AIS 2), pulmonary contusions (AIS 4). He died at the accident site without regaining consciousness.
Protective clothing - not worn. Helmet - full face - fractured above face aperture in 12.30 and 10 o'clock positions and fractures at lower rear margin at 5 o'clock.

Case 30 1/2 Pillion passenger, male, 21 years. Impacts, as 1/1 above but thought to have been struck by car and fallen onto car before falling onto road surface and crossing grass verge to hit fencing posts. Speed - estimated at collision, 50 mph. Injuries: Face and forehead bruises with bilateral periorbital bruising; lacerations to right side of face. Skull fractures - extensive comminuted fractures of both orbital plates, sphenoid, base of skull and frontal bones (AIS 4). Separation of pons from medulla (AIS 6). Left fronto-parietal subarachnoid haemorrhage (AIS 3). Disrupted right optic nerve and both optic tracts (AIS 2). Contusions of right lung (AIS 3). Dislocation of head of right humerus with rupture of deltoid muscle (AIS 2). Fracture of left tibia and fibula (AIS 2). He died at the accident site without regaining consciousness.
Clothing - not used. Helmet - full face - contact marks with car (paint) at 3 o'clock and 8 o'clock; road surface scrapes at 9 o'clock.

Case Summary: Both rider and passenger skidded across a road surface and struck fencing posts with their faces. The rider showed more anterior damage to his helmet. Their helmets did not give protection from the frontal impacts.

Case 046 (Driver only accident) Male, 45 years. Impacts: Hit a car at his 9 o'clock position and was thrown up and over the car, striking its roof as he was spinning. He then hit the road with the back of his helmet at 5.30 position. Speed at impact - estimated 20-25 mph. Injuries: Bruising of scalp at back of head. No skull fracture. Petechial haemorrhages in both hemispheres (AIS 4) and in brain stem (AIS 5). Small, bilateral subdural haematomas (AIS 4); brain swelling (AIS 3), subarachnoid haemorrhage (AIS 3). There were multiple rib fractures bilaterally (AIS 4). Laceration of left subclavian artery. Haemothoraces. Fracture of 8th thoracic vertebral body (AIS 2). Fractures of left clavicle, left scapula and left humerus (AIS 2). He died after 2 hours without regaining consciousness.
Protective clothing - not used. Helmet - full face - scrape from car roof at 9 o'clock; road scrapes at 5-5.30.

Case Summary: He struck a car, was thrown over its roof to land on road. He sustained cerebral injuries but had more severe thoracic injuries. His helmet may have protected against skull fractures.

Comparison between Head and Helmet Damage

In those cases where there was substantial damage to the helmet which, in some, had led to deformity of the shells e.g. cases 009 (1/2), 025 (1/2), 030 (1/1, 1/2) and 046 there were corresponding contusions of the scalp with or without fracturing of the skull in the same area. This finding in four of the seven fatalities and the single survivor who had had a significant head injury is an important correlation. It indicates that, as these foci of damage to helmets and heads match the accident reconstruction information, the approach to testing helmets of similar manufacture as described by T.R.R.L. is valid.

In one case - 029 - where there was evidence of a heavy impact on the helmet, no corresponding head wound was found at post mortem.

Where driver and pillion passenger were involved in an accident e.g cases 009 (1/1,1/2), 013 (1/1,1/2), 025 (1/1,1/2), 030 (1/1,1/2) there was consistency in the pairs with respect to trajectories, impact directions and evidence of damage to helmets. Apart from case 013, where there were complicating factors (1/2 was run over by another vehicle) and case 030 where both died, the damage to the helmet of the more injured or fatal partner was more severe but in a comparable location. Evidence about the impacts suggested either fortuitous factors or augmented impact forces from higher trajectories or greater speed of detachment from a motorcycle out of control.

Types of Brain Damage The types of brain damage found in this small series reflects very short survival or immediate deaths. Some of the lesions of the injured brain take time to develop so that a brain with a nil survival time often shows, as in cases 016, 025, 029 and 046, only a few small haemorrhages diffusely throughout cortex, white matter, brain stem and cerebellum with the more constant locations being in the upper brain stem. These immediate vascular lesions may give no information about theoretical, directional consequences of head injury.

There are, inevitably, complex patterns of injury forces which include linear and rotational components with variable time components in different accidents. In this small series the main helmet impacts with solid objects or road surfaces occurred as follows - six to rear, three to front and two to the side. Three survived without head injury sequelae and one survived after a sixteen hour period of unconsciousness to return to good health. Of the seven fatalities (046) lived for two hours showing small haemorrhages diffusely in the cerebrum and brain stem and having developed small bilateral subdural haematomas. The latter and the number and size of his small haemorrhages was in keeping with survival with continued circulation for the short period described. Case 016 survived for seven hours during most of which time he was undergoing surgery for major blood vessel damage. This period allowed the development of bilateral temporal contusions and small haemorrhages throughout the cerebral white matter.

The other types of brain damage which are currently considered as primary e.g. diffuse axonal injury or secondary e.g. hypoxic and ischaemic damage can only be found in evidence after several days survival. None of the cases under discussion in this paper survived longer than the two (025 and 046) described above. All of the other fatalities occurred at the accident sites.

Comparison between Injury Data, Direction of Principal forces and Head Injury Criteria (HIC) Calculations from Helmet Drop Tests

The HIC values obtained at T.R.R.L. by reconstruction drop testing of identical helmets purchased new for this purpose have been presented. The values obtained where good replication of the helmet damage occurred were:-

Case	No.	HIC		Skull Fracture	Direction of Impact
009	1/1	not done	- survived without head injury	-	Rear
009	1/2	8,862	- " with mild head injury	+	R
013	1/1	not done	- " without head injury	-	Side
013	1/2	not satisfactory	- died but accident complex	+	S
016	1/1	12,775	- died after seven hours	-	Front
025	1/1	not done	- survived without head injury	-	R
025	1/2	7,351	- died at accident	+	R
029	1/1	8,325	- " " "	-	R
030	1/1	not done	- " " "	+	Front
030	1/2	27,294	- " " "	+	F
046	1/1	7,584	- died after 2 hours	-	R

The highest HIC values were 12,775 and 27,294, in the two accidents with frontal impacts. The former had an estimated speed of around 70 mph when he struck a road sign; the latter's estimated speed was around 50 mph when he struck a concrete fence post.

The side impact case was not satisfactorily evaluated.

The rear impact cases vary in their HIC figures; case 009 (1/2) - 8,862, 025 (1/2) - 7,351, 029 - 8,325 and 046 - 7,584.

Case No	HIC		Skull Fracture
009 (1/2)	8,862	survived with mild head injury	+
025 (1/2)	7,351	died at accident	+
029	8,352	" "	-
046	7,584	died er 2 hours	-

Other Injuries in relation to HIC

The other major injuries have been described above.

The highest AIS score for each individual and their HIC scores are:-

		AIS Head	Body	HIC
009	1/1			
009	1/2	4	2	8,862
013	1/1			
013	1/2	6	5	
016		5	4	12,775
025	1/1			
025	1/2	4	5	7,351
029		5	5	8,352
030	1/1	5	5	
030	1/2	5	6	27,294
046		5	4	7,584

These figures show no obvious correlation but the two with the frontal impacts and very high HIC values had a range of very severe injuries to other parts of the body.

In direct relationship to this paper's purposes, the body and limb injuries generally reinforced the ideas of how the individual's injuries occurred and thereby strengthen the evidence about the mechanisms in their head injuries.

Discussion

The eleven individuals in this small series of seven accidents died either at the accident (6), survived for two or seven hours (2) or survived indefinitely (3). One of these 3 survivors had a mild head injury while the other two had no signs of head injury. The accident information tallied with the observed damage to clothing and helmets so that it was possible to state the directions and number of impacts. Estimates of speeds were accepted as notionally correct in all cases as there was usually reliable information about the speed of other traffic or about the road conditions. These seven accidents are from the early part of a continuing study in which a further eighty accidents have now been reviewed in depth and in which relevant clinical and pathological data have been collected. The seven accidents referred to in this paper represent the first from the series where reconstruction drop tests have been done by T.R.R.L.

The correlation between the reconstructed sequence of events in the accidents and the analysis of clothing and helmet damage is good, indicating that the data on direction of impacts is sound. The helmet drop reconstruction information from T.R.R.L. should give good information about the magnitude of the force which caused the helmet damage and should correlate with the velocity of impact from the accident information. This has been shown to be approximately true as the most severely injured were the fastest moving and the most abruptly arrested. In the remainder of the group whose helmets were tested, the majority had rear helmet impacts and less violent accidents. It has not been possible to relate the positions of brain damage to the direction or magnitude of impact possibly because of the generally very short or insignificant post accident survival. In those two fatal cases in which there was survival for two or seven hours, lesions had developed which would not have been present in individuals who died instantly or within minutes of their accidents. The continuation of circulation for at least a few hours is essential to the development of the vascular lesions which are supposedly caused by the positive and negative, post impact, pressure waves which cross the interior of the skull and may create areas of damage - contracoup - on the other side of the brain from the impact site. It is possible to score contusional damage by reading the depth and extent of lesions in different cerebral regions. Such a scheme gives severity values for contusional damage provided sufficient time has elapsed, after the injury, to allow the contusions to reach their maximum size. In this study there is no evidence to allow evaluation of pressure wave theories, there having been only one patient who survived seven hours and who had roughly symmetrical temporal lobe contusions after a left frontal, high speed impact. This area of interest will be evaluated further as the accumulated cases (a further 80) are completely studied with helmet drop tests to provide verification of the vectored forces generated in the accidents.

While it may not be wholly acceptable, theoretically, contusional damage has generally been considered to follow impacts with linear acceleration or deceleration properties. Rotational and angular accelerations have been associated with the lesions which have come to be known as diffuse axonal injury. This term, introduced by one of us, has supplanted other terms such as axonal shearing and diffuse damage to white matter. Axons are damaged in some types of head trauma and the damage may be diffuse - which can be displayed only with specialised microscopical techniques - or focal with areas of damage often being visible to the naked eye after brain cutting. The pattern of focal damage - corpus callosum, dorsal brain stem and degeneration of long, defined tracts of axons has been largely known since the end of last century. There is no information about the mechanisms of generation of such damage in the human brain but it is obviously vitally important that mechanisms be established so that rational protective measures may be taken in all circumstances in which head injuries occur, not least in the road accident area.

As careful studies continue, notions of the generation of types of cerebral trauma alter as incongruities arise and more comprehensively rational ideas supervene. This study is providing a framework for a reappraisal of head injury mechanisms and the mechanisms of injuries to other parts of the body.

Tolerance of tissues to damage from physical forces is also being evaluated. The theoretical concepts embodied in Head Injury Criteria (HIC) have been accepted for some years because no alternative measurement or quantitation satisfies the need of scientific workers in the engineering and protection fields. The HIC calculation is currently considered to be associated with an unfavourable outcome if over 1,000 to 2,000. In this small study a survivor with minor, temporary brain dysfunction following an accident generating an HIC of almost 9,000 (009 - 1/2) suggests that there is more variability in the prognostic value of HIC than had been thought. This is an area in which future studies will probably shed light. Further studies of the survivors of rider-pillion accidents in the accidents described in this paper should give interesting findings because the directional components of these paired injuries are similar. In them, the magnitude of helmet and head trauma - as described above - has been less than in the more injured partner. Such information should give bracketing information about the limits of fatal or serious nervous system trauma but it is not at present available because of the time constraints involved in establishing the methodology and the decision to examine first the helmets of individuals with definite neuro-trauma or who had died and on whom neuropathological studies were complete.

Summary and Conclusions

In seven accidents eleven individuals were involved. The circumstances of the accidents have been assessed in detail as have items of clothing and protective helmets from the injured. These studies have allowed a clear appreciation to be achieved, in most cases, of the directions of impacts and correlation with information about speeds involved at collisions and impacts.

This information has been considered along with the TRRL studies of motorcycle helmet damage reconstructed for individual cases by test drops of new helmets of similar manufacture. From those studies HIC values were calculated for the fatal cases where neuropathology had been done. The helmets of survivors or less injured partners of rider-pillion passenger accidents have yet to be studied by drop testing and it is anticipated that valuable information about HIC values will derive from them. The HIC values of the individuals studied so far have been very high and well above the level at which death was likely to occur. One indefinite survivor, who had a mild head injury, had an HIC of almost 9,000 suggesting that the HIC values of individuals require to be considered with the unique circumstances of each accident.

The types of body, limb, spine and cranio-cerebral trauma in each fatal case has been considered in detail but as all bar two of the fatalities were very immediate after the accidents, there was insufficient evidence of injury to allow patterns of damage to be correlated with incident forces.

In most cases there was good evidence that the helmets protected against much more severe cranial damage but this only benefitted three survivors out of the eleven. It is no consolation to opine that the helmets had been protective when the subjects had died either from cerebral trauma or from a combination of neurotrauma and other serious injuries to the body and limbs.

This preliminary study has validated the concepts on which it was based. It gives an optimistic view of the extension of studies of more cases, particularly those who survived long enough to develop the microscopical features of diffuse axonal injury and patterns of secondary brain damage.

It is anticipated that the information achieved by direct observations of such accidents will allow HIC to be evaluated in this context and allow improvements in the design of safety equipment to be made rationally.

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