THE CORRELATION OF DAMAGE TO CRASH HELMETS WITH INJURY, AND THE IMPLICATIONS FOR INJURY TOLERANCE CRITERIA.

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ABSTRACT

By replicating the damage to the helmets of motorcyclists involved in accidents, the severity of impact can be established. Combining the clinical results of the accident with the impact severity allows the reliability of Head Injury Criterion (HIC) as an injury predictor to be investigated. Experimental data from the study reported here has been combined with comparable data from other researchers to indicate that there is a 8.5% probability of death at an HIC value of 1000, 31% at 2000 and 65% at 4000.

INTRODUCTION

The research described in this paper is part of a programme aimed at providing a new method of head injury prediction which is expected to lead to improved motorcycle safety helmets. In spite of frequent criticism the Head Injury Criterion (HIC) is one of the most widely used and quoted criteria, and so there is considerable data available relating injury to the HIC level. For this reason the research described in this report is aimed at assessing the reliability of HIC as an indicator of injury severity, with the ultimate objective of developing a better indicator if HIC should prove to be inadequate.

The research method is to obtain helmets from motorcycle accidents where the rider had sustained fatal or serious head injuries. (A description of the sample and case selection is given in the next section.) An attempt is then made to replicate the helmet damage by drop testing equivalent new helmets. The resulting impact energy is then related to the injury level and the potential for the impact to be fatal is related to the HIC calculated for each test. Only linear impacts have so far been investigated: crush and rotationally induced injury will be considered in the next stage of the research.

The injuries to the brain were evaluated by Glasgow Southern General Hospital: for the fatal cases diagnosis was by brain sectioning and for the non-fatal cases by computerised tomographic (CT) scanning. Details of the drop test and replication methods and how the brain injuries are evaluated are fully described later. The region of the helmet impacted is also considered important, and this was recorded and is described in a separate section. A detailed description of the brain injuries can be found in a paper by Doyle published at this conference.

The TRRL has never used animals in vehicle crash studies but the present consensus of opinion in those countries that have done so is that animals, even large primates, are unsatisfactory surrogates for the prediction of injury to the human brain. Thus the method reported here which attempts to correlate human brain injury directly with the dynamics of an impact is a significant advance on research using animals. Experiments have shown that visible damage to many types of helmet is closely related to impact energy. Therefore the assumption which forms the basis for this research is that the energy needed to replicate the accident damage is similar to the energy which was absorbed in the accident and hence produced the brain injury.

ACCIDENT SAMPLE, CASE SELECTION AND BRAIN INJURIES

Case Selection

The motorcycle accidents, from which data is gathered for this report, are from the area covered by the Strathclyde Police and date back to April 1984. To date 79 accidents have been recorded, some of which involved more than one casualty. Of the 102 individual subjects involved in this study 14 deaths are directly related to head injury. Table 1 gives the case number and summarises the 36 fatal and 6 non-fatal cases which have been found to be suitable for injury correlation. Six additional non-fatal cases are listed which have been used for the impact location survey.

The case number is followed by two numbers, 1/1 for example. The first number denotes whether this was the first (1/1) or subsequent (2/1) motorcycle involved in the accident, and the second number whether the victim was the rider (1/1 or 2/1) or a passenger (1/2 or 2/2). The cause of death is indicated under COD, column HI indicates if a head injury was recorded. The next column indicates whether or not the helmet was rejected, i.e. replication not attempted, and the reason. In general, replication was attempted only if death was due to head injuries. However when a non fatal case with significant helmet damage was encountered this too was replicated.

A number of cases are also noted in Table 1 where the helmet was not made available. The large proportion of rejects gives an indication of the large number of cases which have to be collected to yield a few which are directly useful. The final column headed "location" gives the position of any impact damage on certain helmets. The code used refers to fig 1. A fuller description of the impact location survey is given in the following section.

The damage to the helmets varied greatly even where fatal head injuries were sustained. There were two cases where death resulted from head injury and yet the helmet did not sustain any replicable damage by which to establish a HIC value i.e. the helmet was scuffed but there were no cracks to the shell nor permanent liner compression. The procedure adopted for these cases is discussed later. In the other cases there was significant damage to both the shell and the liner.

Each case was considered also in terms of survival time.(Table 2, which will be considered in detail later, lists survival times for seven cases for which replication has been attempted). This is not only a useful method of ranking the extent of the injury but is an indication of how close the injury was to the tolerance threshold. A long survival period i.e. around 30 days, indicates a head injury very near the tolerance threshold reputed to equate to a HIC of 1000. The dead on arrival cases (DOA) have usually sustained a very high impact energy, with an equivalent HIC significantly greater than 1000. However, a normal distribution of tolerance to head injuries is to be expected, with HIC=1000 towards the lower end of this distribution and with some people surviving very much higher levels. Consequently high energy impacts provide information to establish the range of the distribution.

Non-fatal head injury cases are being investigated by computer tomography and these results will be used in the next phase of the research to explore the effects of lower energy impacts. The information obtained from a CT scan is not as detailed as brain sectioning but it does give a good indication of the extent of brain injury. In most of these cases, the damage to the helmet was only superficial, although there were a few cases where the damage was substantial. Non-fatal head injuries and fatalities due to injuries other than to the head are of limited value in establishing a HIC-fatality relationship. Details of the injuries are available, however, and their relevance will be examined further when a general study is undertaken.

Impact Location

The frequency with which impacts occur to different parts of the helmet is an important factor when considering helmet design and the protection afforded. So that the impact points in this survey could be categorised and assessed, zones were defined. The surface of the helmet has been divided into 40 sections and the resulting coarse grid is illustrated in fig 1. So far in this study a total of 27 helmets have been inspected for damage and thus impact location, and of these only 23 showed any sign of damage. Figure 2 shows the number and location of the impacts and fig 3 summarizes the occurrences of impact to the main areas of the helmet i.e. front, back etc.

The results show that 22% of impacts are to the back, 22% to the crown, and only 17% are to the front of the helmet. The results also show that 30% of impacts occur to the left side of the helmet and only 9% to the right side. This does not support the findings of previous work by Otte, Jessl and Suren (1) which has shown that impact points are predominantly to the front of helmets with relatively few to the rear. However it should be noted that the sample size is much smaller in this study (23 compared with 152).

Brain Injury Data

Details of injury to the brain are recorded by a neuropathologist on prepared forms (fig 4) showing a set of layered vertical sections through the brain. The hand colour coded drawings are sent to TRRL where the information from the 17 sections is transcribed into a computer memory for subsequent analysis. The types of injury recorded are primary and secondary. The primary injuries are divided into axonal, damage to the nerve paths; haematoma, areas of blistering; contusions, areas of large bruising. Secondary injuries include hypoxic/ischaemic damage and microglial scars. A computer program is used to analyze this information and calculate amount, amount of each type and apparent direction of injury. The present analysis is based on the area of injury indicated on the forms. Direction is estimated by establishing the centroid of the volume bounded by the areas of injury, but these results are not reported here because so far insufficient cases have been analyzed in this way. Weighting has not been applied to different types of injury though it would be very easy to implement this refinement. Surviving subjects are examined by CT and their radiological sections are encoded using the same scheme as for the pathological sections. For technical reasons the CT scans are taken in a plane perpendicular to those of the pathological sections. A program has been developed to manipulate the data to produce sections in any plane. However data from the CT scans have not yet been used in this research.

TEST PROCEDURE

Drop Tests and Replication

The method of replicating damage to case helmets was by drop-testing new similar helmets using equipment described later. A number of attempts (using a new helmet each time) were usually required. Each time the conditions were altered i.e. drop height, angle etc, until a visual inspection showed that the damage was accurately replicated on both the shell and liner. The impact velocity, HIC and angle of impact were subsequently calculated. Fig 5 shows the polar coordinate convention used to define the angle of impact. The general concept of replication was found to be perfectly practicable, the operator having little difficulty in matching the damage.

Some helmets showed no permanent deformation but only scuff marks. To assess these cases, similar helmets were drop-tested from an increasing height to a point where damage was just visible. In this way the maximum possible impact velocity and HIC value were established.

The Test Helmets

The collection of material started in April 1984. Since then a new standard for motorcycle helmets has been introduced, BS6658/1985. This new standard is a combined revision of BS2495/1977 and BS5361/1976 which were withdrawn following a transition period after which only helmets complying to BS6658 could be sold for road use. Helmets complying with BS2495 were originally intended for high speed motor car racing but came to be used in other competitive events and as high-protection helmets for motorcyclists on public roads. Two types of helmet, A and B, are specified in the new standard. Type A corresponds to the former high-protection standard, and is intended for competitive events and for use by wearers who demand a high degree of protection. Type B is intended for the ordinary motorcycle rider on public roads.

The revision differs from the standard which it replaces as follows. New materials are permitted, an oblique impact test replaces many of the former constructional requirements, and there are new tests for chin guards and for the effectiveness of the retention system. The concept of separate component testing has also been introduced.

The new standard has obviously created a problem as far as finding equivalent new case helmets is concerned since most of the earlier helmets included in this study were purchased before BS6658 came into force. Also, some of the case helmet manufacturers no longer produce helmets and some current manufacturers have changed their designs. Preliminary work has established that the performance of most recent helmets is similar. Where possible, case helmets were replicated using helmets of the same model and British Standard. If an exact match could not be made then a helmet of similar design/construction was employed, aimed at giving a good approximation of the HIC experienced by the wearer of the case helmet.

EXPERIMENTAL EQUIPMENT

The drop-test equipment consists of two parallel vertical wire guides with a ferrule on each. The helmet containing a wooden head-form is suspended from the ferrules and from a release mechanism which is activated by a solenoid. This allows the helmet to fall freely under gravity but guided by the ferrules, which are very light and have no effect on the impact. The complete system can be raised to 10.4m (34 ft), which provides a maximum impact velocity of 14.3m/s (32 mile/h).

A catching device was constructed so that a secondary impact does not occur after rebound. This consists of a conical net with a hole through which the helmet passes, first on the drop and then on the rebound. The hole is then drawn closed, by a string, catching the helmet.

A solid wooden headform to BS6489 and of mass 5kg was modified to allow a triaxial accelerometer (Endevco type 7267A) to be installed approximately at the centre of gravity. The impacts are normal to a rigid piezoelectric transducer (Kistler type 9293) mounted on a 1000kg anvil. The output data from the transducers are captured on a 12 bit digital recording system sampling at 100kHz, and although frequency filtering is not required for the analogue signal, for the digital recordings the recorder was preceded by an analogue low pass filter with a 68db per octave attenuation at 4kHz to avoid possible aliasing. Digital filtering to SAE J 211 B was available, but it was not used here. The modified headform was found to be free from spurious response, and it was considered that for this research high frequency data which may be relevant should not be excluded. Searle et al (2) and Hodgson and Patrick (3) support this view.

RESULTS

Replication

Table 2 summarises the results of the replications, showing for each attempt the impact speed, impact angle and HIC, and whether a replication was satisfactory or not. It can be seen that the method is very sensitive, with small changes in speed and angle distinguishing between successful and unsuccessful replication (in case G016 the results of the unsuccessful drops were not calculated).

The test rig is configured to replicate impacts with hard blunt objects. No attempt has been made to replicate impacts where scuffs were the only witness on the helmet. In general, when the impact velocity did not exceed the capability of the drop rig (14.3 m/s), the replication was good (as assessed by visual inspection - see plate 1).

Not surprisingly, when the HIC values obtained were in excess of 7000 most of the subjects' survival times were short, the majority being DOA (Table 2). The lowest value of HIC, with a satisfactory replication, was 6,099 the subject surviving for 389 days (G0027 1/1). The next longest survival, with satisfactory replication, was 7 hours 20 minutes (G0016), the HIC being 12,775 (however the pathologist's opinion was that this subject should have been DOA because of his extensive head injuries). Although an HIC of 5830 is indicated against G012 the test helmet was not the same model as the original. When the impact velocity of the case helmet was assessed as being beyond the capability of the rig, as in case G0013 1/2, the replacement helmet was dropped from the maximum height of the rig at the correct angle. This did not give satisfactory replication but it can be deduced from the results that the HIC was greater than 15,400 in this case. One helmet (G0027 1/1) displayed a pronounced crease, indicating a probable impact with a kerb or post. Replication was attempted using the edge of a plate placed on the impact anvil to reproduce the above conditions. Reasonable replication was achieved with a HIC value of about 6000.

Low energy impacts were conducted to assess the lowest velocity at which damage becomes visible to both thermoplastic and glass fibre helmets. For the two types of helmet the impact velocity was not less than 5 m/s (11 mile/h), which yielded a HIC of approximately 2000. At low impact velocities the thermoplastic helmets showed damage first to the liner when no damage to the shell could be seen, but in the glass fibre helmets damage to the shell appeared first. There have been 2 fatalities at impact levels where the helmets sustained no visible damage and a maximum HIC of 2000 was indicated by the above tests (G007 1/1 and G041 1/1).

The impact severity has been established by replication in the mid range of energies. Impacts above and below the range where replication is possible have been estimated. Those helmets which show damage too extensive for the rig to replicate have had their impact energy estimated according to the area and extent of damage. Helmets which have no replicable damage have been assessed according to the magnitude of any surface scuffs i.e. the greater the scuffing the higher the estimated impact energy. It was considered important to determine the severity of injury sustained at given energy levels. The injuries for each case were assessed against the AIS scale. The DOA cases were assumed to be 6, those who survived less than 30 days were rated between 5 and 6 with AIS 5 representing 30 days survival. The single case with a survival time longer than 30 days (G027 1/1 who survived 389 days) was plotted just below AIS 5. The non-fatal cases were assessed according to the medical records and to provide a ranking by degree of injury for the minor cases the AIS scale was subdivided between 0 and 1. Fig 6 is a graph of the results. However there is no obvious trend except that there were no survivors above 400J and survival is unlikely above 250J.

Of more use to the designer of protective devices is a prediction of the response to a given value of HIC of a range of the population. Fig 7 provides this data plotted on normal probability graph paper, and shows that when related to HIC the probability of death approximates closely to a normal distribution. Details of this important result are to be found in the next section.

Data from brain sections

Data obtained from pathological sections has been analyzed by a computerised system. Only a small portion (volume) of the brain has to be damaged to produce death: the largest injury found by the analysis program is 4.3% , and the smallest is 0.07% by volume. The centre of injury as located by the program is approximately in line with the point of impact on the helmet. A detailed analysis of injury is contained in Doyle's complementary paper in this publication (IRCOBI).

DISCUSSION

Helmets have two major components, the shell and the liner. Previous work by Chamouard and Tarrier (4) showed that the shell distributes the impact load efficiently and prevents skull fracture, yet brain injury can still be present even at low velocities. The brain is susceptible to injury resulting from acceleration. The liner can reduce this injury but the choice of material is crucial. It should provide a uniform acceleration, but as the liner is only about 30mm thick the protection that can be achieved at high speeds is limited.

So far there is no subject who survived where the damage to the helmet was greater than could be replicated. However, there is one case where impact has occurred with an object of small radius and the subject survived for 389 days after the accident. The damage to the helmet is disproportionately large and drop-tests indicate a HIC in the range of 6000. In cases where the subject did survive the majority of the helmets suffered only superficial damage. This supports the view of previous work by Hopes and Chinn (5) that current helmets are designed to withstand impacts at speeds beyond the range where survival is likely. Further support to this view is that although helmets drop-tested to replicate non-survival impacts were badly damaged, they still retained their structural integrity and could have absorbed more energy. Conversely, two fatalities occurred in potentially survivable impacts where the helmets received very little damage. Some energy would have been absorbed elastically but this would have been reapplied during rebound, the effect being to increase the length of exposure.

It is necessary to establish the human brain tolerance in order to develop better crash helmets. Fatal head injury is said to occur at a HIC of 1000, but there is clearly a wide distribution of tolerance to head injury and values of between 177 and 4000 are implied from other criteria. Previous work by Hopes and Chinn (5) shows that a large change of the target level of HIC to which a helmet should protect yields only a small change in the velocity at which a practical helmet could offer protection. Table 3 summarises the probability of fatality at a given HIC indicated by this study and shows that a HIC value of up to 2000 gives a chance of survival of 71.4%. Rather surprisingly one case out of a total of eight (12.5%) did survive in the 8000+ range. There have been no cases in the 2001-4000 range.

The data from Fig 6 has been manipulated into a form suitable for presentation on a normal distribution graph (Fig 7). This has produced five points at increments of 2000 HIC representing percentage of fatality at each level. The lower limit of replication is HIC 2000. Data from other sources has been used to provide information in this area of interest. Kessler (6) has established a statistical relationship between HIC and chance of death. Points from his research are used in Fig 7. Vallee et al (7) have found that the risk of death or serious injury is 38% when the helmet shell fractures and 21% when it does not. The minimum energy required to produce fractures equates to a HIC of 2000 and if a normal distribution of impact severities is assumed, the data from Vallee's study may be presented as a probability of death at a HIC of 2000. This has also been added to Fig 7, and it can be seen that there is good agreement between all three sources (Vallee, Kessler & TRRL) as to the relationship of HIC with the probability of death. Using logarithmic / normal distribution graph paper and simple line fitting methods a straight line with a correlation coefficient of r = .973 was obtained. The probability of death or serious injury predicted from the combination of results (Vallee, Kessler & TRRL) is:-

8.5% at HIC 1000 and 31% at HIC 2000
Or in terms of +/- 1 Standard Deviation :-
The fatal HIC Level for the 16 percentile is 1375. (-1 S.D.)
The fatal HIC level for the 50 percentile is 2950.
The fatal HIC level for the 84 percentile is 6400. (+1 S.D.)

This wide spectrum of tolerance to head injury is in keeping with medical reference books (Damon(8), Evans (9), Yamada(10),) which remind the reader that a large scatter (4 to 1) is to be expected for the strengths of biological structures. The helmets tested in this study have not been assessed for angular acceleration (rotation) but this must have been present in at least some of the cases. Replicating rotation causes difficulty as there are little or no witness marks to indicate the extent of rotation present in the case helmets. However, replication will be attempted in the next phase of this research and the drop rig will be set up to assess helmet rotation. The liner of the helmet has a limited travel in which to absorb the energy of a linear impact and if it is optimised for one set of conditions it may run out of crush in more violent impacts. Rotation does not have this constraint and a design for reducing angular acceleration is likely to be effective at all values. It must be remembered that angular acceleration is governed by the moment of inertia of the helmeted head, friction and the normal reaction, but it is largely independent of the velocity parallel to the surface of impact.

Recent medical research suggests that diffuse axonal injury is associated with rotation, whereas focal injury is associated with linear acceleration. Experiments have been set up in the U.S.A. using monkeys to produce rotation without linear acceleration, and these have produced diffuse injury. However it need not be the case that linear acceleration produces only focal type injuries, for when these induce rapid death the diffuse axonal injuries are masked because they require considerable time for "scarring" to develop before they can be detected.

This report shows that in the range 0-10000, HIC can indicate the probability of death in a satisfactory manner. The underlying principle that injury is a result not only of peak acceleration but the length of exposure is probably valid. It follows from this that if the shock absorbing mechanism of a helmet is resilient the same peak acceleration would produce injury proportional to the degree of resilience, i.e. a perfect spring would probably produce twice the injury of a perfect energy absorber, though the peak acceleration would be the same. If a body which absorbs energy perfectly is brought to rest at 300g from 7.5m/sec (as is permitted by the British Standard) it would produce an HIC value of 3972, but if it recoils with perfect resilience a value of 7945 would be produced. Most helmets rebound at about 0.6 of the initial velocity (1) resulting in a HIC of typically 3500 at an impact velocity of 7.5m/sec. Eliminating this resilience would reduce the HIC to around 2190 under the same impact conditions. If the same peak g was retained as is specified in the current tests, but a time limit on exposure were imposed, a pro-rata reduction in injury potential would be achieved without affecting protection in severe impacts.

CONCLUSIONS

1. Helmet damage sustained in fatal accidents can be replicated using a drop test method. The replication assessed by visual inspection is sensitive to changes in impact velocity as small as 0.5m/s.

2. The best estimate of risk of death in relation to impact severity is:-

   HIC 1000 = 8.5% HIC 2000 = 31% HIC 4000 = 65%

3. Current helmets are too strong, and their design is optimised for an impact severity that gives little chance of survival. It has been shown that both thermoplastic and glass fibre helmets can withstand an impact of 11 mile/h producing a HIC of around 2000 without visible damage, and hence having absorbed little or no energy.

4. Current helmets are too resilient. The typical rebound velocity is 0.6 times the impact velocity. If the resilience were eliminated, the HIC at an impact velocity of 7.5m/sec (BS requirement) would be reduced typically from 3500 to 2190.

5. Helmet standards should state the maximum duration of acceleration as well as the peak. The permitted resilience would thus be controlled because a limit on the peak acceleration and its duration automatically limits the velocity change on rebound.

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Table 1
Description of cases examined so far, and selection for replication

Case No	C.O.D.	HI	Reject	Why	Location
G0002 1/1	NECK INJ	NO	YES	NO HI	
G0003 1/1	HEAD & NECK	YES	YES	NO HELMET	
G0004 1/1	HEAD CHEST ABD	YES	YES	NO REPLIC DAMAGE	NONE
G0004 1/2	MULTIPLE	YES	YES	NO HELMET	
G0007 1/1	MULTIPLE	NO	YES	NO HI	TBM
G0007 1/2	MULTIPLE	NO	YES	NO HI	NONE
G0011 1/1	OTHER	YES	NO		NONE
G0012 1/1	MULTIPLE	YES	NO		TMM
G0013 1/2	MULTIPLE	YES	NO		LTM
G0014 1/1	CHEST & ABD	NO	YES	NO HI	FBM
G0016 1/1	HEAD INJ	YES	NO		TFL
G0017 1/1	MULTIPLE	YES	NO		BBR
G0018 1/2	MULTIPLE	YES	YES	NO REPLACEMENT	FBM
G0019 1/1	MULTIPLE	NO	YES	NO HI	
G0020 1/1	CHEST & HEAD	YES	YES	FAIL BY CRUSHING	RMM
G0025 1/2	HEAD & CHEST	YES	NO		LMR
G0026 1/1	MULTIPLE	YES	NO		LBM
G0027 1/1	N/K	YES	NO		LTM
G0028 1/1	MULTIPLE	YES	YES	NO HELMET	
G0029 1/1	CHEST THOR SPINE	YES	NO		BTL
G0030 1/1	HEAD INJ	YES	NO		
G0030 1/2	MULTIPLE	YES	YES	NO HELMET	
G0031 1/1	MULTIPLE	NO	YES	NO HI	
G0031 1/2	MULTIPLE	NO	YES	NO HI	
G0032 1/1	HEAD & CHEST	YES	NO		LMR
G0034 1/1	MULTIPLE	NO	YES	NO HI	
G0036 1/1	HEAD INJ	YES	YES	NO HELMET	
G0039 1/1	MULTIPLE	YES	YES	NO HELMET	
G0040 1/1	ABDOMINAL	YES	YES	NO REPLIC DAMAGE	TFM
G0041 1/1	MULTIPLE	YES	YES	NO REPLIC DAMAGE	
G0046 1/1	HEAD & MULTIPLE	YES	NO		
G0049 1/1	OTHER	YES	YES	SLIGHT HI	
G0054 1/1	HEAD	YES	NO		
G0064 1/1	MULTIPLE	NO	YES	NO HI	
G0065 1/1	HEAD	YES	NO		
G0066 1/1	SHOCK	N/K	YES	HI N/K	
	NON FATALS				
G0001 1/1				IMPACT STUDY ONLY	TFL
G0008 1/1				IMPACT STUDY ONLY	FTM
G0009 1/2	AIS 4	YES	NO		BMR
G0013 1/1		NO			BMM
G0015 1/1				IMPACT STUDY ONLY	LTL
G0022 1/1				IMPACT STUDY ONLY	BTR
G0023 1/1				IMPACT STUDY ONLY	NON
G0025 1/1				IMPACT STUDY ONLY	LTL
G0035 1/1	DROWSY AIS 1	YES			RML
G0041 1/2	KO AIS 2	YES			
G0042 1/1	CUTS AIS 1	YES			FBL
G0059 1/1	SUSPECTED HI	YES			

For explanation of the terminology ,see text

Details of replication for some cases
Table 2

		Attempts at replication			
Case No	Survival	Impact speed	Impact angle	HIC	Rep
G0091/1	Survived	11.63 m/s	XY= 146.6 Z = 48.2	14099	NO
		11.27 m/s	XY= 138.7 Z = 50.3	8862	YES
G0131/1	D.O.A.	10.28 m/s	XY= -163.7 Z = 64.1	6071	NO
		14.08 m/s	XY= 133.9 Z = 62.2	15378	NO
G0121/1	D.O.A.	11.34 m/s	XY = 106.5 Z = 85	6253	NO
		9.72 m/s	XY = 92.7 Z = 89.2	5860	YES
G0161/1	7 HR 20 MINS	10.85 m/s			NO
		14.00 m/s			NO
		13.97 m/s			NO
		14.00 m/s			NO
		13.99 m/s			NO
		14.04 m/s			NO
		14.16 m/s	XY= 102.6 Z = 60.7	12775	YES
G0251/2	D.O.A.	10.39 m/s			NO
		10.85 m/s	XY= -103 Z = 52.3	7351	YES
		11.72 m/s	XY= -96.4 Z = 73.4	9733	NO
G0271/1	Survived 389 DAYS	11.53 m/s	XY= -65.1 Z = 42.8	8204	NO
		11.37 m/s	XY= -31.5 Z = 36	6099	YES
G0291/1	D.O.A.	11.23 m/s	XY= -135.6 Z = 64	8325	YES
		11.37 m/s			NO
G0301/1	D.O.A.	9.50 m/s	XY= -110.9 Z= 38	4923	NO
		12.92 m/s	XY= -122.7 Z = 31.7	13340	NO
		14.19 m/s	XY= -127.9 Z = -10.5	9123	NO
		14.11 m/s	XY= -127.7 Z = -1.7	9386	NO
		13.53 m/s			NO
		13.54 m/s	XY= -104.2 Z = 27.2	27294	YES
G0461/1	D.O.A.	11.09 m/s	XY= 9.6 Z = 22.4	7584	YES
		13.07 m/s	XY= -17.4 Z = 21.8	16777	NO

TABLE 3
Surviving and fatal cases categorised by HIC

H.I.C.	0-2000	2001-4000	4001-6000	6001-8000	8001+
SURVIVAL	5	NO DATA	0	0	1
FATALITY	2		2	3	7
TOTAL	7		2	3	8
% SUR	71.4		0	0	12.5
% FAT	28.6		100	100	87.5

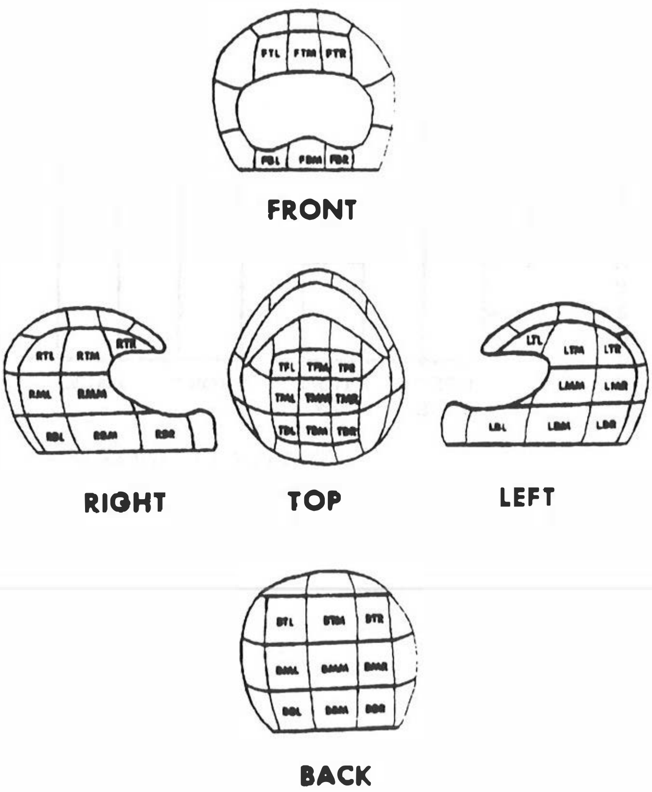

Figure 1 IMPACT ZONES

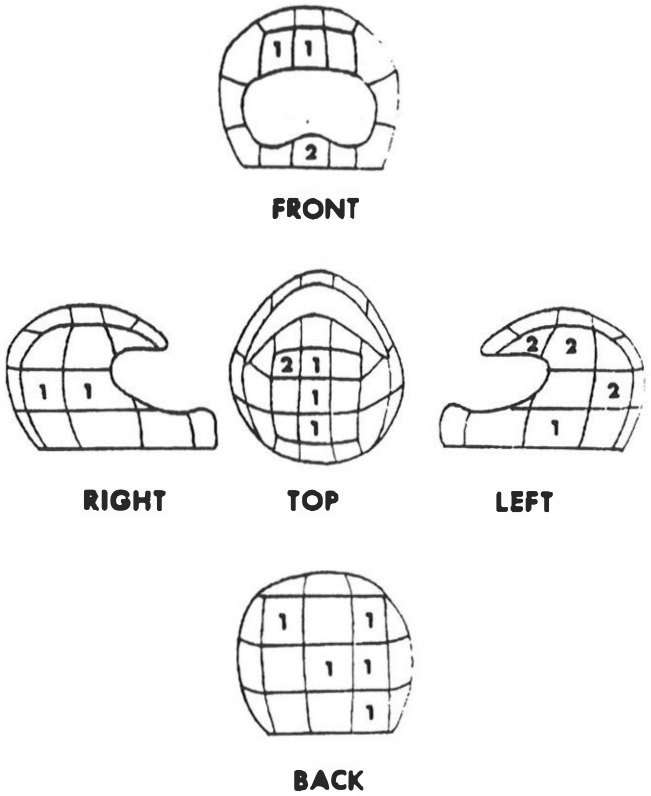

Figure 2 LOCATION OF IMPACTS

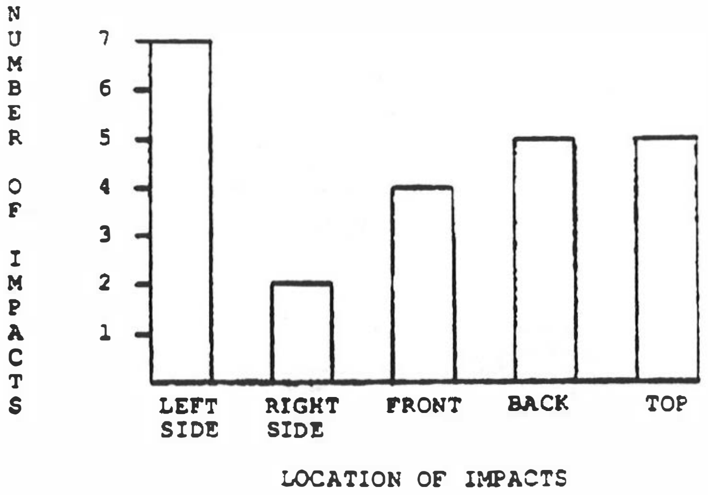

Figure 3 IMPACT DISTRIBUTION

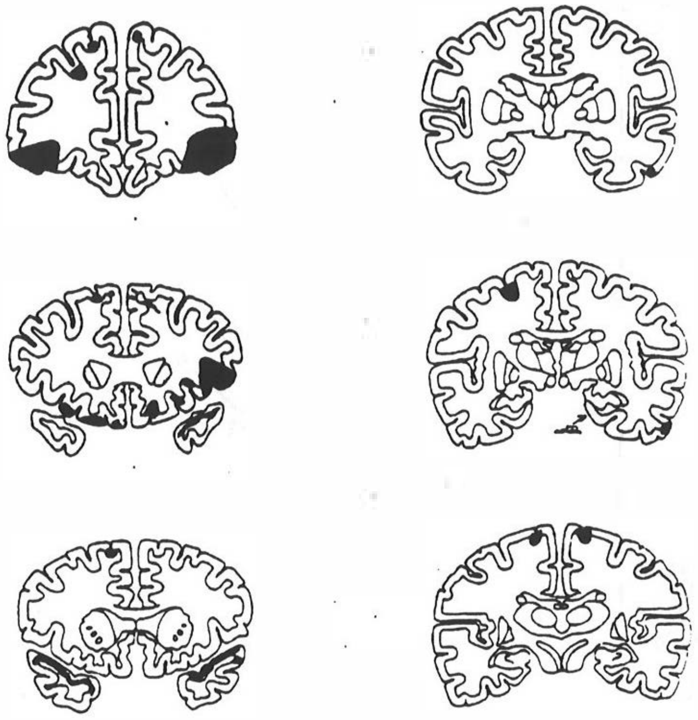

Figure 4 SAMPLE OF PREPARED FORMS (1/2 SIZE) ILLUSTRATING A RECORD OF INJURY SHADING REPRESENTS AREAS OF CONTUSION

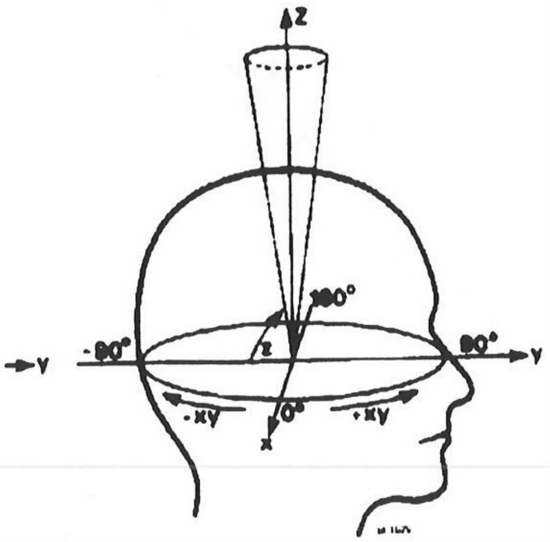

Figure 5 POLAR CO-ORDINATE CONVENTION

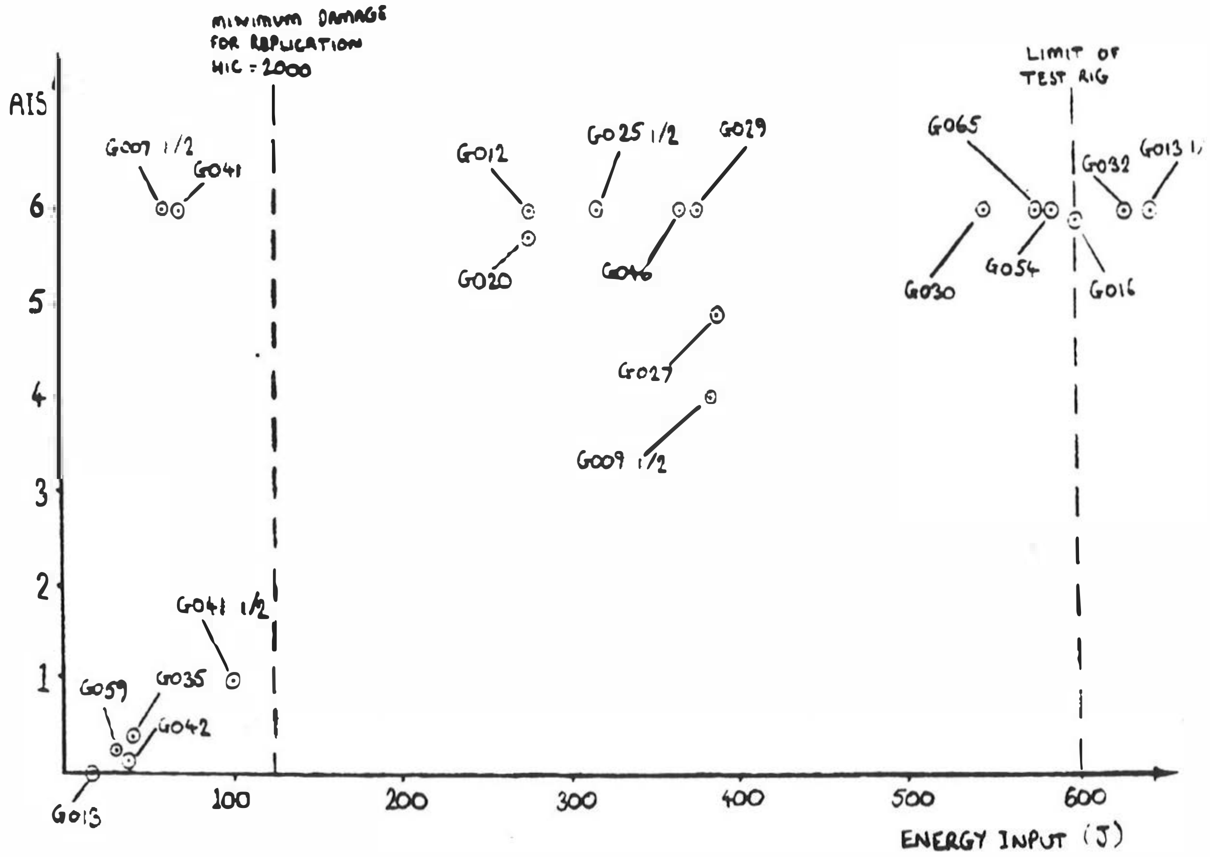

Figure 6 INJURY AGAINST ENERGY

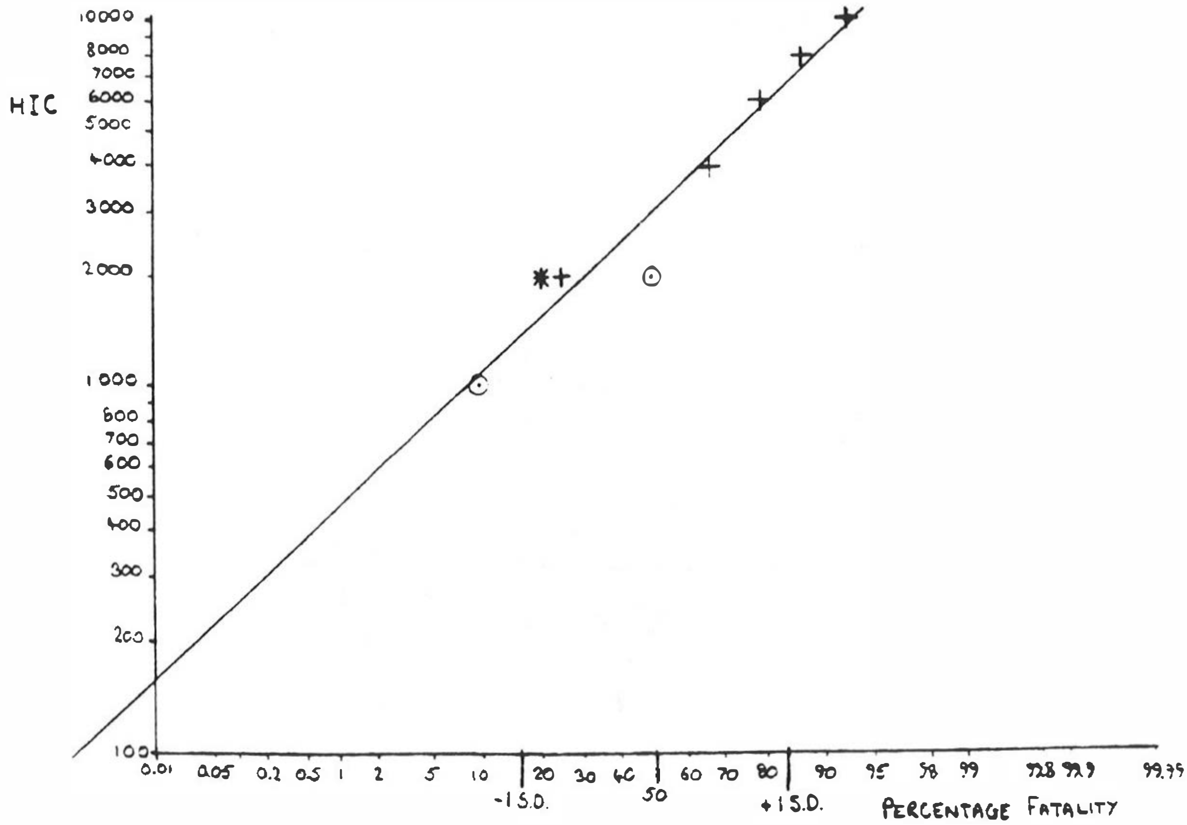

Figure 7 DISTRIBUTION OF HIC TOLERANCE
KEY:- + TRRL o KESSLER * VALLEE

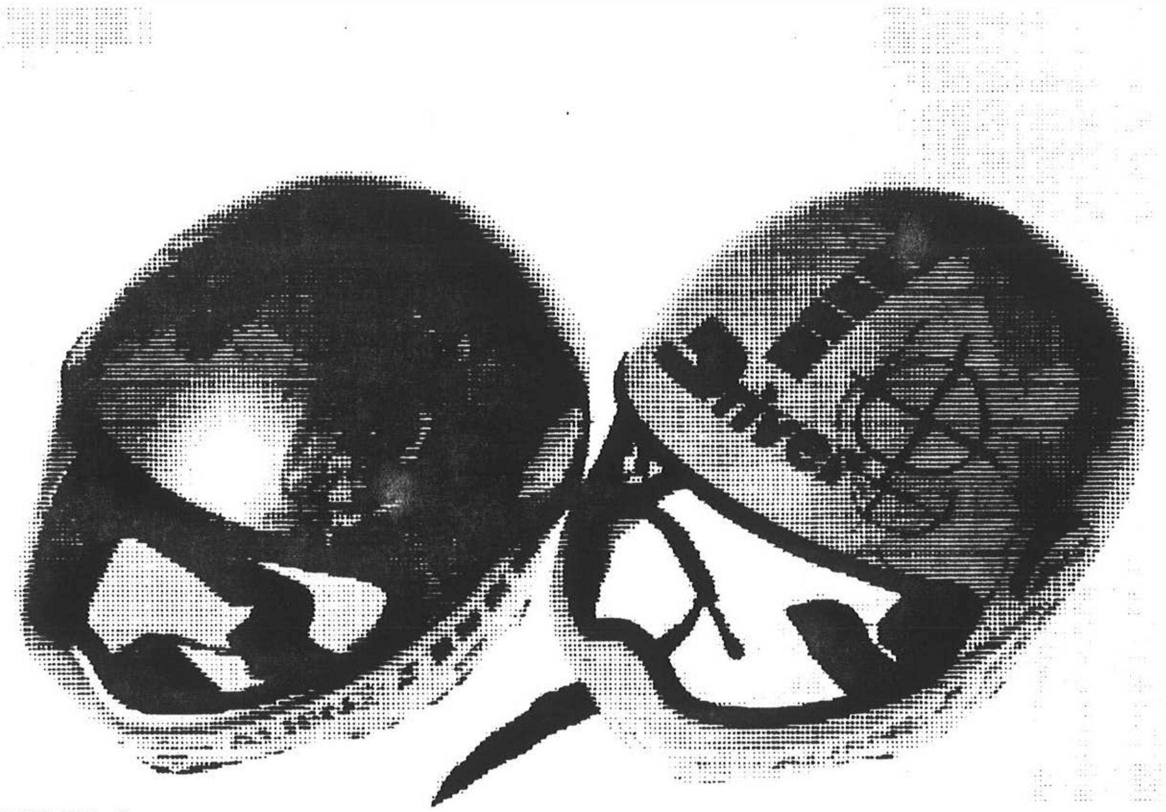

PLATE 1