IMPORTANCE OF MORTALITY FROM HEAD INJURY IN IMMEDIATE SURVIVORS OF VEHICULAR INJURIES

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ABSTRACT:

Analysis of 174,160 patients admitted to 165 trauma centers in the United States was undertaken to compare mortality of those injured by vehicular mechanisms with non-vehicular causes. Vehicular injuries (49.7%) were divided into those to vehicle occupants (VO, 36.4%), pedestrians (PED, 7.2%) and motorcyclists (MC, 6.0%) while non-vehicular injuries were subdivided into penetrating (gunshot (8.7%), stabbings (8.0%) and other (1.8%)) and blunt (falls (18.4%), assaults (13.2%)) causes. Each injury was categorized by severity by AIS-85 and by the presence of injury to the skull or brain (head injuries = HI). Of the 59,713 HI, vehicular causes produced more head injures (66.6%) than all other causes, despite the preponderance of non-vehicular injuries in the overall series (50.3%). For each of the vehicular injuries, HI mortality was higher than if no head injury (NHI) occurred: VO 11.5% v. 4.9%; PED 20.7% v. 7.3%; MC 15.3% v. 4.2% for HI and NHI respectively. This was also true for each AIS level. Analysis of these mortality rates, combined with the frequency of their occurrence, measures overall importance of each combination of HI and NHI in vehicular crashes. The greatest "vehicular mortality harm" in immediate survivors of crashes is caused by VO with HI of AIS = 3-6 who also have extracranial injuries of AIS = 3 severity. This group has three times the importance of any PED group and almost six times the importance of any MC group. These data can be used to target injury reduction strategies.

INTRODUCTION

Head injuries have long been regarded as important types of trauma that result from various causes. In order to assess the importance of head injuries due to vehicular injuries compared to other injury producing mechanisms, data from the recently completed Major Trauma Outcome Study (MTOS) was analyzed. This paper reports the outcome of the largest series of head injured patients to date.

METHODS:

Over the 8 year period from 1982 to 1989, data on proscribed forms were submitted voluntarily to the Major Trauma Outcome Study (MTOS) from 165 hospitals. Of these hospitals, 85% were designated as trauma centers by regional authorities and 15%

were self designated. For the first 18 months, participating centers submitted all trauma deaths that occurred in the hospital (including the emergency department) plus either all trauma patients admitted to hospital or all trauma patients admitted to intensive care units. Later, all centers contributed all trauma deaths and all hospitalized trauma patients. As the study proceeded, more trauma center hospitals submitted data. For the first four years, the database consisted of 65 hospitals was expanded to 165 by the end of the collection period.

The information was collated and analyzed at the Washington Hospital Center, where all injuries in all areas of the body were coded according to the 1985 version of the Abbreviated Injury Scale (AIS)[1]. The AIS ranks injuries on an ordinal scale of increasing severity from 1 (minor) to 6 (virtually unsurvivable). Because of the type of data available from the trauma centers, several coding conventions were adopted that differed slightly from those recommended in the AIS manual. The convention that most affected the head injury coding was that only the anatomic section of the AIS dictionary was used. Consistent information regarding the length of unconsciousness and the level of unconsciousness precluded injury coding using these two sections of the AIS.

For this study, only a small number of the many elements of the MTOS database were analyzed at the University of Pennsylvania. Patients were divided into two major categories, those with **head injury** (HI) and those with **no head injury** (NHI). Patients were considered to have a head injury if at least one injury to the brain or skull was present. Therefore, at least one injury with an AIS severity code greater than zero existed. All other injuries, including those to the face were not considered head injuries and were designated as extracranial injuries (ECI). Thus, all patients with NHI had head or skull AIS scores of zero. The HI patients were further classified according to the presence or absence of ECI in addition to their head injury. Thus, some patients in the HI category may have had ECI as well as head injury, but no patient in the NHI category had a head injury. In both the HI and NHI groups, a patient may or may not have had more than one injury. If this were the case, only the injury with the highest severity was used for analysis. The patients were also categorized into seven mechanisms of injury causation: motor vehicle occupants (VO), motorcycle riders (cycle), pedestrians (PED), gun shot wounds (GSW), stab wounds, falls, and assaults. The latter category also contained a small number of other injury mechanisms such as sports injuries. The first three categories were combined as vehicular injuries, the next two were considered as penetrating injuries and the last two as non-vehicular injuries.

RESULTS:

OVERALL INJURY INCIDENCE:

Injury information was available from 174,160 patients. Of these, 114,447 (66%) had no head injury (NHI) and 59,713 (34%) incurred a head injury (HI). Only 8,137

of the head injured patients had no extracranial injury (ECI), thus the incidence of pure head injury was 5% and the true incidence of all ECI was 95%. However, 28,508 patients with head injury had only very minor ECI of AIS 1 or 2 (usually abrasions, contusions or lacerations of the skin), so that there were 36,645 patients with almost pure head injury (21%).

The causes of the injuries are shown in Table 1. Overall, vehicle occupants were the most commonly injured group and comprised more than one-third of this series (36.4% of all patients). Falls and assault injuries ranked next in frequency and each contributed about one-sixth to one-eight of the patients (18.4 and 13.2% respectively). Pedestrian and motorcycle injuries were less common (7.2 and 6.0%) and were equal to gunshot and stabbings (8.7% and 8.0%).

When subdivided by mechanism of injury, differences in the frequency of occurrence of HI and NHI are apparent. Compared to the expected overall incidence of 34.6%, HI are over-represented in motor vehicle occupants (VO = 46%), cycle injuries (44%), and pedestrians (PED = 48%). HI occur less frequently than expected in gun-shot wounds (GSW = 14.9%), stabbing (1.5%) and falls (27.2%) and are as common as expected in assaults (37.1%).

The mechanisms of causation of the 59,589 patients with head injury, ranked as follows: vehicle occupants 48.8%, falls 14.6%, assaults 14.4%, pedestrians 10.1%, motorcyclists 7.7%, gunshots 3.8%, stabs 0.4%, other penetrating injuries 0.2%.

TABLE 1 **INCIDENCE OF INJURY MECHANISMS** (N = 174,160)

INJURY MECHANISM	HI	No HI	TOTAL
BLUNT	32.7	48.6	81.3
VEHICULAR	22.8	26.9	49.7
Occupants	16.7	19.7	36.4
Pedestrians	3.5	3.8	7.2
Motorcyclists	2.6	3.4	6.0
NON-VEHICULAR	9.9	21.7	31.6
Fall	5.0	13.4	18.4
Assault	4.9	8.3	13.2
PENETRATING	1.5	17.0	18.5
Gunshot	1.3	7.4	8.7
Stab	0.1	7.9	8.0
Other	0.1	1.7	1.8

OVERALL MORTALITY

The overall mortality in this series was 8.3% (14,506 of 174,160). The numbers dead with HI (8636) were 1.5 times greater than those with NHI (5870) (59.5% vs 40.5%). This is a striking difference, especially when considering the much smaller numbers of HI patients in the whole series (59,713 and 114,447 respectively). Thus, though HI patients were only one-third of the whole series (33.6%), they comprised 59.5% of the deaths. Deaths with head injury, therefore, are disproportionately high.

Figure 1 shows the percent of HI and NHI deaths for every mechanism of injury. More patients died with HI than without HI in five of the seven injury categories. Patients with HI lead the deaths due to vehicle occupants (66.3%), cyclists (74.0%), pedestrians (72.5%), falls (63.9%) and assaults (68.3%). NHI deaths exceeded those with HI only for penetrating injuries (62%).

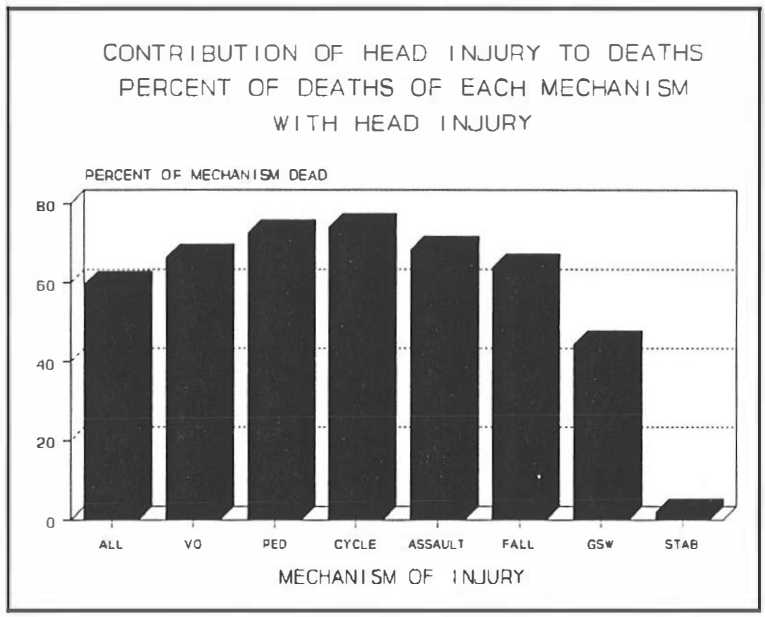

Figure 1 Percent mortality of head injured patients by mechanism of injury.

The high number of head injury deaths is due to a high mortality rate for head injured patients. The overall mortality with HI of 14.5% was three times higher than if no head injury occurred (5.1%).

VEHICULAR INJURIES

Of all the head injuries, two-thirds (66.6%) were vehicular in origin. Almost half were sustained by vehicle occupants (48.7%), by far the leading cause of HI in this trauma center population. Vehicle occupants incurred more than three times the number of HI of the next most frequent cause of HI (falls 14.6%) and almost equalled the number of HI produced by all other causes combined. Pedestrian (10.2%) and assault (14.3%) mechanisms produced head injury almost as commonly as falls while motorcycle riders comprised 7.7% of the head injuries. Penetrating injuries caused were uncommon causes of HI (4.4%).

Pedestrians sustained head injury most commonly. Of all injured pedestrians 48.6% had a head injury while of injured occupants and cyclists, 45.9% and 43.3%

respectively suffered head injuries.

TABLE 2 OVERALL PERCENT INCIDENCE OF VEHICULAR INJURIES

AIS	OCCUPANTS		PEDESTRIANS		MOTORCYCLIST		ALL
	NO HI	HI	NO HI	HI	NO HI	HI	
1	4.7	-	0.6	-	0.4	-	5.7
2	4.9	10.1	0.9	1.6	0.8	1.2	19.6
3	6.7	3.1	1.8	0.8	1.7	0.6	14.9
4	2.2	2.7	0.3	0.8	0.3	0.6	6.9
5	1.0	0.7	0.1	0.2	0.2	0.1	2.3
6	0.1	0.1	0.04	0.03	0.03	0.01	0.3
ALL	19.7	16.7	3.8	3.5	3.4	2.6	49.7

The overall incidence of the vehicular causes for HI and NHI are shown in Table 2 according to the highest AIS of either the HI or the ECI. The percentages in this table reflect the incidence relative to the entire MTOS population. Overall, vehicular injuries of AIS = 2 severity were the most common (19.6%). The most frequent severity of HI was AIS = 2 injuries to vehicle occupants (10.1%) while the most common group with no head injury was occupants with AIS = 3 severity (6.6%). Relatively few patients had injuries of AIS = 5 (2.3%) and these were equally divided into HI and NHI.

MORTALITY IN VEHICULAR INJURY--Table 3 depicts the percent mortality in patients with HI and NHI from vehicular causes. Several findings are of note. Although mortality with AIS = 6 head injuries are almost universally fatal, without head injury this was only true of pedestrians. Nearly one fourth of vehicle occupants with AIS = 6 extracranial injuries survived.

TABLE 3 PERCENT MORTALITY OF VEHICULAR INJURIES

AIS	OCCUPANTS		PEDESTRIANS		MOTORCYCLIST	
	NO HI	HI	NO HI	HI	NO HI	HI
1	0.6	-	1.0	-	0.5	-
2	1.1	2.6	1.8	4.8	0.5	2.5
3	2.7	17.6	4.0	26.0	1.4	18.7
4	14.2	27.2	27.6	36.3	14.2	27.1
5	29.7	44.5	50.0	53.4	27.1	48.4
6	75.6	97.1	95.2	100.0	86.8	94.4

In both HI and NHI categories mortality increased with AIS severity as expected. However, at each AIS severity, HI mortality was higher than if no head injury occurred. Occupants and cyclists had similar mortalities at each AIS level of severity while pedestrians, both with and without head injury, had uniformly higher mortalities at each comparable AIS level.

INTERACTION OF HEAD INJURY AND EXTRACRANIAL INJURY

While the HI group has much higher mortality than the NHI group, the HI group contains patients with extracranial injury (ECI). Therefore, the mortality in the HI group could represent an interaction between the HI and an ECI. To analyze these potential interactions further, Figures 2-4 show the mortality of each combination of HI and ECI AIS severity.

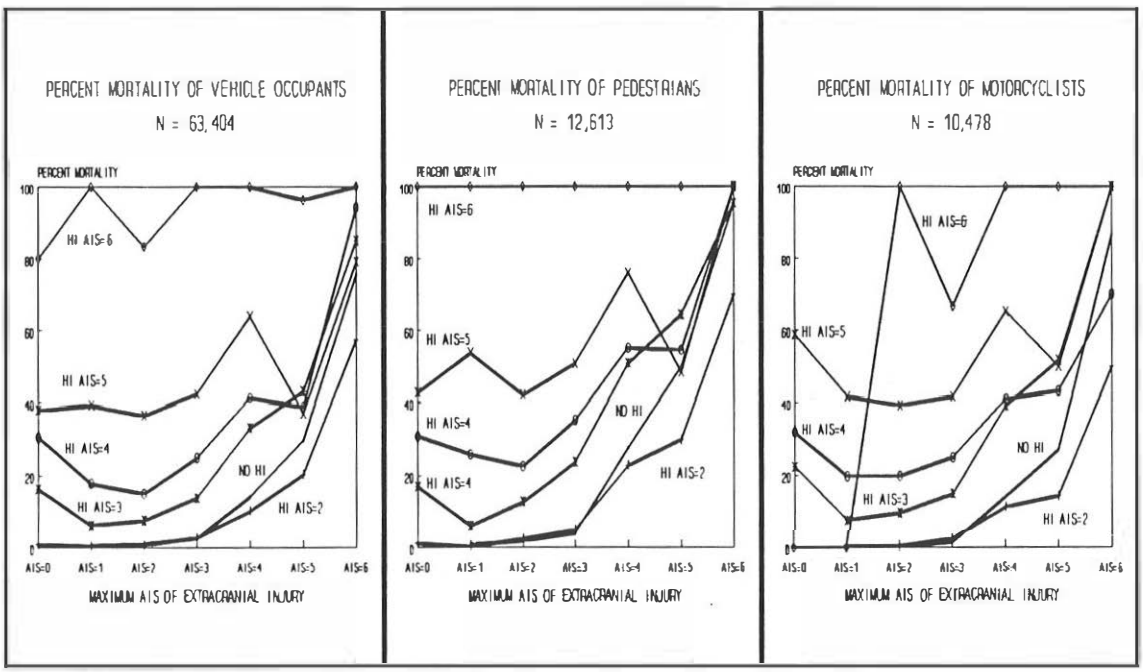

Figure 2 **Figure 3** **Figure 4**

Figures 2-4 each show that the mortality of extracranial injuries without head injury (no HI) closely parallels the mortality of the head injured group of AIS 2 severity (HI AIS = 2). This suggests that death is probably related to ECI rather than head injury at higher degrees of ECI severity (ECI 4-6). These figures also show that the mortality for head injuries with AIS 2-6 is little different from that of pure head injury (ie. when the AIS of ECI = 0) when associated with ECI 1-3. These deaths are most likely to be due to the head injury. When the AIS of ECI gets to 4 or 5, there appears be a synergism where the mortality is higher than expected from either the head or the extracranial injury.

TABLE 4 PERCENT MORTALITY OF ALL VEHICULAR INJURIES

HI AIS	AIS OF EXTRACRANIAL INJURY							ALL
	0	1	2	3	4	5	6	
0	--	0.6	1.1	2.7	15.7	31.2	80.8	5.2
2	0.9	0.3	0.9	3.1	11.5	20.3	58.6	2.9
3	17.4	6.3	8.6	15.9	36.2	48.1	89.0	19.2
4	30.8	19.6	17.2	27.2	43.4	42.2	91.8	29.0
5	41.6	41.9	38.0	44.5	66	40.3	85.3	46.8
6	90.0	100	92.9	96.8	100	97.7	100	97.8
ALL HI	13.1	4.2	6.1	12.6	31.3	38.4	84.1	13.3

In Table 4, data from Figures 2-4 are summarized for all vehicular injuries. The column of ECI = 0 represents pure head injury and the row with HI AIS = 0 is no head injury. The injuries presumptively due to ECI are shaded, those due to HI are enclosed within double lines and those due to a combination of HI and ECI are within heavy lines. Analysis of these data show that extreme severity of injury is always associated with high mortality. Thus AIS = 6, whether due to HI or ECI is a limit to survival. It can also be appreciated that an approximation of the cause of death can be made by comparing the mortality of patients with pure ECI and pure HI to the combined injuries. In all vehicular injury, ECI dominates HI only when AIS of HI is 2 and ECI is 3-6 (or if ECI AIS is 6). Otherwise, mortality from HI dominates except for a true synergism that occurs when HI's of AIS 3-5 are associated with ECI's of 4-5.

IMPORTANCE OF HI AND NHI DEATHS

In order to appreciate the significance of HI and NHI deaths in this series, consideration must be given not only to the mortality of HI and NHI, but also to the frequency with which the injuries occur. Thus, an injury may be highly fatal (have a high mortality rate), but may occur so infrequently that it does not cause many deaths. On the other hand, an injury with only moderate mortality may occur very commonly and cause more deaths than an uncommon lesion with a higher mortality rate. Thus, the importance of an injury can be estimated by the product of its frequency (incidence) and its mortality rate. This product, the mortality index, can then be used to determine the overall importance on an injury in a population of patients. The mortality index normalizes the injury's importance for a series of 10,000 similar patients and represents the number of patients of that 10,000 who will die of a particular injury. Therefore, the sum of all the mortality indices for all injury causes will equal the total number of deaths in a series of 10,000. Stated another way, the mortality index divided by 100 is equivalent to the percent of patients in a

series who die of a particular injury. The mortality index is then one measure to quantify the "mortality harm".

Table 5 ranks the mechanism of injury in order of decreasing mortality index or mortality harm for all mechanisms of injury. For this analysis all types of penetrating injuries are lumped together. As shown in this table, vehicle occupants were the most important group with respect to deaths after injury. They had 1.2 times more "mortality harm" than penetrating injuries and 3 times as much as pedestrian and fall injuries. Occupants were 5 times as important as were assault and motorcycle injuries in terms of causing deaths. One-third of all deaths were attributable to vehicle occupant injuries and almost two-thirds were due to occupant and penetrating injuries. Including pedestrians to these two comprises three-fourths of the deaths.

TABLE 5 RANKING OF CAUSE OF INJURY BY MORTALITY INDEX

RANK	MECHANISM	MI	RELATIVE HARM*	% of DEATHS	CUM % DEAD
1	VEHICLE OCCUPANTS	288.7	1.0	34.7	34.7
2	PENETRATING	231.6	1.2	27.9	62.6
3	PEDESTRIANS	99.4	2.9	12.0	74.6
4	FALLS	97.2	3.0	11.7	86.3
5	ASSAULTS	59.6	4.8	7.2	93.5
6	MOTORCYCLISTS	54.5	5.3	6.6	100.0
TOTAL		832.9		100.0	

*Relative Harm is the MI of the highest ranking cause divided by the MI of each mechanism and represents the factor by which each mechanism is less harmful that the most important mechanism.

Table 6 ranks the relative importance of the causes of the head injured and non-head injured groups. Occupants who sustained head injuries were more than twice as important than penetrating injuries, the second leading cause of HI deaths. Pedestrians with HI were 2.6 times less important than occupant head injuries while motorcyclist head injuries were 5 times less important. For those with no head injury, penetrating injuries were most important. Occupants were 1.5 times less important but were still much more important than were the other mechanisms producing in producing fatalities.

TABLE 6 RANKING OF MORTALITY INDICES BY MECHANISM

	HEAD INJURY			NO HEAD INJURY		
RANK	MECHANISM	MI	RELATIVE HARM	MECHANISM	MI	RELATIVE HARM
1	Occupant	191.5	1.0	Penetrating	143.5	1.0
2	Penetrating	88.1	2.2	Occupants	97.2	1.5
3	Pedestrian	72.1	2.6	Fall	35.1	4.1
4	Fall	62.1	3.1	Pedestrians	27.3	5.3
5	Assault	40.7	4.7	Assault	18.9	7.6
6	Motorcycle	40.3	4.75	Motorcycle	14.2	10.1

Table 7 ranks the injury categories from Table 6 together to show the ranking of injuries by mortality importance. Vehicle occupants are the most important injury group, comprising nearly one-fourth of all deaths and are twice as important as occupants without head injury.

TABLE 7 OVERALL INJURY IMPORTANCE RANKING

RANK	MECHANISM	HI	MI	HARM	%OF DEATHS	CUM % DEAD
1	Occupant	YES	191.5	1.0	23.0	23.0
2	Penetrating	NO	143.5	1.3	17.3	40.3
3	Occupant	NO	97.2	2.0	11.7	52.0
4	Penetrating	YES	88.1	2.2	10.6	62.6
5	Pedestrian	YES	72.1	2.7	8.7	71.3
6	Fall	YES	62.1	3.0	7.5	78.8
7	Assault	YES	40.7	4.7	4.9	83.7
8	Motorcycle	YES	40.3	4.8	4.9	88.6
9	Fall	NO	35.1	5.5	4.2	92.8
10	Pedestrian	NO	27.3	7.0	3.3	96.1
11	Assault	NO	18.9	10.1	2.3	98.4
12	Motorcycle	NO	14.2	13.5	1.7	100.0
TOTAL			832.9		100.0	

Table 8 shows the ranking of the vehicular subset of injuries. Injuries to occupants comprise two-thirds of all vehicular deaths and one-third of deaths from all causes. Occupants with head injuries are twice as important as injured occupants without head injury and are provide the greatest mortality harm from vehicular injuries, being roughly 10 times as important as either pedestrians or motorcyclists without head injury.

TABLE 8 IMPORTANCE RANKING for VEHICULAR INJURIES

RANK	MECHANISM	HI	MI	HARM	% OF ALL DEATHS	% VEH DEATHS	CUM % VEH DEAD
1	Occupant	YES	191.5	1.0	23.0	43.3	43.3
2	Occupant	NO	97.2	2.0	11.7	22.0	65.3
3	Pedestrian	YES	72.1	2.7	8.7	16.3	81.6
4	Motorcycle	YES	40.3	4.8	4.9	9.1	90.7
5	Pedestrian	NO	27.3	7.0	3.3	6.2	96.9
6	Motorcycle	NO	14.2	13.5	1.7	3.2	100.0
TOTAL			422.6		53.3	100.0	

Figure 5 shows the details of the MI for vehicular injury types (O = occupants, P = pedestrians, C = cyclists) with head injury (HI) or with no head injury (NHI) according to the maximum AIS of either the head or extracranial injury respectively. For vehicular injuries, the most important cause of death in this population was to occupants with a head injury severity of AIS 4. The second most important was to AIS 3 head injured occupants.

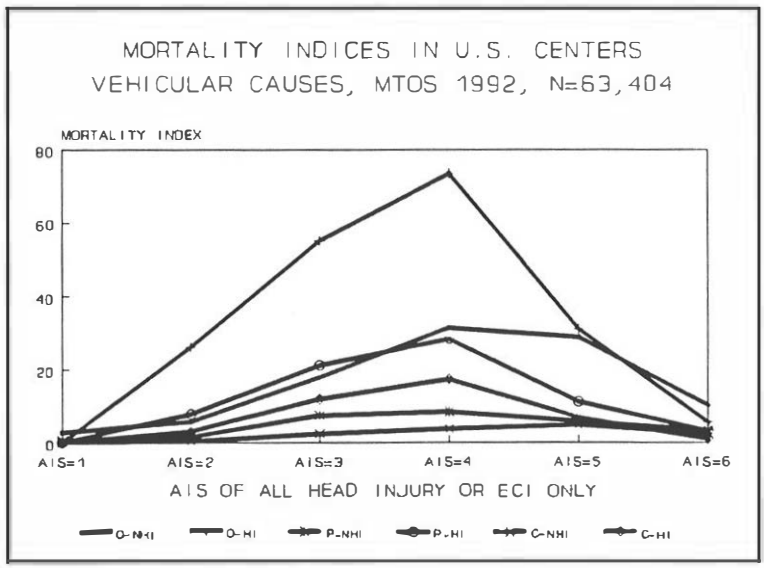

Figure 5

These data show that vehicle occupants with head injuries of AIS severity 4 and 3 are the two most important vehicular injuries with respect to death. These two categories comprise 29% of all vehicular deaths. The top ten most important vehicular injuries comprise 75% of all vehicular deaths. Of these, patients with head injury comprise seven of the top ten most important injury situations. The top five

most important vehicular injuries are in occupants, two of the top ten are in pedestrians and only one of the top ten is in motorcyclists; all involve head injury. The next 17 categories comprise 10% of all vehicular deaths and are noteworthy in that this group contains all AIS = 6 injuries to cyclists and pedestrians as well as all AIS = 5 injuries to cyclists and AIS = 5 pedestrians without head injury.

DISCUSSION:

This study represent one of the largest groups of trauma patients reported to date. This paper focuses on mortality from these injuries. Mortality was defined as deaths while in hospital and this definition may therefore be quite different from other road traffic data sets that use 7 -30 days from injury to define death. Further , this is not a population based study and therefore its findings cannot be generalized to the entire trauma population. More properly, the data presented here can only be viewed as representative of vehicular injuries in which survival was sufficiently long so that patients arrived at a trauma receiving hospital. Thus, the 60-75% of vehicular head injury deaths that occur on-scene or during transport to hospital are not available for analysis. Nonetheless, these data can provide some degree of insight as to the relative importance of head injury with respect to extracranial injury in the study population and the relative importance of vehicular injuries with respect to other mechanisms of injury production.

Since this report arose from already sophisticated trauma care centers, it is unlikely that substantial further reductions in mortality will be forthcoming. Therefore, continued efforts toward injury prevention and mitigation must be undertaken. Using fatality from injury as an indicator of importance or harm, injuries, especially head injuries, to vehicle occupants is the most important source and thus remain as the most important target for injury mitigation efforts. Penetrating injuries remain an important cause of injury but this may be more significant in the United States than in other countries of the world.

Of patients who initially survive their vehicular injury, the presence or absence of a head injury is an important factor in their ultimate survival. For vehicle occupants, mortality was twice as high if head injury occurred (11.5%) than if no head injury occurred (4.9%). For motorcyclists and pedestrians, comparable mortality was three times higher with head injury than without (15.3% versus 5.2% for cyclists; 20.7% versus 7.3% for pedestrians). Although it could be argued that the head injured group was worse because of additional superimposed extracranial injures, subset analysis showed that this was only true for a small proportion of head injured patients.

Were one interested in developing strategies to prevent or mitigate vehicular injuries, the data from the mortality index analysis might be most useful. Despite their higher mortality, the frequency of very severe injuries (AIS 6) was so low that they caused fewer overall deaths than did injuries of lesser severity. Thus, of the top ten highest causes of vehicular deaths, seven were injuries of AIS 3 or 4 severity.

Similarly, because of their much higher incidence, vehicle occupant injuries were more important overall causes of death, even though they had lower mortality than did pedestrian or motorcycle injuries. One-third of vehicular deaths occurred to occupants with head injury. Half of all vehicular deaths in immediate survivors occurred in vehicle occupants with injuries of AIS 3-5 severity. These specific groups would be appropriate targets of future interventional strategies.

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