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USAARL Report No. 76-22

HEAD INJURY PATHOLOGY AND ITS CLINICAL, SAFETY AND ADMINISTRATIVE SIGNIFICANCE

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April 1976

Final Report

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Fort Rucker, Alabama 36362

ADA073532
Technical Report

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER USAARL Report No. 76-22	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Head Injury Pathology and its Clinical, Safety and Administrative Significance		5. TYPE OF REPORT & PERIOD COVERED Report for Publication
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Stanley C. Knapp, M.D. Thomas M. Erhardt, B.S.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bioengineering and Life Support Equipment Division US Army Aeromedical Research Laboratory Fort Rucker, Alabama 36362		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE April 1976
		13. NUMBER OF PAGES 19
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) US Army Medical Research and Development Command Washington, DC 20314		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

This document has been approved for public release and sale; its distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Head Injury	Aviation Accidents	Test methodology
Helmets	Motor vehicle accidents	
Safety Engineering	Injury cost analysis	
Crashworthiness	Epidemiological methods	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The occurrence of head trauma is so common that its true importance as a major statistic associated with accidental injury and death may be overlooked. A review of head trauma in war, vehicular accidents, sports, and aviation demonstrates that while the head constitutes roughly 9 percent of the body's weight, surface area and volume, it is implicated in 7 out of 10 body injuries. Generally speaking, head trauma causes an unacceptable 1 in 4 deaths and for

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motorcycling it causes a staggering 1 out of every 2 deaths. Head protective devices have been available since antiquity; but except in isolated circumstances they cannot be shown to have had a mitigating effect on the magnitude of the injury rate. Yet, the technology exists to prevent head-injury deaths and to greatly reduce injury severity in survivable accidents, especially in aviation.

While it is accepted that helmets, indeed, provide significant protection, most systems of accident investigation, injury analysis and data recording do not recognize head trauma as endemic or even epidemic. Thus, the problem has not been approached epidemiologically. Instead, the bulk of head injury research is directed toward improved treatment and prevention of disability. These efforts are on the secondary and tertiary levels of prevention. Head trauma is expensive, as is the technology to avert it; but the authors contend that available statistical data cannot support the cost effectiveness of preventing head injury. In the future, examination of head trauma, its cost and the effectiveness of provided protection must apply the analytic tools of epidemiology not only to the injury but to the equipment as well. Prevention requires anticipatory action, based on the knowledge of protective performance history, in order to make the onset or further occurrence of injury unlikely.

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SUMMARY

The occurrence of head trauma is so common that its true importance as a major statistic associated with accidental injury and death may be overlooked. A review of head trauma in war, vehicular accidents, sports, and aviation demonstrates that while the head constitutes roughly 9 percent of the body's weight, surface area and volume, it is implicated in 7 out of 10 body injuries. Generally speaking, head trauma causes an unacceptable 1 in 4 deaths and for motorcycling it causes a staggering 1 out of every 2 deaths. Head protective devices have been available since antiquity; but except in isolated circumstances they cannot be shown to have had a mitigating effect on the magnitude of the injury rate. Yet, the technology exists to prevent head-injury deaths and to greatly reduce injury severity in survivable accidents, especially in aviation.

While it is accepted that helmets, indeed, provide significant protection, most systems of accident investigation, injury analysis and data recording do not recognize head trauma as endemic or even epidemic. Thus, the problem has not been approached epidemiologically. Instead, the bulk of head injury research is directed toward improved treatment and prevention of disability. These efforts are on the secondary and tertiary levels of prevention. Head trauma is expensive, as is the technology to avert it; but the authors contend that available statistical data cannot support the cost effectiveness of preventing head injury. In the future, examination of head trauma, its costs and the effectiveness of provided protection must apply the analytic tools of epidemiology not only to the injury but to the equipment as well. Prevention requires anticipatory action, based on the knowledge of protective performance history, in order to make the onset or further occurrence of injury unlikely.

Approved:

ROBERT W. BAILEY
Colonel, MSC
Commanding

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

... there is no such thing as an accident. What we call by that name is the effect of some cause which we do not see.

Voltaire

Accidental death from unavoidable causes is a tragedy. Death and major injury that can be mitigated or prevented, but isn't, in sane societies, is irresponsible if not criminal.

... if preventable, why not prevented?
Edward VII

Since the very dawn of Man, he has had the exclusive disposition to major head injury from relatively minor impacts. With the exception of only a few monkeys, the human skull alone is a comparatively delicate housing for the most vital of all organs. Man has potentially fatal mechanical flaws in his calvarium perhaps as a result of a trade off for large brain mass, and superior mental ability. A survey of the rest of the animal kingdom shows excellent protective structures such as thickened cranial vaults, high sagittal and occipital crests, protruding orbital ridges, horns and hydraulic dampers. Man's intelligence and potential for wise judgement should divert him from high risk situations that involve head impact. Ironically, man is not wise but foolish and seeks situations that place him at risk.

... when there is no vision, the people perish.
Proverbs 39:18

In 1960, Dr. L. B. Leakey discovered the skull fragments of an ancient man which showed obvious fracture at the time of death. Whether from a fall or combat, we will never know.[1] Recently, projects have been undertaken to x-ray a number of Egyptian mummies.[2] Quite often the results demonstrated violent death and a few actually showed massive head injury. The Edwin Smith Surgical papyrus [3] translated by Breasted in 1930 points out the extensive knowledge that the Egyptians had concerning the head and brain. (See Figure 1) They were apparently familiar with the dura and cerebrospinal fluid but generally treated head trauma expectantly. The war loving, combat seeking Indians of Central and South America created weapons specifically to inflict trauma on the head. As their tools of injury became more efficient so did their science of head injury diagnosis and treatment with skillful trephining. No longer was head trauma classified as expectant and a number of repeatedly traumatized skulls exist that demonstrate successive surgical interventions with subsequent recovery.[4]

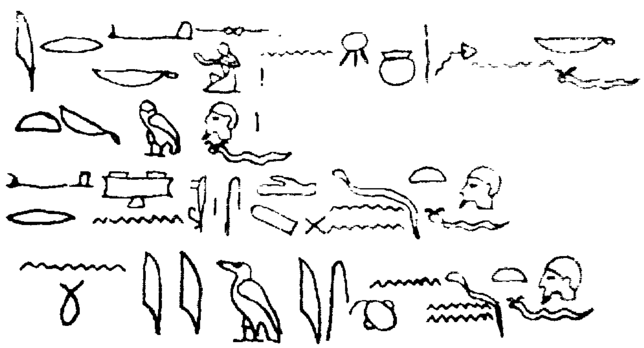

Figure 1. Hieroglyphics describing neuroanatomy and treatment of head injury*

The actual history of mankind could have been changed except for the choice of wearing or not wearing a protective helmet. The biblical outcome of the story of David and Goliath may have been quite different if Goliath had not been too proud to wear his helmet against an opponent of such small stature as David with his sling and rock. David refused the heavy armor of Saul, opting for mobility and reliance on Divine protection.

Throughout history man has designed hundreds of different helmets to mitigate the seriousness of head impact. Each was an improvement. Coincidental with these improvements, he seems to have come up with equally effective ways of defeating the protection which he was affording himself. His tools of injury began with rocks, clubs, arrows and spears, and have evolved to bullets, bombs, missiles and motor vehicles. Man seems bent on placing his head in the path of objects with great potential energy. The single trauma producing characteristic which makes each different is their velocity. As helmets were changed from animal hide to bronze, metals to composites and finally to multilayered energy absorbers, the velocity of the impact devices increased at the same time.

As we shall see, there is minimal data to substantiate the thesis that head protective devices actually reduce mortality and morbidity rates.

*After Breasted, 1930.

HISTORICAL PERSPECTIVES OF HEAD TRAUMA

There is ample evidence in the literature to support a contention that head trauma and its resultant effects is a serious problem to the health of the world's peoples.[5 6 7 8 9 10] It is not being bold to offer that major head injury is endemic to nearly every occupation, recreation, mode of travel and even to life itself. It achieves epidemic proportions in the tragedies associated with war, aviation and vehicular transportation. The following is a cross sectional sampling of head trauma statistics:[11]

TABLE I
MORTALITY FROM HEAD WOUNDS IN WAR*

Crimean War	898 cases	73.9 %
War of Rebellion	704 cases	71.7 %
World War I	- -	35 %
World War II	582 cases	14.0 %
Korean War	879 cases	9.6 %
Vietnam	1,132 cases	11.23%
US Military	1,171 cases	9.74%
Free world and civilian	561 cases	14.48%

From 1961 to 1966 there was a 15% incidence of fatal head injury in survivable** US Army helicopter accidents, and a 15% incidence in nonsurvivable accidents for a total of 15% fatal head injury.[12] From 1967 to 1969 there was a 23% incidence of fatality due to head injury.[13] During this period, no changes in head protection took place but Army helicopters became faster and smaller and mission envelopes became more hazardous. In a survey covering 1971 to 1974, the US Army is still maintaining a 22% incidence of fatal head injury in relation to total numbers of injuries from survivable and nonsurvivable crashes.[14]

US Air Force aircraft crashes during the period 1963 to 1967, demonstrated a 19% incidence of major or fatal head injury. Considering total numbers of injuries, regardless of severity, head injury was found in 86% of the accidents.[15]

The automobile accounts for millions of injuries and fatalities. For example, in 1974 there were 2 million injuries and 55,800 fatalities. The United States National Safety Council publishes a list of accident

*After Gurdjian, 1974.

**Crash acceleration forces calculated at the floor are within human tolerance and there is habitable cockpit structure left post-crash.

facts each year and consistently reports head trauma occurring in 70% of the accidents involving injury.[16] Of the accidents which result in fatalities, 20-30% can be directly attributed to head injury. Helmets are not a common item of protection used by US motor vehicle occupants. Seat belts and shoulder harnesses are available, irregularly used and not statistically implicated in altering US head injury figures.

A 1974 Australian and New Zealand Journal of Surgery report states that head injury accounted for 65% of the injuries in auto accidents from 1962-73.[17] It goes on to point out that 25% of these cases involved major head injury.

The Australian data in Tables II, III and IV by Jamieson and Kelly before and after safety laws had gone into effect appear to show that passive devices such as seat belts in the auto industry and helmets for motorcycle riders have had a mitigating effect on the incidence of head injury. Similar comparisons have not been made from the general US data. In unbelted drivers, the incidence of major head injury dropped from 27% to 7% in belted drivers. They also reported in a separate study, that head involvement was reduced from 68% to 52% after passage of the motorcycle-helmet-mandatory-use-law.[18] Major head injury dropped from 29% to 18% after the passage and enforcement of the law.

TABLE II

INJURIES SUFFERED BY AUSTRALIAN DRIVERS*
(PERCENTAGE OF EACH INJURY IN BRACKETS)

NUMBER OF DRIVERS	435
NUMBER OF INJURIES	654
Major head°	107 (24.6)
Minor head°°	176 (40.5)
TOTAL HEAD INJURIES	283 (65.1)
Chest	125 (28.7)
Abdomen or pelvis	68 (15.6)
Spine	20 (4.6)
Limbs	158 (36.6)
Injuries per driver	*1.50*

TABLE III

COMPARISON OF INJURY PATTERNS OF BELT WEARERS AND NON-WEARERS IN DRIVERS**
(PERCENTAGE INCIDENCES IN BRACKETS)

	NONBELTED	VOLUNTARY USE	BELTED
NUMBER OF DRIVERS	267	55	30
NUMBER OF INJURIES	415	96	39
Major head	71 (26.6)	16 (29.1)	2 (6.7)
Minor head	101 (37.8)	27 (49.1)	16 (53.3)
TOTAL HEAD INJURIES	171 (64.0)	43 (78.2)	18 (60.0)
Chest	91 (34.1)	14 (25.4)	5 (16.7)
Abdomen or pelvis	48 (18.0)	10 (18.2)	5 (16.7)
Spine	11 (4.1)	4 (7.3)	1 (3.3)
Limbs	94 (35.2)	25 (45.4)	10 (33.3)
Injuries per driver	*1.55*	*1.74*	*1.30*

*Abridged from Jamieson and Kelly, 1974.
**After Jamieson and Kelly, 1974.
°Cranial or facial fracture with brain injury as demonstrated by X-ray examination, operation or autopsy.
°°Clinical neurological signs of injury without fracture.

TABLE IV

INJURY PATTERNS OF 254 AUSTRALIAN MOTORCYCLE, MOTORSCOOTER AND PILLION RIDERS*

INJURY CATEGORY	BEFORE LEGISLATION	AFTER LEGISLATION
NUMBER OF PERSONS	151	103
Frequency of each injury:		
Arm	29 (19.2%)	19 (18.4%)
Thigh	29 (19.2%)	20 (19.4%)
Leg	27 (17.9%)	29 (28.2%)
Chest	22 (14.6%)	20 (19.4%)
Abdomen or pelvis	16 (10.6%)	19 (18.4%)
Major head	44 (29.1%)	19 (18.4%)
Minor head	58 (38.4%)	34 (33.0%)
ALL HEAD	102 (67.6%)	53 (51.5%)
Injuries per person	*1.49*	*1.55*

An analysis by the authors of the primary cause of death in 92 motorcycle accidents (Coroner's office autopsy data)[19] from the Dade County, Miami, Florida area (Tables V and VI) where a mandatory helmet law is strictly enforced, revealed that 46% of the deaths were directly attributed to head trauma.

TABLE V

DADE COUNTY, FLORIDA
MOTORCYCLE FATALITIES

YEAR	Mortality Rate	Head Injury Rate
1971	28%	12%
1972	20%	9%
1973	27%	16%
1974	17%	5%

*Abridged from Jamieson and Kelly, 1973.

TABLE VI

DADE COUNTY, FLORIDA
MOTORCYCLE FATALITIES PRIMARY CAUSE OF DEATH
1971 - 1974

Body Area	Percentage	No. of Cases
Head	45.65%	42
Neck	8.70%	8
Chest	16.30%	15
Head & Chest	18.48%	17
Other	10.87%	10

Interesting data from other reporting activities further emphasizes the prevalence of head injury. The US National Ski Patrol data from 1973-1975 indicates 13% of reported primary injuries involve the head.[20] Among US high school age football related deaths, 60% are from head trauma, although the incidence appears to be decreasing as better helmets are introduced.[21]

It is disheartening when a review of the best and most recent head injury data leads to a preliminary conclusion that in an activity like motorcycling where helmet-use laws are in effect, one out of every two deaths are still attributable to head trauma. No conclusion can be reached as to the reduction of nonlethal injury resulting from the use of helmets.

While mortality statistics are plentiful, the data is poor. Methods of reporting vary widely. There is a universal lack of common terminology for reporting the pathologic findings of well investigated accidents. "Multiple Injuries, Extreme" is a coroner's common excuse for failing to pin-point the true or primary cause of death. Too often, mortality statistics reflect the effect of forces entirely too catastrophic for any survival and fail to identify those accidents which should have been sublethal or survivable.

Morbidity statistics are worse. Injury reporting and its diagnostic vocabulary are haphazard and incomplete. Head injuries that at a distant time contribute to death or significant disability are not properly identified. Head trauma morbidity is a concern of clinical medicine with early disgnosis and treatment as the objective. Cause and effect are of minimal importance. Mortality concerns the pathologist with establishing the mechanism of death as his objective. Few investigators inquire as to the external forces that perpetrated the injury. Fewer yet integrate and correlate external forces to the effectiveness of active and passive protective devices and in turn to the resultant injury.

Nevertheless, it is reasonably safe to state that 7 out of 10 of across the board aviation and motor vehicle crash injuries involve the head, and 1 out of 4 of the deaths are attributable to head injury. Intervening protective devices whether they be body restraint, structural crashworthiness or helmets indeed mitigate injury, but to what degree is unknown. Several attempts to assess degree of protection have been made. Unfortunately, the data is descriptive and is used primarily as supporting rationale for continual empirical equipment development. Sound epidemiologic techniques are rarely used by engineering disciplines to evaluate the effectiveness of a piece of equipment.

HEAD INJURY ECONOMICS

The cost of pain, mental anguish, and disability is incalculable. In the United States, the courts "reward" an accident victim's grief in the form of large cash settlements that to some observers is penitence for social guilt caused by a total inability, helplessness or unwillingness to prevent the injury in the first place. The actual medical costs can only be estimated. The National Safety Council and several major US insurance companies report 1974 automobile accident costs for fatalities (excluding liability) to be $6.3 billion and rising exponentially.[16] All head injury conservatively contributes $2.4 billion of this total. Nonfatal injury costs are estimated at $9.7 billion. Motorcycle accidents contribute 3% of the total injuries and 3% of the fatalities. Based on the same cost data, all motorcycle injuries cost $606 million with $424 million attributable to head trauma. The cost of motorcycle fatalities is $189 million of which $47.3 million is attributable to head trauma.

The raw data does not isolate those injuries or deaths that could have been prevented had protective devices been used or that were reduced in severity because of the proper functioning of a device. Thus, monetary savings from preventing mortality or mitigating morbidity cannot be determined even from localities where safety devices are legislated.

Zilioli and Bisgard, using 1969 and 1970 US Army UH-1 helicopter accident data, demonstrated that human costs often exceed aircraft hardware costs especially in partially survivable and nonsurvivable accidents.[22] Direct military medical care costs for 126 specific nonfatal injuries in survivable crashes for the two year period were in excess of $755,000. US civilian health care costs for these military injuries could have been estimated at $7 million had the military health care facilities not been used. Head trauma accounted for 20% of the primary injuries involved and represented 16% or $122,000 of the total treatment costs. Answers to the following questions are unknown.

a. How many of these head injury cases returned to flying?

b. How many could not return to flying because of history or sequelae that was unwaiverable by regulation?

c. How many were disabled and left the service?

Since some of the nonfatal head-injured aviators did not return to flying and had to be replaced; and some were awarded life-long compensation, the true direct costs may be double or even triple these estimates.

UH-1 fatalities from all accident classifications during 1969 had costs identifiable to the taxpayer in excess of $16 million.[22] Assuming one out of four deaths were caused by head injury, $4 million represents the head-death portion.

In the United States during 1975, an estimated 2.5 million civilian helmets were manufactured and sold for a gross sales value of $35 million.[23] Thousands of sophisticated military helmets are purchased each year at an unidentified but surely staggering cost. Has this investment in protection been cost effective?

In 1969, the total US government funded budget for head injury research was $8 million and has remained relatively stable since then.[10] Helmet research expenditures are negligible in the private sector. Nearly all of the military helmet development money is spent on areas other than injury mitigation. Assuming a $55-56 million head injury research expenditure during the period 1969-75, it should be acceptable to ask:

> ... "what have the results of this expensive research netted in eliminating mortality and reducing morbidity?"

The reader should note that the cost estimates for one (1) year's motorcycle head-death fatalities nearly approximate the research expenditure for seven years.

SAFETY SALESMANSHIP

Even though it seems callous and contrary to medical ethics, the only rationale considered acceptable by administrators in support of programs of safety and injury prevention is economic and not loss of blood. They commonly ask these questions:

a. How much will it cost?
b. What are the recurring costs?
c. How much money will be saved?
d. How can you prove money will be saved?
e. How many lives will be saved?

Unfortunately, satisfactory answers cannot be provided. Less than 4% of the US government (nonmilitary) head injury research budget is for epidemiology studies.[10] Little or none of the resulting data finds its way into answering these questions.

Military aviation medical accident data is not recorded or reported with the intent of answering these questions. Thus, administrators correctly ask medical people the question, "if these suggested expensive safety features are implemented, on what basis will you evaluate the cost effectiveness of something that does not happen; or by what means can you demonstrate that the safety feature will indeed prevent the incident and injury?"

The engineering community has not met the challenge either. Protective performance too frequently is appraised on the basis of a summation of the mechanical properties of each component rather than on the performance of the system as a whole. Helmets are evaluated for impact protective characteristics using physical test methods that provide standardized, reproducible engineering data. Many of these methods enjoy international acceptance or are comparable to individual national standard methods.[24] None of the methods except that proposed by the National Operating Committee on Standards for Athletic Equipment[21] attempt correlation of the test method results with human head tolerance. Until the recent paper by Y. King Liu, et al, on Optimal Protection in Direct Closed Head Impact,[25] there has been no attempt to correlate predictive head injury modeling techniques with actual helmet development. Great emphasis is placed on investigating and mathematically modeling the biodynamics of closed head injury. Rather satisfactory optimization is achieved with fatal injuries but there are no attempts to refine the equations for nonlethal trauma. The dependent variable of performance of the protective helmet is not introduced to these models because its dynamic behavior when attached to a living head is unknown. Alterations in helmet performance that occur as a result of aging, poor maintenance, chemical degradation, abuse, or weak-link-components are not known. Yet, it is assumed that protective performance remains constant throughout the service life. US Army and US Department of Transportation helmet analysis data does not support this assumption.[26] [27]

The authors conclude that it is statistically unreasonable to compare head injury data before and after the introduction of a new or improved helmet and consider the comparison as a valid representation of protective performance. Too many changes in the environment occur, not withstanding the abstractness and inaccuracies of available injury statistics.

PRAGMATIC PREVENTION

Leavell and Clark[28] define prevention as "to come before or precede," and relate it to the English dictionary explanation that to prevent is "to anticipate, to precede, to make impossible by advance provision." They contend that in disease states,"prevention requires anticipatory action, based upon the knowledge of natural history, in order to make the onset or further progress of disease unlikely." It is appropriate and valid to substitute the words,"protective performance history," for, "natural history." Likewise, substituting, "occurrence of injury," for, "progress of disease," does nothing to alter the definition. It follows that:

> ...prevention does require anticipatory action, based on the knowledge of protective performance history, in order to make the onset or further occurrence of injury unlikely...

Leavell explains that primary prevention is accomplished before the event (prepathogenesis) by taking measures to "... specifically protect man against disease agents, or the establishment of the barriers against agents in the environment...". The words "accident, impact force and helmets" can be substituted in this statement to bring the definition into proper context with this paper.

We have already shown that most head injury research deals with injury mechanics, early diagnosis, treatment and, to a lesser degree, disability limitation and rehabilitation. Leavell would place these efforts in a classification of secondary prevention (after pathogenesis occurs) or tertiary prevention (corrective therapy).

"Epidemiology is the study of the distribution and determinants of disease prevalence in man."[29] If we interpret the definition and application of the discipline correctly, it is safe to substitute, "injury," for, "disease". The process can be extended to engineering terms-of-reference by substituting, "damage," for, "disease", and, "equipment", for, "man". Epidemiology is an applied discipline that has the descriptive component of "...study of distribution" and the analytic component of "...study of determinants." The discipline should not necessarily be viewed in the classic sense of a "medical science of treating epidemics" (Webster) although it has been shown that head injury is both endemic and epidemic in proportions. Epidemiology can be an effective tool in the hands of engineers and physical scientists as well as medical personnel.

In the field of aviation safety, epidemiology is not a completely unknown science. In the early stages of US Army rotocraft use, it was found that some aviator fatalities were caused by post-crash fires. The problem was identified. A crashworthy fuel system was designed. The problem was attacked. The fuel system was installed. The problem was solved. Recent data (see table VII) has shown a dramatic decrease in the rate of injuries and fatalities due to post-crash fires in survivable accidents.

The new generation helicopters are being designed and advertised to the Army with special emphasis on their crashworthy features.[31] A simple but typical example is that in a crash sequence, the troop seats collapse (natural history). Under high g loads, spinal compression fractures are found. The problem is identified. The new troop seat is designed with stroking, tri-axial energy absorbers. The problem is attacked. Preliminary tests have shown a reduction in energy by about 3 g's. The average g level for serious injury is around 18-20 g's. In combination with other crashworthy features, the new troop seat adds a significant safety valve for fliers. The problem is solved.

Under sound, systematic, epidemiological principles: 1) the authors have identified the problem; now 2) it is up to the engineers to attack the problem. The use of mathematical modeling 3) should then give close approximations to the natural phenomena.

TABLE VII
ROTOCRAFT ACCIDENT EXPERIENCE
WITHOUT CRASHWORTHY
FUEL SYSTEM[30]

	Classification	No. of Accidents	No. of Personnel	Thermal Injuries	Non-thermal Injuries	Thermal Fatalities	Non-thermal Fatalities
FY 71	Nonsurvivable	30	126	0	3	19	102
	Survivable	188	893	11	277	6	49
FY 72	Nonsurvivable	12	54	0	4	7	43
	Survivable	101	348	7	75	9	43
FY 73	Nonsurvivable	5	25	0	0	1	12
	Survivable	27	88	0	30	0	2
FY 74	Nonsurvivable	3	6	0	0	0	6
	Survivable	14	40	0	14	0	1
FY 75	Nonsurvivable	0	0	0	0	0	0
	Survivable	15	35	0	14	0	1

TABLE VIII
ROTOCRAFT ACCIDENT EXPERIENCE
WITH CRASHWORTHY
FUEL SYSTEM[30]

	Classification	No. of Accidents	No. Of Personnel	Thermal Injuries	Non-thermal Injuries	Thermal Fatalities	Non-thermal Fatalities
FY 71	Nonsurvivable	1	2	0	0	0	2
	Survivable	107	778	0	105	0	7
FY 72	Nonsurvivable	6	26	0	3	0	23
	Survivable	34	422	0	86	0	6
FY 73	Nonsurvivable	5	9	0	4	0	5
	Survivable	38	198	0	46	0	19
FY 74	Nonsurvivable	2	9	0	2	0	3
	Survivable	31	138	1	32	0	0
FY 75	Nonsurvivable	3	11	0	2	0	7
	Survivable	31	109	0	23	0	11

CONCLUSION

Reduction of head-trauma deaths and prevention of head-trauma injuries in survivable accidents appears to be an achievable challenge provided that:

> ...the statistical community, design analysts, and accident investigators use epidemiologic methods to delineate the problems of accident head trauma and to justify the economy of whatever preventive measures must be taken to significantly eliminate or reduce mortality and morbidity...

Thus, they must go beyond the currently used descriptive aspects of the discipline and provide analytic and predictive data from the field and laboratory:

> ...the engineering community must accept the premise that a helmet or any piece of life support equipment, to be medically acceptable, must provide its protective function as effectively on the last day of its service life as on the day it was removed from the packing box and tested...

Thus, there must be changes in the orthodox test methodologies so that results correlate to field performance. These methods must yield data that is extrapable to predicting biologic injury.

> ...the medical community must accept the research opportunity to study the most costly of all human experimentation, the accident sequence. It is insufficient to continue determining only cause of death. Sound epidemiologic principles must be mixed with failure-mode analytic techniques to directly correlate crash forces, injury pathology, mechanisms of injury and structural performance of protective equipment...

These data must then be used to optimize mathematical models of head injury and provide precise recommendations to designers.

> ...the designers in turn must approach head protection from a systems viewpoint. The goal is not a helmet that gives acceptable physical test results but acceptable protective performance when mounted on a living head in the crash environment...

The authors contend that in environments where safety education is accepted and use of protective equipment can be regulated, the current and historical incidence of head trauma morbidity is unacceptable. Death resulting from head trauma in survivable crashes is inexcusable.

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