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Basilar Skull Fracture in U.S. Army Aircraft Accidents (Reprint)

By

Dennis F. Shanahan

Biodynamics Research Division

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U.S. Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-0577

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Of the 222 flight helmets retrieved from Army aircraft accidents during 1971 -- 79 under the Aviation Life Support Equipment Retrieval Program, 175 were SPH-4 helmets that were analyzed for physical damage and for the relationship of damage to injury sustained by the wearer. This analysis showed that lateral impacts resulted in a significantly higher rate of serious injury (AIS>4) than impacts to other regions (68% versus 46%, $p<0.001$). Lateral impacts yielded a higher rate of basilar skull fracture than impacts to other areas of the helmet (46% versus 18%, $p<0.001$). It is concluded that lack of energy-absorbing material in the lateral portions of the helmet causes the high rate of basilar skull fracture and the increased prevalence of severe injury associated with lateral impacts. The incorporation of an energy absorbing earcup design is recommended to reduce the high rate of severe injuries associated with lateral impacts.

Basilar Skull Fracture in U.S. Army Aircraft Accidents

DENNIS F. SHANAHAN, M.D.

U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama 36362

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Of the 222 flight helmets retrieved from Army aircraft accidents during 1971–79 under the Aviation Life Support Equipment Retrieval Program, 175 were SPH-4 helmets that were analyzed for physical damage and for the relationship of damage to injury sustained by the wearer. This analysis showed that lateral impacts resulted in a significantly higher rate of serious injury (AIS≥4) than impacts to other regions (68% versus 46%, p<0.001) Lateral impacts yielded a higher rate of basilar skull fracture than impacts to other areas of the helmet (46% versus 18%, p<0.001). It is concluded that lack of energy-absorbing material in the lateral portions of the helmet causes the high rate of basilar skull fracture and the increased prevalence of severe injury associated with lateral impacts. The incorporation of an energy-absorbing earcup design is recommended to reduce the high rate of severe injuries associated with lateral impacts.

HEAD INJURY in U.S. Army aviation mishaps continues to be a major problem in spite of mandatory use of flight helmets by all crewmembers during helicopter flight operations. A recent report of injury patterns in U.S. Army helicopter accidents (7) showed that 24% of all injuries were to the head and face, and nearly 25% of these were fatal injuries. Recognizing this problem, the U.S. Army Aeromedical Research Laboratory (USAARL), has studied head injury in aviation accidents and the relationship of head injury to the performance of aviator protective helmets. Haley *et al.* (4) report that, while the current flight helmet does reduce the incidence and severity of head injury, incorporating more padding is required to further reduce the present head injury rate. One of the problems they specifically identified was the relative lack of protection offered by the Sound Protective Helmet-4 (SPH-4) flight helmet to lateral impacts. A finding not reported by Haley *et al.* was the high incidence of basilar skull fracture in their sample population. Their data show that 56% of all discrete linear or depressed skull fractures were basilar fractures. This is in contrast to the 30% incidence of basilar skull fracture reported by Kulowski (6) in a study of head injuries sustained by non-helmeted occupants involved in severe automobile accidents. The present study defines the relationship of lateral helmet impacts to the production of basilar skull fracture.

METHOD

The Aviation Life Support Equipment Retrieval Program was established in 1971. The purpose was to systematically retrieve and analyze aviation life support equipment from aviation mishaps when such equipment was in any way implicated in the cause, prevention, or mitigation of injury. One of the major items retrieved and analyzed has been aviator flight helmets. During the period 1971–79, 222 helmets were retrieved and analyzed for damage and for the relationship of this damage to the injury or lack of injury sustained by the wearer.

Only the SPH-4 helmet was considered in this study, since it is currently the standard helmet in the Army and has been since the early 1970's. Consequently, it comprised the vast majority of helmets retrieved from the field during the period of study. Of the 222 helmets examined, 175 were included in the study. These were SPH-4 helmets on which a primary impact site could be identified and for which there was adequate medical information available concerning the head injuries sustained by the wearer. Of the 47 cases not included in this study, five were excluded due to insufficient medical information, and the remainder were excluded either because they involved other helmet types, the helmets were undamaged, or the helmets were so completely destroyed by fire or crushing that no definitive site of impact could be identified. The primary impact site on a particular helmet was the discrete area judged to have received the most severe impact.

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This judgment was based on the degree of external shell damage, residual foam compression, bending of suspension clips, impression of suspension straps on the foam, and area covered by the impact. Since most helmets received more than one impact, the same criteria were used to identify the other areas of impact as secondary, tertiary, and so on based on decreasing severity. In most cases, the primary impact site was fairly obvious; however, the secondary and tertiary impact sites were somewhat more difficult to rate. These subjective determinations were agreed upon by a team of investigators consisting of flight surgeons, life support equipment specialists, and engineers.

To identify impact areas, the helmet shell was divided into five major zones: crown, front, back, right side, and left side. The crown was further divided into four quadrants by two perpendicular lines intersecting the center of the crown and oriented 45° from the midsagittal plane. For this study, the two lateral quadrants were considered together and identified as "crown (lateral)." Likewise, the anterior and posterior quadrants were combined and identified only as "crown." No distinction was made for right- or left-side impacts for either the crown or the sides. Therefore, five major areas were considered in the study: crown, crown (lateral), side, front, and back (Fig. 1). A template helmet was made, and all impact locations were assigned based on this standard. If an impact overlapped two areas, it was assigned to only one area based on which area received the brunt of the impact.

Injury data for the individual wearing each helmet were obtained from the official accident report (Department of the Army Form 2397) or from any autopsy reports filed with the accident report. Each case was assigned a head injury Abbreviated Injury Scale (AIS) rating as detailed in the 1976 revision of *The Abbreviated Injury Scale* (5). Table I reviews the basic guidelines of the AIS. In addition to assigning an AIS rating, all cases involving skull fracture were identified and the location of the fracture listed as whether there was basilar involvement. A basilar fracture is defined as any fracture involving the floor of the anterior, middle, or posterior cranial fossae. In some cases the skull was described in the accident report as "crushed" or involving "multiple fractures." In our experience from reviewing autopsy photographs, these cases almost invariably include basilar involvement although they were excluded from the basilar category since basilar involvement could not be conclusively established.

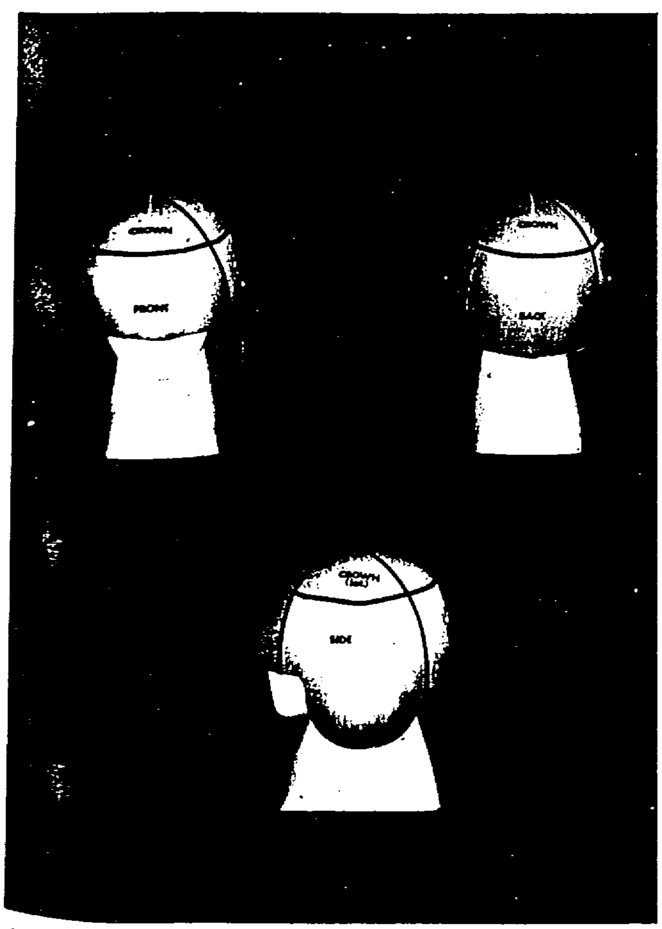

Fig. 1. Template helmet depicting the five major impact areas.

TABLE I. SUMMARY OF AIS SEVERITY CODES.

AIS	Description
0	No Injury
1	Minor
2	Moderate
3	Severe (not life threatening)
4	Serious (life threatening)
5	Critical (survival uncertain)
6	Maximum (currently untreatable)

As an additional element of this study, all cases with damage to the hard plastic earcup used to house the communications earphones were identified and evaluated separately. Unpublished studies performed at USAARL have shown that the dynamic load required to damage this earcup ranges from approximately 750 pounds to crack the inner flange to over 5,000 pounds to fracture the main body of the earcup.

RESULTS

Since tolerance to fracture in the temporoparietal area of the human skull is as little as 400 pounds (8), only 175 cases out of the total 222 met the criteria of having an identifiable primary impact to the helmet and sufficient head injury information concerning the wearer to be included in this study. Distribution of the study cases according to location of primary impact and AIS rating of the head injury sustained by the wearer is shown in Table II. It is interesting to note that only 40% of the helmet wearers sustained either no injury (AIS =0) or injuries that could be considered relatively minor (AIS = 1 or 2). The percentage of primary impacts that resulted in serious injury or greater (AIS$\geq$4) was calculated separately for each impact area (Fig. 2). A significantly higher rate of serious

TABLE II. DISTRIBUTION BY PRIMARY IMPACT LOCATION AND DEGREE OF INJURY.

Primary Impact Area	AIS 0	1	2	3	4	5	6	Total
Crown	8	5	2	0	0	4	9	28
Crown (lat.)	2	4	2	0	1	2	4	15
Sides	5	7	2	0	5	8	18	45
Front	7	24	8	1	4	13	12	69
Back	3	3	3	0	3	3	3	18
TOTAL	25	43	17	1	13	30	46	175

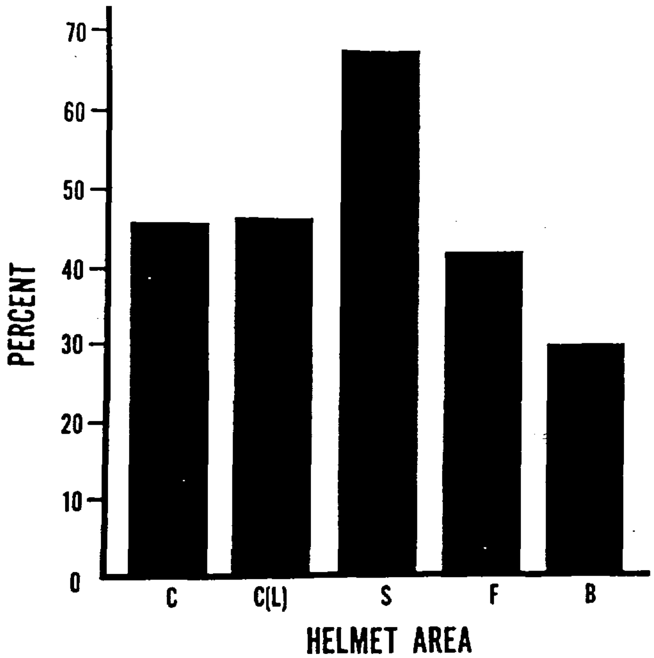

Fig. 2. Percentage of primary impacts resulting in serious injury or greater (AIS≥4) by helmet area. C=Crown, C(L)=Crown (lateral), S=Side, F=Front, B=Back.

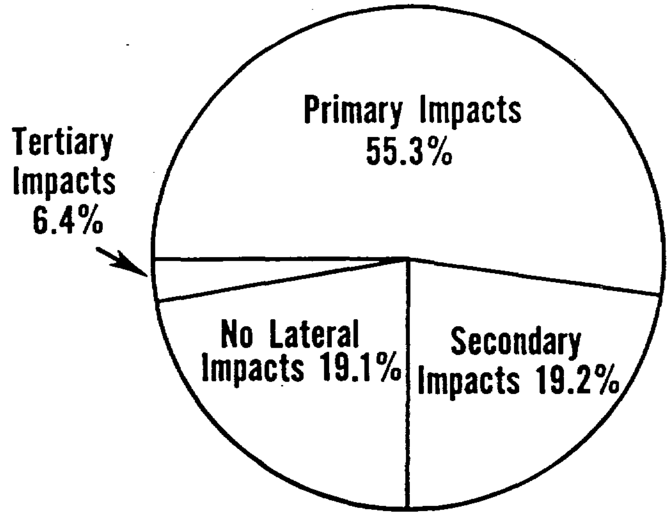

Fig. 3. Percentage of basilar skull fractures associated with primary, secondary, and tertiary lateral impacts.

injury was observed for primary side impacts (68.9%) compared to impacts to all other helmet areas (average 46%), $x^2=10.84$, df=1, $p<0.001$.

Another consideration was the relative frequency of basilar skull fractures arising from impacts to the different areas of the helmet shell. These data are depicted in Table III and

TABLE III. DISTRIBUTION OF BASILAR SKULL FRACTURES (Fx) BY PRIMARY IMPACT AREA.

Primary Impact Area	No. of Cases	No. of Basilar Fx	% Basilar Fx
Crown	28	4	14
Crown (lat.)	15	7	47
Sides	45	19	40
Front	69	14	20
Back	18	3	17
TOTAL	175	47	

reveal that lateral impacts, i.e. crown (lateral) and sides, are significantly more likely to result in basilar skull fracture than impacts to other helmet areas, $x^2=13.135$, df=1, $p<0.001$. Another way of viewing these data is to consider the proportion of all basilar skull fractures produced by lateral impacts. As shown in Fig. 3, 55.3% of all basilar fractures were associated with primary lateral impacts. When primary, secondary, and tertiary lateral impacts are included, this association increases to 80.9%.

Forty of the helmets examined sustained damage to either one or both earcups. Two were excluded from the earcup damage group since one sustained earcup damage after it was dislodged from the aviator's head and the other was punctured by a metal tube and did not receive a blunt impact. Table IV shows the distribution by AIS of the 38 cases with earcup damage. This was clearly a severe-injury group, with 92% receiving critical or fatal injuries (AIS 5 or 6) and 97%

TABLE IV. AIS OF CASES WITH EARCUP DAMAGE.

AIS	No. of Cases
0	0
1	1
2	0
3	0
4	2
5	9
6	26
TOTAL	38

receiving serious injuries or greater (AIS≥4). The one case with AIS=1 sustained a fractured tooth when the helmet rotated on his head. In the earcup damage group there were 18 (47%) with definite basilar skull fracture and 12 (32%) listed as crushed skull or multiple fractures, the majority of which probably had basilar involvement.

DISCUSSION

Basilar skull fracture has long been regarded by clinicians as potentially ominous due to its association with vital structures at the base of the brain and its relatively high complication and mortality rates. It has been shown that, given sufficient energy, blows to most areas of the calvarium can result in extension of linear fractures to the base of the skull (1). Gurdjian *et al.* (2) report that blows to the temporoparietal area are particularly prone to result in basilar fracture, most commonly producing a longitudinal fracture of the temporal bone. Gurdjian and others have also shown through extensive impact research on human cadaver material and animal surrogates that the production of a skull fracture requires localized deformation of the skull (3). In impacts to the helmeted head, sufficient force must somehow be transmitted directly to the skull for the requisite deformation to result in a fracture. If the helmet provides adequate spreading or attenuation of the impact load, skull deformation and, therefore, fracture will not occur, although intracranial injury may occur due to acceleration of the head. If fracture results from a helmeted head impact, there must be a point of transmission of force directly to the skull.

Two major conclusions can be drawn from the present study: (a) impacts to the sides of the SPH-4 helmet produce a significantly greater degree of injury than impacts to other helmet regions and (b) there is a definite relationship between lateral impacts, i.e. sides and crown (lateral), and the production of basilar skull fracture. Although primary lateral impacts were identified in only 34% of the 175 cases studied, they were associated with 43% of all injuries of AIS 4 or greater and 55% of all basilar skull fractures. Based on the force required to damage an earcup, the cases with earcup damage not only sustained extremely severe injuries (92%≥AIS 5) but also showed a high correlation with basilar skull fracture. A minimum of 47% of these cases sustained basilar skull fracture compared to a 20% incidence of basilar skull fracture for those without earcup damage.These data indicate that the relative degree of protection afforded by the SPH-4 flight helmet to lateral impacts is considerably less than that for impacts to other regions of the helmet. This is because there is no padding between the helmet shell and the wearer's head over most of the temporoparietal region (4). The foam liner of the helmet does not extend into this area; this allows space for communications headsets. Each of the speakers is housed in a hard plastic earcup which fits snugly around the ear and provides excellent sound attenuation but no impact attenuation. Consequently, impacts to the lateral helmet region are transmitted with relatively little attenuation through the earcup directly to the head of the wearer. In effect, the current earcup acts as a circumaural impactor since it is able to withstand dynamic loads up to 5,000 pounds without yielding.

In order to reduce the rate of severe injury associated with lateral impacts, it is apparent that padding will have to be incorporated in or around the earcup. An energy absorbing earcup has been designed at USAARL and is undergoing testing on headforms, dummies, and cadavers under various impact conditions. Preliminary results of these tests show a significant reduction in both loads and accelerations when the prototype earcup is substituted for the standard earcup in the SPH-4 helmet. The prototype earcup also displays noise attenuating capability equal to that of the standard earcup. It is expected that this or another equally effective means of increasing lateral impact protection will soon be incorporated into U.S. Army flight helmets.

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