Factors Involved in Emergency Medical Service Helicopter Occupant Crash Survival

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Since the first hospital-sponsored emergency medical service (EMS) helicopter transport program began in 1972, more than 846,000 patients have been transported by helicopter, the majority since 1980. During the same period, 84 EMS helicopters were involved in crashes. The National Transportation Safety Board (NTSB) evaluated 59 EMS helicopter crashes occurring during the period 1980 to 1986. The NTSB found, among other things, that in numerous EMS helicopters the interior was not modified to the applicable FAA standards for crashworthiness or good engineering practices. Injury outcomes for EMS helicopter occupants and those in air taxi helicopters are compared. NTSB crash records were reviewed and survivors surveyed to determine occupant injury experience. It was found that occupants of EMS helicopters were more likely to be seriously injured in a survivable crash than those in the comparison population (relative risk = 2.10, 95 percent CI $1.21 < RR < 3.64$, $p < 0.008$). Forty-two percent of the injured EMS helicopter survey respondents identified medical equipment or components as a factor in their injury compared with just 3 percent of the injured comparison population when asked about the helicopter interior and their injury causation. Twenty-three percent of the EMS helicopter passengers experienced serious head injuries, a level twice as large as any other group in the study. Opportunities exist to reduce the exposure of EMS helicopter occupants to serious injury during the design and modification of the helicopter interior for the EMS patient care mission.

The use of helicopters to transport injured and ill patients is a relatively new part of the nation's health care transportation system. Since the first hospital-sponsored helicopter transport program began in 1972, more than 846,000 patients have been transported by helicopter, the majority since 1980. During the same period, 84 emergency medical service (EMS) helicopters were involved in crashes.

As of July 1, 1990, 178 EMS helicopter programs were in operation throughout the nation. The majority of the programs are operated by hospitals that either own and operate or lease their own EMS helicopters. The programs operate 225 helicopters that are dedicated to patient transfers and modified for the patient transport mission (*1*). Besides hospitals, state governments and other publicly funded agencies, such as police departments, operate EMS helicopters. Currently, 11 such agencies operate more than 30 helicopters in the EMS role (*2*).

EMS helicopter missions include the transport of cardiac patients, critical medical patients, neonatal patients, and trauma victims. The hospital-based programs typically operate both direct flights to the scene of accident or injury and interfacility flights from one hospital to another. The interfacility transports are often planned in advance and account for approximately 70 percent of all EMS helicopter flights (*3*). EMS helicopters are normally available 24 hr a day, 365 days a year. The decision to incorporate an EMS helicopter into a health care system represents a significant commitment in capital, manpower, training, and operating costs.

Helicopters used for EMS transport are highly complex and expensive. Usually, they are extensively modified for the EMS mission by the addition of multiple medical components to provide advanced life support. Before the medical components are installed, the interior of the aircraft is generally stripped of all unnecessary furnishings, carpeting, and equipment, leaving only the pilot's station. The helicopter is then modified with new seats for medical personnel, patient litters, and medical equipment. The modifications are usually conducted to the contracting hospital's specifications and are often based primarily on a need for compatibility with other hospital emergency equipment (*4*). The helicopter medical crew is typically composed of a pilot and two medical care professionals: a physician or critical care nurse and a paramedic or equally trained technician (*5*). The medical care personnel are highly trained for advanced, and, if necessary, aggressive medical care in the flight environment and represent a valuable resource as skilled health care practitioners.

EMS HELICOPTER CRASH EXPERIENCE

In 1987, the National Transportation Safety Board (NTSB) initiated a special study on commercial EMS helicopter safety. In this descriptive study, NTSB found that, from 1980 to 1985, EMS helicopters under commercial operation for hospitals had an estimated crash rate of 12.34 per 100,000 flight hr while on patient transport missions. Similar helicopters operating as commercial air taxis, not involved in EMS activities, experienced a crash rate of 6.69 per 100,000 flight hr, approximately half that of the EMS helicopters.

During the same period, EMS helicopters on patient transport missions had an estimated fatal crash rate (where at least one occupant died) of 5.40 per 100,000 flight hr. Commercial air taxi helicopters had a fatal crash rate of 1.60 per 100,000 flight hr, a rate less than one-third that of the EMS helicopters. For crashes in which occupants were not fatally injured,

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there was little difference: EMS helicopters had a rate of 2.31 per 100,000 flight hr and air taxi helicopters had a rate of 2.45 per 100,000 flight hr.

The NTSB study evaluated 59 EMS helicopter crashes occurring during the period 1980 to 1986 (*5*). The NTSB found that poor weather—specifically, reduced visibility due to precipitation, darkness, and fog—was a predominant factor in 25 percent (15) of the crashes studied. Eleven of the 15 crashes resulted in at least one fatality, leading to a conclusion by NTSB that ". . . it is clear that poor weather conditions pose the greatest single hazard to EMS helicopter operations."

Whereas reduced visibility was clearly an important variable in many crashes, NTSB was also critical of the potential compromise of the EMS helicopter's crashworthiness by the interior modification process. Crashworthiness has been defined as ". . . the relative ability of a particular vehicle design to withstand crash impact forces with minimal structural damage. Progressive structural collapse may be engineered to reduce the loads on the occupant through energy absorbent techniques. Thus, crashworthiness relates to protection of the occupants" (*6*).

NTSB found that in numerous EMS helicopters, the interior was not modified to the applicable FAA standards for crashworthiness or good engineering practices (*4*). Findings included lack of shoulder harnesses, seats improperly attached to the floor, seats constructed from nonapproved materials, medical equipment (such as oxygen cylinders) not properly restrained, fixed intravenous hooks projecting from the helicopter interiors, and loosely stored or mounted equipment, some of it of substantial mass. The lack of crashworthiness considerations in many EMS helicopter designs may be a factor in the 3.5-fold increase in fatality rates seen by NTSB compared with helicopters that have not been modified.

A recent study by Rhee et al. (*7*) failed to find a difference when the crash experience of United States hospital-based EMS helicopters were compared with Federal Republic of Germany EMS helicopters for the period 1982 to 1987. The authors found that the U.S. EMS helicopter crash rate of 11.7 per 100,000 flight hr was not significantly different from the West German rate of 10.9 per 100,000 flight hr. The fatal crash rates were also similar to a U.S. rate of 4.7 and a West German rate of 4.1. The authors conclude that the similarity in crash and fatality rates between the two countries may indicate a shared experience inherent in EMS operations.

A study conducted by Conroy et al. (*8*) evaluated fatal occupational injuries related to helicopters. The authors found that 62 percent of the women in the study were killed while functioning as medical personnel on EMS helicopters. Death rates were not developed for this group since relevant exposure data were not available. The authors state, however, that their findings suggest that women in medical occupations who routinely fly in EMS helicopters may be at proportionately higher risk for fatal occupational injuries than other female occupational groups. The authors suggest that this is an area that deserves additional study.

CRASH SURVIVAL: EXPERIENCE AND THEORY

Whereas efforts to reduce injuries and death in aviation crashes have historically focused on preventing crashes rather than preventing or minimizing injuries when a crash does occur, significant research has been conducted on crashworthiness and occupant survival (*9*). Little research has been conducted on civilian helicopter crashworthiness and occupant survival, however, and none has been conducted on EMS helicopters. Most helicopter crash survival research has been conducted by, or for, the U.S. Army over the last 30 years and has included a combination of experimental and observational approaches. The cumulative findings from this research are compiled in a seminal five-volume design guide for U.S. Army aircraft to improve crash survival (*10*). Topics covered include aircraft design criteria for crashworthiness, the crash environment and human tolerance, aircraft structural crashworthiness, seats and restraint systems, and postcrash fire reduction or elimination.

Current Helicopter Crashworthiness Standards

Measurement of impact forces in aircraft are usually reported along one of the three major axes of aircraft motion. The axes are longitudinal (fore and aftdenoted as $\pm\ G_x$), lateral (left or right denoted as $\pm\ G_y$), and vertical (up or down and denoted as $\pm\ G_z$). FAA sets the performance and safety standards for all aircraft manufactured in the United States. The standards for crashworthiness are far below the impact tolerance thresholds determined through research, experience, and the available technology for aircraft crashworthiness. For helicopter crashworthiness, the FAA states:

> The (helicopter) structure must be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing when—
> 1) Proper use is made of seats, belts, and other safety design provisions;
> 2) The wheels are retracted (where applicable); and
> 3) The occupant experiences the following ultimate inertia forces relative to the surrounding structure:
>
> | | | |
> |---|---|---|
> | (i) | Upward | 1.5 g |
> | (ii) | Forward | 4.0 g |
> | (iii) | Sideward | 2.0 g |
> | (iv) | Downward | 4.0 g |
>
> or any lower force that will not be exceeded when the rotorcraft absorbs the landing loads resulting from impact with an ultimate descent velocity of five feet per second (3.4 mph) at design maximum weight. (*11*)

The FAA regulations require only the copilot and pilot positions to have shoulder harnesses.

U.S. Army Standards

The U.S. Army has developed crashworthiness standards far in excess of those required by FAA for civilian helicopters (*11*). The Army requires that helicopters be designed to protect occupants in crashes with average aircraft *g* loadings as follows: downward ($+G_z$), 24 *g*; longitudinal ($+G_x$), 15 *g*; and lateral ($\pm G_y$), 9 *g*.

These standards have been incorporated in all new Army helicopters, and a retrofit program is in place to improve the crashworthiness of older Army helicopters where feasible. The program has proven successful and indicates that the knowledge and technology exist to improve crash survival.

Vertical Loads and Spinal Injury

In many helicopter crashes, occupants receive serious back injuries because of the associated high vertical loads. Shanahan and Mastrolanni (*12*) evaluated spinal injury of occupants involved in survivable crashes in U.S. Army OH-58 series helicopters, an older design without enhanced crashworthy features. The OH-58 is similar to a common EMS helicopter, the Bell model 206. A review was conducted of all crashes between 1971 and 1981 in which ground contact occurred. Information on spinal injury was categorized as (*a*) no spinal injury, (*b*) sprain or strain, (*c*) fracture or dislocation, or (*d*) multiple extreme injury.

The authors found that there was a moderate correlation between vertical velocity change and injury category and no, or very weak, correlation between horizontal velocity change and spinal injury category. A dramatic increase in the rate of spinal injury occurring just above the design sink speed of the helicopter landing gear (12 ft/sec) suggests that the fuselage and seat provided little additional impact protection above that of the landing gear alone. The authors conclude that 80 percent of all spinal injuries in survivable and partially survivable crashes in the OH-58 occur at impact velocities less than 30 ft/sec vertical velocity. They recommended that the helicopter be modified by the incorporation of energy-absorbing seats.

Civilian Helicopter Crashworthiness Research

Coltman et al. (*13*) conducted a comprehensive retrospective evaluation of civilian helicopter crash survival. In this study, all civilian helicopter crashes occurring between 1974 and 1978 were reviewed. Only crashes judged to be survivable and that had postcrash fire, major or minor injury, or major structural damage were included (a total of 311).

The authors found that the following hazard mechanisms, listed in order of importance, accounted for the majority of injuries in the study population: burns due to fuel system failure on impact, spinal injuries due to excessive vertical loading, injuries of all types due to in-flight wire strike on the frontal plane of the helicopter, secondary impact of the upper torso and head due to restraint system deficiencies, and secondary impact due to lack of upper torso restraint. They also found that, for survivable crashes reviewed in the study, the average yearly distributions of occupant injuries in civilian helicopter crashes were as follows: 68 percent (370) received no injuries, 17 percent (95) received minor injuries, 11 percent (57) received serious injuries, and 4 percent (23) died.

The authors concluded that the study indicated a need for improved crashworthiness in U.S. civilian helicopters. Most research indicates that prevention of injuries among helicopter occupants through improved crashworthiness is both desirable and achievable. There are also indications that the crashworthiness of existing helicopter designs can be improved by modifications of the aircraft.

RESEARCH ISSUES

The civilian EMS helicopter crash experience has clearly been worse than non-EMS helicopter populations studied. Research conducted to date has not adequately explored the factors involved in the differences in survivable crash outcomes in EMS helicopters compared with other civilian helicopter crash populations. Occupant risk of fatal or serious injury appears to be greater in EMS helicopter crashes than in crashes of other helicopter populations.

The basic research questions are as follows:

1. Are EMS helicopters more hazardous for occupants than non-EMS helicopters?
2. To what extent is the modification of the helicopter for the medical role related to the injury experience of the occupants?
3. Can specific crash hazards be identified for the development of preventive measures?

This paper reports on the exploration of these issues.

METHODS

A nonconcurrent cohort study design was used to evaluate exposure and relative risks of injury and death for occupants involved in crashes of EMS helicopters. (The relative risk, or risk ratio, indicates the strength of certain associations and is equal to the risk in Group A divided by the risk in Group B.) The study cohort included occupants of all EMS helicopter crashes that occurred between 1978 and 1990. Exposure and outcome data for the study population were obtained from crash investigation records maintained by NTSB and follow-up questionnaires for crash survivors. The occupants of the EMS helicopters were the exposed population. The nonexposed comparison population consisted of occupants of similar non-EMS helicopters involved in crashes for the time period 1983 to 1990.

The study consisted of three phases. The first phase was the development of preliminary measures in which crashes that were survivable or not survivable in both populations were identified. Incidence rates for various injury categories and rates of injury outcome were developed. The focus of this analysis was the evaluation of variables likely to have an influence on crash survival.

The second phase of the study focused on the variables with the greatest potential influence on injuries among EMS helicopter occupants. This evaluation examined the impact conditions associated with survivable crashes as well as factors determined from Phase 1 to have potential influence on the dependent variables of interest.

The last phase of the study focused on the identification of the hazards most important to injury causation among the occupants of survivable crashes.

Data Sources

The primary data source for this study was records maintained by NTSB. NTSB defines an aircraft accident as an occurrence associated with the operation of an aircraft that results in fatal or serious injury or in substantial damage to the aircraft. A fatal injury is one that causes death within 30 days of the crash. Serious injuries include any injury that (*a*) requires hospitalization for more than 48 hr; (*b*) results in fractures (except simple fractures to the nose, fingers, and toes); (*c*) causes severe hemorrhages, nerve, muscle, or tendon damage; (*d*) involves any internal organ; or (*e*) involves second- or third-degree burns over 5 percent or more of the body surface (*14*).

In this study, all crashes of non–public use EMS helicopters that meet the NTSB definition of an accident were included as the study population. All crashes of turbine engine–powered helicopters operating as air taxis [Federal Aviation Regulation (FAR) Part 135] and not modified for other non-passenger operations composed the pool from which the comparison population was selected.

The comparison population sample was limited to FAR Part 135 air taxi helicopters meeting the following criteria:

1. The make and model of aircraft were limited to the same type used by EMS helicopter operators.
2. Water contact crashes were not included.
3. The crashes included were limited to passenger operations conducted under FAR Part 135. No agricultural operations, sling loads, or other special use helicopters were included.

The period for inclusion of EMS helicopter crashes was 1978 to 1990 (the majority of the crashes occurred after 1983). The period for the comparison population was 1983 to 1990.

Exposure information using hours flown for the Part 135 helicopter air taxis was obtained from an annual survey of helicopter operators conducted by FAA (*15*). Hour estimates for EMS helicopters were based on the number of patients transported per year, a surrogate measure for hours flown. Past research indicates that one patient transport correlates well with 1 flight hr (*5*).

A follow-up questionnaire was also administered to helicopter crash survivors of both groups by mail. The questionnaire was sent to a sample of survivors identified through the NTSB records. The questionnaire was designed to obtain supplemental information from the survivors not available from the NTSB crash record. The questionnaire requested information on the survivor's age and weight, function in the helicopter at the time of the crash, seating position and orientation, individual restraint availability and use, damage to the seat, personal protective equipment (such as Nomex flight suits or helmets), damage to the helicopter, events remembered of the crash sequence, injury status and severity, identification of injury source, and presence or absence of post-crash fire.

Causal Factors

Each crash was reviewed to determine causal factors. Both the narrative contained in the hard copy record and the official NTSB probable cause were used in the development of these causal factor categories. Up to two causal factors could be listed for each crash. The factors are as follows:

1. Mechanical problems, not including engine failure, that were directly related to the crash;
2. Engine failure;
3. Weather—specifically, poor visibility;
4. Wire strike while in flight;
5. Control problem, usually involving mechanical problems with the control system of the helicopter;
6. Spatial disorientation of the pilot, usually associated with poor visibility or dark nights;
7. Power loss or reduced power;
8. Pilot judgment error;
9. Tail rotor failure;
10. Weather (other than poor visibility), such as high winds and downdrafts;
11. Loss of control;
12. Struck object;
13. Foreign object damage, usually caused by material being sucked into the engine or rotor systems;
14. Fire;
15. Fuel exhaustion;
16. Fuel starvation (fuel was present on board the aircraft but was unavailable to the engine); and
17. Other not covered by the preceding categories.

Crash Survivability

The survivability and severity of the crashes were determined through review of hard copies (microfiche) of the NTSB crash record. Injury status of the occupants was not evaluated during this phase of the study to avoid the introduction of bias based on the injuries actually received by the occupants. Information reviewed included estimates of both horizontal and vertical velocity provided by the investigator, structural damage to the helicopter, ground scarring, and review of photographs when available. The primary goal of this analysis was to determine which crashes were clearly survivable, which were clearly not survivable, and those for which survivability could not be ascertained.

Crashes were categorized as survivable, not survivable, or unknown. For a crash to be considered survivable, the estimated acceleration forces experienced by the occupants had to be within the accepted limits of whole body *g*-loading tolerance for properly restrained individuals. In addition, enough space needed to remain within the helicopters for the occupants to survive.

Crash severity was also evaluated during the determination of the crash survivability. The measurement of crash severity was based on the narrative description of damage to the helicopter contained in the NTSB crash record or from the responses of the occupants to the questionnaire, or both. The primary goal of the crash severity measure was to develop a relative baseline for comparison between the two populations. The crash severity measures are as follows:

1. Hard landing/minor damage: The aircraft landed hard in a primarily vertical direction and experienced relatively little damage. Typical damage includes minor damage to the landing gear with skin wrinkles on the fuselage and tail boom. Aircraft whose tail boom was severed by the rotor blades flexing down were also included in this category.
2. Rollover/minor damage: This crash scenario typically involved a helicopter that rolled over either after a low-impact landing or from a low hover. The damage to the aircraft could be substantial although the *g* forces were relatively minor.

Typical damage includes transmission and rotor damage along with fuselage skin damage and broken windows. The interior usually received no major damage.

3. Hard landing/substantial damage: The aircraft landed hard in a primarily vertical direction and experienced more substantial damage than described in Measure 1. Typically, the landing gear received substantial damage, with skids being separated and wheeled landing gear being seriously damaged. The fuselage also received damage with tail boom separation, possible structural damage, and perhaps broken plexiglass. The interior was not compromised and did not receive major damage.

4. Hard landing/rollover/substantial damage: This crash scenario resulted in damage to the aircraft as described in Measure 3 but was followed by rollover of the helicopter after the initial impact.

5. High vertical impact with survivable space and substantial damage: This type of crash was characterized by high vertical impact in which the landing gear was destroyed, with serious damage to the structural members of the helicopter attached to the landing gear. The fuselage also received considerable damage, with crushing of the fuselage floor and possible distortion of the cabin or cockpit. Space remained for the occupants, but the interior may have also experienced disruption, with distorted seats, loosened interior panels, broken windows, and distorted floor panels.

6. High vertical impact/survivability unknown: The aircraft was typically destroyed along with the landing gear. The fuselage received significant damage, which often included some crushing and loss of occupant space. Also, the interior usually received extensive damage. The damage to the aircraft was such that potential survivability of the occupants could not be determined with any accuracy.

7. Slow-speed collison with ground/substantial damage: The aircraft had a greater longitudinal than vertical impact component. The speed at which impact occurred was below 60 kts and the aircraft received substantial damage, with landing gear destruction, significant fuselage damage and distortion, and interior distortion.

8. High-speed collision with ground/severe impact: This type of crash involved greater longitudinal than vertical impact forces and occurred at speeds greater than 60 kts. The forces were such that fuselage was usually destroyed.

9. Collision with object: Most of these crashes involved collisions with wires or other high obstructions such as trees or structures. These crashes typically occurred during approach or departure but could also occur during cruise flight.

10. Midair collision/severity unknown.

11. Unknown: Not enough information to make an estimate of crash severity.

12. Other: Fits none of the categories above.

Injury Coding

Each occupant in both the study and comparison populations had been classified by NTSB according to injury level (none, minor, serious, or fatal). In addition, information on specific injuries sustained by occupants was collected through additional review of the associated NTSB crash record and from the questionnaires. Injury status was determined through survey responses, data contained in the injury supplement (Supplement K) of the NTSB accident report, and review of the narratives written by the investigator contained in the official NTSB report. All occupants of the EMS helicopter population and a random sample of the occupants of the non-EMS helicopter population were included in this review.

Once the individual injuries sustained by the occupants were determined, they were coded using the Abbreviated Injury Scale (AIS), 1990 revision (*16*). The AIS was first developed in 1972 to provide researchers with a numerical method for ranking and comparing injuries by severity and to standardize the terminology used to describe injuries. Since that time, the AIS has become a widely used method for measuring blunt force injuries. AIS scores range between 1 (very minor) and 6 (not survivable), and each individual injury is scored. Specific information is coded for body region of the injury, type of anatomic structure, and the specific anatomic structure involved.

Though the AIS is a well-developed and accepted method for measuring injuries, it does not allow for an evaluation of the cumulative effect of multiple injuries. For this reason, Baker's injury severity scale (ISS) was also calculated for each injured occupant. The ISS is calculated by taking the square of the highest three AIS scores in three different body regions and summing the values. The resulting value gives a much better fit between overall injury severity and probability of survival.

RESULTS

Crash Evaluation and Rates

The NTSB data base contained 75 EMS helicopter crashes occurring between May 11, 1978, and November 2, 1989, with 239 occupants. Of the 75 crashes, approximately 68 percent (51) resulted in injuries (including fatalities) to occupants, whereas 32 percent (24) caused no injuries to the occupants. Of the 239 occupants, 33 percent (80) received no injuries, 19 percent (45) received minor injuries, 15 percent (36) received serious injuries but survived, and 33 percent (78) died. Of the 75 crashes, 27 percent (20) were determined to be unsurvivable. The survivability status could not be determined for four.

From January 6, 1983, to October 10, 1989, 663 crashes of FAR Part 135 turbine-powered air taxi helicopters were investigated by NTSB. Of these, 147 with 486 occupants were eligible for inclusion in the study. Fifty-seven percent (83) of the crashes had occupants who were injured (including fatalities), and 43 percent (64) resulted in no injuries to the occupants. Of the 486 occupants, 56 percent (274) received no injuries, 22 percent (113) received minor injuries, 11 percent (54) received serious injuries, and 10 percent (45) died. Of the 147 non-EMS crashes included in this study, 11 percent (16) were deemed to be unsurvivable. The survivability status could not be determined for six.

Table 1 compares the injury status of the crash for both EMS and air taxi helicopters for all crashes, survivable and unsurvivable, and provides the same comparison for survivable crashes alone.

TABLE 1 MOST SEVERE INJURY CATEGORY

INJURY STATUS	EMS HELICOPTERS (n=75 crashes)		AIR TAXI HELICOPTERS (n=147 crashes)		RELATIVE RISK	CONFIDENCE INTERVAL#
	NUMBER	RATE*	NUMBER	RATE*		
SURVIVABLE AND NON-SURVIVABLE CRASHES						
MINOR	15	20.0	34	23.13	0.86	0.50<RR<1.48
SERIOUS	9	12.0	25	17.00	0.71	0.35<RR<1.43
FATAL	30	40.0	24	16.33	2.45	1.55<RR<3.88
SURVIVABLE CRASHES						
MINOR	15	29.41	34	27.20	1.08	0.65<RR<1.81
SERIOUS	9	17.64	25	20.00	0.88	0.44<RR<1.76
FATAL	3	5.88	2	1.6	3.68	0.63<RR<21.36

* Rate per 100 crashes.
\# 95% confidence interval.
Note: C.I. for the relative risk that does not include 1 represents significance at the 5% level.

As can be seen, the only significant difference between the two populations appears at the fatal crash level, in which at least one aircraft occupant died (relative risk = 2.45, 95 percent CI $1.55 < RR < 3.88$, $X^2 = 13.86$, $p = 0.0002$). When the crashes were evaluated for their survivability status, that is, whether the impact forces were within the range considered survivable, the difference between the crash severity groups at the fatal level disappeared.

Crash Factors

Twenty-four percent (18) of all EMS crashes in this study involved poor visibility. Poor visibility was involved in only 10 percent (15) of the non-EMS air taxi helicopter crashes. Mechanical failure (including engine failure) was involved in 27 percent (20) of the EMS crashes and 26 percent (38) of the non-EMS air taxi crashes. Other categories include wire strike [EMS = 8 percent (6), non-EMS air taxi = 6 percent (9)], power loss [EMS = 4 percent (3), non-EMS air taxi = 10 percent (14)], loss of control [EMS = 8 percent (6), non-EMS air taxi = 20 percent (29)], and struck object [EMS = 8 percent (6), non-EMS air taxi = 5 percent (7)].

Crash Severity

Evaluation of the distribution of crash severity categories indicated no difference of interest in crash severity between EMS and non-EMS air taxi helicopters. Detailed evaluation of the injuries experienced by the occupants with relation to the crash severity was not conducted, but initial review indicated that an increase in injuries and injury severity occurred as the crash forces increased. This dose response was expected.

Occupant-Based Analysis

Occupant Injuries

Occupant injuries were evaluated through information gathered from survey responses, narrative information contained in the NTSB hard copy crash records, and coded information contained in Supplement K of the NTSB computer crash records. There were 159 occupants in survivable crashes of EMS helicopters and 430 eligible occupants in survivable crashes of air taxi helicopters. In EMS helicopters, 56 percent (89 occupants) received no injuries, 25 percent (40) received minor injuries, 16 percent (25) received serious injuries, and 3 percent (5) died. In air taxi helicopters, 63 percent (273 occupants) received no injuries, 26 percent (112) received minor injuries, 10 percent (43) received serious injuries, and 0.4 percent (2) were fatally injured.

When occupant injuries were compared between the two groups by injury status considering the occupant location (pilot or passenger), a statistically significant increased risk of serious injury for EMS helicopter passengers and crew was found when compared with non-EMS air taxi passengers (RR = 2.10; 95 percent CI $1.21 < RR < 3.64$, $X^2 = 7.11$, $p = 0.008$). No significant association for serious injuries was discovered for pilots of the two different populations. The difference in injury severity by location was not unexpected, since the pilot's position in EMS helicopters is typically not changed when the interior is modified for the medical mission. The injury experience of the two pilot groups should therefore be essentially the same given similar crash acceleration forces. No statistical evaluation was conducted for difference in fatal injury outcome among occupants between groups, since the total number of fatal injuries was too small.

Injury Severity

The injury information for the EMS helicopter population was developed from review of the NTSB crash records for all occupants and from survey information for a small subset of occupants. The injury information derived from these sources can be considered representative, since all EMS helicopter occupants were accounted for. Information was collected on 55 injured EMS helicopter occupants in survivable crashes. Injury information for the air taxi helicopter occupants was also obtained from review of NTSB crash records and survey information. All non-EMS air taxi crashes, however, were not reviewed. A systematic sampling technique was used to select 57 crashes for detailed review. In these crashes, the injuries of 51 occupants were coded for detailed analysis.

The injuries of these occupants were coded using the AIS and a summary measure was developed by calculation of the ISS. The mean ISS scores were then calculated for pilot and passengers for both EMS and non-EMS air taxi helicopters. The results of this analysis are given in Table 2.

The injuries of EMS helicopter pilots were, on the average, less severe than those of the pilots of non-EMS helicopters, as indicated by the mean ISS score. The injuries of EMS helicopter passengers, however, were more severe than those sustained by the comparison passengers in non-EMS air taxi helicopters, on the average. In neither case were the differences statistically significant. When the ISS scores are evaluated, it should be remembered that these are mean values of all ISS scores of the occupants for each group. For this reason, the range of scores for each group is presented for additional insight. In addition, the ISS score is nonlinear and should be interpreted accordingly.

Injury Characteristics

Once specific injuries were coded, they were further categorized for ease of analysis and review. The categories are as follows:

- Serious back injuries include spinal fractures of the lumbar, thoracic, and cervical spine along with disc compression or rupture.
- Serious head injuries include concussion, subdural bleeds, skull fracture, and serious lacerations.
- Minor head injuries include unspecified head injuries and head contusions.
- Internal injuries include any damage to internal organs and are of varying severity. They include heart or lung contusions, ruptured spleen, bladder contusion, and bruised kidneys.
- Fractures include fractures of the extremities, facial bones, and ribs.

Table 3 gives the results of the analysis of specific injury categories.

For all four groups, serious back injuries constituted a major injury risk. This finding supports the conclusions of Shanahan (*12*) and Coltman (*13*) already cited. As in those studies, the majority of the occupants in the rear of the aircraft evaluated for this study were not wearing shoulder harnesses. Past research indicates that shoulder harnesses improve resistance to back injury slightly. The other finding of interest is the difference in serious head injuries among the groups. The rate for EMS helicopter passenger serious head injury per 100 injured passengers of 23.25 is roughly threefold greater than that of non-EMS helicopter passengers.

Survey Responses

The survey was developed to gain additional insight into the variables associated with occupant injury, or lack of injury,

TABLE 2 MEAN ISS SCORES FOR OCCUPANTS INJURED IN SURVIVABLE CRASHES

	MEAN PILOT ISS SCORE	PILOT ISS SCORE RANGE	MEAN PASSENGER ISS SCORE	PASSENGER ISS SCORE RANGE
EMS HELICOPTERS	3.17	1-9	6.98	1-34
AIR TAXI HELICOPTERS	5.46	1-12	4.40	1-12
DIFFERENCE	-2.29		2.57	
P-VALUE *	0.16		0.17	

* Kruskal-Wallis test for two nonparametric groups.

TABLE 3 INJURY CATEGORY FOR OCCUPANTS BY LOCATION

	EMS PILOTS n=12	AIR TAXI PILOTS n=26	EMS PASSENGERS n=43	AIR TAXI PASSENGERS n=25
SERIOUS BACK INJURIES	16% (2)	38% (10)	47% (20)	36% (9)
SERIOUS HEAD INJURIES	8% (1)	8% (2)	23% (10)	8% (2)
MINOR HEAD INJURIES	0	12% (3)	7% (3)	8% (2)
INTERNAL INJURIES	0	0	12% (5)	4% (1)
FRACTURES	8% (1)	23% (6)	19% (8)	28% (7)

Note: Percentages may total less than 100 % since very minor injuries not included. Percentages may also total more than 100 % since many occupants had more than one injury.

in a sample of both EMS and air taxi helicopters. The questionnaire was pretested on a sample of 20 air taxi helicopter pilots. The pilots, and the associated crashes, were not included in the air taxi helicopter data base used for this study.

Once the pretest questionnaires were received, they were reviewed and appropriate modifications made. A total of 350 questionnaires were then mailed to a sample of both EMS and air taxi helicopter crash survivors. Only occupants whose complete address was part of the NTSB crash record (not all NTSB investigators record this information) were mailed a questionnaire with a postage-paid return envelope.

Overall, the response rate after the two mailings was 37 percent (128). Approximately 30 percent (106) of the 350 survey subjects had moved and left no valid forwarding address for the questionnaire package, which indicates that approximately 33 percent (116) survey subjects received the questionnaire but did not respond.

Whereas this response rate may not appear impressive, it is not difficult to understand the low rate when it is remembered that the event being investigated was probably emotionally traumatic for the individual, and concern about legal issues in events such as these is always present. However, the descriptions of the injuries received by the occupants, and their associated comments and recommendations, were of considerable value.

Although the possible influence of EMS helicopter interior modifications on the severity of occupant injuries was not clearly shown in this preliminary analysis, the responses to the survey offered some interesting insight into the issue of injuries in EMS helicopter crashes. In addition to formatted questions which allowed no flexibility in response, the questionnaire asked the following questions about the occupant injuries:

> Please provide a description of your injuries (such as a broken left arm, with cuts and abrasions, or multiple bruises to the face and a sprained left ankle). Please be as detailed as you can.
>
> Do you know what caused your injuries? For example, what object or structure inside the helicopter did you contact? If yes, please describe in as much detail as possible.

The major responses to these questions were categorized for ease of analysis and presentation for both the EMS and non-EMS survey respondents who were injured. The categories for injury causation are as follows:

- Aircraft interior: This category includes occupants striking doors or windows or their associated structures, instrument panel, and throttle quadrant.
- Harness problem: This involved shoulder harnesses being fastened incorrectly and failure of the shoulder harness.
- Medical/other equipment: Occupants struck or were struck by patient stretcher, oxygen tanks, portable radios, cardiac monitors, medical equipment panels behind pilot, and fire extinguisher.
- Hit other occupant.
- Lap belt related: involved lap belt/abdominal trauma and seat belt clasp injury unspecified.

Table 4 gives the findings from this analysis.

The most noticeable difference in these responses appears in the medical/other equipment category. The fact that 42 percent of those passengers and crew injured in EMS helicopters attribute their injuries to striking medical equipment is certainly of interest. None of these occupants cited other loose equipment in the aircraft other than the medical equipment. The one non-EMS passenger who responded in this category struck his head on a fire extinguisher that was mounted near his seat. Although Table 4 summarizes the experience of the occupants, the following excerpts from the surveys are typical and offer an additional perspective on the experiences of injured occupants.

One nurse who was wearing only a lap belt, and whose aircraft hit hard and rolled over, described her experience by saying

> I had a concussion with a large laceration over the right side of my skull. I also had bruises and abrasions to all of my face. . . . I assumed the crash position and while we were rolling, the cardiac monitor broke loose from its case and gave me the head injuries.

Another flight nurse, restrained by a lap belt, was in a helicopter that had a very hard landing after an engine failure. She described her experience and injuries this way:

> I received fractured ribs, multiple lung contusions, fractured lumbar vertebrae [L5-S1], multiple facial lacerations, and a broken arm and ankle. . . . [The damage] to my face and teeth was caused by the oxygen tank, the broken arm and ribs caused by slamming into medical pouches and 1/2" plexiglass behind the pilot's seat. . . . The fractured ankle happened because it was stuck under the stretcher and I pulled it out to free my foot breaking [it] in the process.

Other observations by both EMS and non-EMS passengers seriously injured include the following:

> I believe that the forces of the helicopter and not having shoulder restraints was the main cause of my injuries. . . . We were lucky, the aircraft landed in six feet of fresh powdered snow.

TABLE 4 INTERIOR HELICOPTER STRUCTURE AND EQUIPMENT IMPLICATED IN OCCUPANT INJURIES

	EMS OCCUPANTS n=29	AIR TAXI OCCUPANTS n=35
AIRCRAFT INTERIOR	31% (9)	34% (12)
HARNESS PROBLEM	10% (3)	8% (2)
MEDICAL/OTHER EQUIPMENT	42% (12)	3% (1)
HIT OTHER OCCUPANT	7% (2)	0
LAP BELT RELATED	17% (5)	0

> Head hit back firewall, other nurse's knees in my chest, other injuries from striking items inside the cabin [such as] patient litter, portable oxygen tank, etc.

> I assume it was all "whiplash" injury due to not having a shoulder harness.

> I only know [the] monitor was airborne and hit me in the face.

> I feel that 3 or 4 point restraint system certainly would have reduced number of injuries.

Equally interesting were the observations of those not seriously injured in the crashes. One EMS helicopter pilot observed:

> The use of helmets by everyone may have prevented injury. The diagonal shoulder harness was useless. Recommend installation of lap belt and double shoulder harness in all crew and passenger stations.

A paramedic who received minor head and burn injuries in a crash stated:

> Our program has initiated the use of Nomex flight suits as well as helmets. If I had been wearing these at the time of the incident, I believe I would not have injured.

A physician who received minor injuries in an EMS helicopter observed that "the helmet prevented much more serious injuries."

DISCUSSION OF RESULTS

The fact that a statistically significant association exists between the risk of serious injury among helicopter passengers and the type of helicopter they are passengers in (i.e., EMS versus non-EMS) supports the hypothesis that EMS helicopters are more hazardous to passengers than the non-EMS helicopter comparison population used in this study (RR = 2.10; 95 percent CI $1.21 < RR < 3.64$, $X^2 = 7.11$, $p = 0.008$). There is, however, no statistical difference between the injury experience of the pilots of the two study groups. This finding generally supports the supposition that EMS helicopter pilots should be at the same risk for injury as non-EMS air taxi helicopters pilots, since the modification of EMS helicopters typically makes little or no changes in the pilot's position.

Evaluation of any differences in fatal injury outcome in survivable crashes between the two groups was not feasible due to the lack of reliable information. The survivability of many of the potentially survivable crashes in which occupants died could not be determined with accuracy. In these cases, the crashes were coded conservatively as "survivability unknown." This category was not included in the analysis of occupant injuries. Furthermore, specific information on the injuries sustained by the occupants killed in potentially survivable crashes was not available in the NTSB crash record. The NTSB investigators almost universally coded the occupant as having received multiple injuries in lieu of completing the injury supplement. This bias made the NTSB record of no value for this aspect of the analysis. A logical follow-up of this study would be the reëvaluation of the potentially survivable crashes through review of additional records and collection of autopsy data for individuals killed in the crashes to exactly determine their injuries.

Evaluation of individual injuries of those who survived the crashes does not provide enough evidence to reliably determine that the modification of the EMS helicopter was the sole cause of the increased risk of serious injuries. It is reasonable to assume, however, that this lack of association might be due to limitations in the sample sizes or measurement methods used at this level of analysis and may not be because of no difference between the two study groups. This assumption is supported by the EMS occupant survey responses in which 42 percent indicate that they believe their injuries were caused or exacerbated by the medical or other equipment in the helicopter. This percentage stands in contrast to the 3 percent of non-EMS occupants who identified other equipment in the helicopter as involved in their injuries. In addition, the fact that EMS helicopter passengers received serious head injuries twice as often as passengers of non-EMS helicopters or the pilots of either group supports the general hypothesis that the medical modification of the EMS helicopter may be responsible for increased injuries among this group.

The review of injuries among all occupants in this study indicates that serious back injury is a serious problem for all survivors of helicopter crashes. This finding supports the conclusions of the research conducted by both Shanahan (*12*) and Coltman (*13*) and indicates that the most serious helicopter crash scenario for occupant injuries involves a component of vertical acceleration in excess of the design requirements specified by the FAA for helicopters, but well within that tolerated by the human body. Incorporation of double shoulder harnesses and energy-absorbing seats in currently designed helicopters, where feasible, would prevent, or reduce, these injuries.

CONCLUSIONS

The preliminary review and analysis of the crash and injury data for these two populations indicate that there is an increased risk of serious injury among EMS helicopter passengers and that these injuries are, at least in part, due to medical modifications and associated equipment in the helicopter. Strategies to reduce, or eliminate, the seriousness of injuries among this group include the incorporation of double-strap shoulder harnesses for all passenger locations in the helicopter along with energy-absorbing seat. The results from this study support previous research indicating that these features should be made available to all helicopters, not just EMS helicopters.

Portable equipment such as cardiac monitors, oxygen cylinders, and radios also pose a hazard. Preventive interventions for these components would have to be developed on a case-by-case basis, but some general design characteristics might include the following:

1. Oxygen cylinders should be mounted outside the passenger compartment and should be constructed only of aviation-approved cylinders and hardware. Common sense also dictates that the oxygen flow should be controllable at cylinders regulator and that all oxygen lines into the aircraft passenger compartment should be low pressure.

2. Cardiac monitors should be permanently mounted in the passenger compartment. In cases where portable monitors must be carried when not in use, they should be stored in a secure location where they will not come loose in a survivable crash.

3. Patient stretchers and other structures of mass such as infant incubators should be secured to the aircraft in such a way that they will not come loose during very mild accelerations as allowed by the FAA in the design specifications for helicopter crashworthiness.

4. IV hooks in the interior and other projections such as oxygen line connections should be mountd behind the sidewall of the aircraft and not project into the interior.

The need to design both for crashworthiness and for efficient patient care may appear to be mutually exclusive. The opportunity exists, however, to incorporate both factors into the helicopter when designing for interior modification. The potential for preventing or reducing serious injuries, and perhaps preventing needless death, makes the effort worthwhile.

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