Analysis of Injuries among Pilots Killed in Fatal Helicopter Accidents

NARINDER TANEJA AND DOUGLAS A. WIEGMANN

TANEJA N, WIEGMANN DA. *Analysis of injuries among pilots killed in fatal helicopter accidents.* Aviat Space Environ Med 2003; 74: 337–41.

Background: Despite advancements in the crashworthiness of helicopters, both the rate and severity of injuries sustained in helicopter accidents remain a cause for concern. The mechanism and pattern of injuries sustained in aircraft accidents can provide vital information for improving survivability. The purpose of this study was to analyze patterns of injuries sustained by pilots involved in fatal helicopter accidents. ***Method:*** Detailed information on the pattern and nature of injuries was retrieved from the Federal Aviation Administration's autopsy database for pilots involved in fatal helicopter accidents from 1993 to 1999. ***Results:*** A review of 84 autopsies revealed that blunt trauma was cited as the primary cause of death in 88.1% of these cases. The most commonly occurring bony injuries were fractures of the ribs (73.8%), skull (51.2%), facial bones (47.6%), tibia (34.5%), thorax (32.1%), and pelvis (31.0%). Common organ/visceral injuries included injury to the brain (61.9%), lung (60.7%), liver (47.6%), heart (41.7%), aorta (38.1%), and spleen (32.1%). Injury patterns did not appear to be related to the age of the pilot or the phase of flight. The use of a shoulder harness afforded protection to the occupant against certain injuries. ***Conclusions:*** The findings and their significance are explained in the overall context of crash survivability and have implications for the design of crashworthy aircraft and making helicopter accidents more survivable.

Keywords: helicopter accidents, injuries, autopsy, survivability.

HELICOPTERS ARE DEFINED as aircraft in which all flight attitudes are supported in the air wholly or in part by a rotor or rotors (15). They provide convenient and rapid transport and are used for a wide range of purposes such as aerial surveys, medical evacuations, aerial spraying of agricultural areas, and transporting equipment and workers to or from remote work sites, as well as sightseeing and recreation.

There is a concern in the aviation community over the high rates of accidents and fatalities in helicopter accidents. For the past decade, the number of helicopter accidents in the United States has not shown any significant decline from the average accident rate of 8.00/100,000 flying hours (9). A recent study has identified higher accident rates in lower vs. higher cost helicopters, and among private compared with professional pilots (9). Some studies have reported an increase in the case-fatality ratio (defined as the proportion of pilots fatally injured among all the pilots involved in crashes) of 23.8% for helicopters (14). There has also been a noticeable increase in accident and fatality rates among the hospital-based emergency helicopter transport programs, with a reported three times higher fatality rate compared with non-scheduled air taxi helicopter services (16).

Aircraft accident investigations serve at least two major purposes. First, they aim to determine the cause of the accident so that future recurrences can be prevented or minimized. Second, these investigations attempt to analyze the cause and nature of injuries sustained by the aircrew and other occupants. Injury analysis assists in identifying possible features within the cockpit environment that may have resulted in such injuries. It also enables the investigator to characterize survivable and non-survivable crash forces. Such information eventually helps establish crashworthiness design standards (5). Historically, these issues generally have received greater attention in military helicopters than commercial helicopter operations and have distinctly influenced crash dynamic patterns and most probably altered injury patterns as well (17).

Li and Baker observed that the most important correlates of pilot fatality in general aviation crashes were variables possibly related to increased impact forces (14). On the other hand, Krebs et al. concluded that the likelihood of a pilot surviving a helicopter crash could be greatly improved by preventing crash-associated fires and promoting the usage of shoulder restraints (10). A recent study comparing injuries across various categories of aircraft observed that the upper body was injured more often in rotary wing aircraft accidents compared with fixed wing (3). However, this study included only 22 fatalities from helicopter accidents.

To date, few studies have examined the types of injuries sustained in fatal civil helicopter accidents. As stated earlier, analysis of injuries can guide crashworthiness design standards. Such standards, however,

From the Aviation Human Factors Division, Institute of Aviation, University of Illinois at Urbana-Champaign.

This manuscript was received for review in November 2001. It was revised in June and November 2002. It was accepted for publication in December 2002.

Address reprint requests to: Douglas A. Wiegmann, Aviation Human Factors Division, University of Illinois, 1 Airport Road, Savoy, IL 61874; dwiegman@uiuc.edu.

Narinder Taneja, M.D., is Wing Commander, Indian Air Force, and Visiting Research Scholar, Aviation Human Factors Division, Institute of Aviation, University of Illinois at Urbana-Champaign.

need to be based on the characteristics of existing military and civil helicopters. Timely and regular information analyzed from these crash investigations can help accomplish this objective. The purpose of the present study, therefore, was to analyze the nature and severity of injuries sustained by pilots involved in fatal civil helicopter accidents and their relation, if any, with aircraft and environmental factors.

METHODS

Autopsies are performed on pilots involved in fatal civil aviation aircraft accidents in the U.S. by the local medical authority under whose jurisdiction the accident occurred. These reports are then forwarded to the Medical Statistical Section at Civil Aerospace Medical Institute (CAMI), FAA, Oklahoma City, OK. A total of 84 autopsies on pilots involved in 74 fatal helicopter accidents from 1993 to 1999 were analyzed. For the corresponding period, there were 272 fatal helicopter accidents, which yield an autopsy-reporting rate by local medical authorities of approximately 27%.

The autopsy report contained information on the age of the pilot, type of aircraft, and a description of injuries classified according to the body region/organ system. The available information in the database was used without any modification to the nature or severity of injuries. The corresponding accident database maintained by the National Transportation Safety Board (NTSB) was used to access aircraft information and environmental factors.

RESULTS

External Cause of Death/Primary Cause of Death

Blunt trauma was attributed as the primary cause of death in 88% (n = 74) of the autopsies. The next highest cause of death was drowning in 3.6% (n = 3) of the cases. Exsanguination and inhalation of smoke and toxic gases were responsible for two deaths each. Hypothermia, asphyxia, and thermal were cited as the cause of one death each.

Nature of Injuries

Traumatic injuries by body region: In the autopsy database, different categories of injury patterns exist for a single organ such as lacerations, ruptures, hemorrhages, etc. All categories of injuries to a single organ (e.g., lacerations, ruptures, hemorrhages) have been combined to make patterns that are more meaningful.

Of the injuries to the head and neck region, fractures of the skull (51.2%) and facial bones (47.6%) were predominant, with injury to the brain documented in 61.9% of the autopsies. Lacerations of the face were documented in 31.0% of the autopsies. There was a statistically significant relation between skull fractures and injuries to the brain [χ^2 (n = 84,1) = 14.191, $p < 0.001$]. A statistically significant relation was also observed between fractures of the facial bones and lacerations of the brain [χ^2 (n = 84,1) = 5.560, $p < 0.01$] and fracture of the ribs [χ^2 (n = 84,1) = 4.947, $p < 0.03$].

Injuries to the lungs were documented in 60.7% (n = 51) of the autopsies. Injuries to other intrathoracic organs like the heart and aorta were also high (41.7% and 38.1%, respectively). Fractures of the sternum were present in 25.0% of the autopsies. Injuries to the heart were significantly associated with fracture of the facial bones [χ^2 (n = 84,1) = 10.560, $p < 0.001$], and fractures of the ribs [χ^2 (n = 84,1) = 6.764, $p < 0.01$]. Fractures of the ribs were also significantly associated with injuries to the liver [χ^2 (n = 84, 1) = 22.171, $p < 0.001$], lung [χ^2 (n = 84,1) = 13.975, $p < 0.001$], aorta [χ^2 (n = 84,1) = 10.633, $p < 0.001$], and spleen [χ^2 (n = 84,1) = 10.408, $p < 0.001$].

In the abdominal region, all categories of injuries to the spleen (32.1%) occurred less often than injuries to the liver (47.6%). Fractures of the pelvis were reported in 30.9% (n = 26) of the cases; urinary bladder damage was reported in only 8.3% (n = 7) of cases. Lacerations/avulsions of the gastrointestinal tract were documented in 13.1% of the autopsies.

Fractures of the tibia, femur, and fibula were documented in 34.5%, 27.4%, and 31.0% of the cases, respectively. Among bones of the upper extremities, fractures of the humerus were the highest (25%) followed by fractures of the clavicle in 21.4% of the cases. Fractures of the radius and ulna bones were present in 16.7% of the autopsies.

Injuries to the spine also occurred in numerous cases. Fractures of the thoracic spine were present in 30.9% (n = 26) of the autopsies followed by fractures of the cervical spine (25%, n = 21). Fracture of the lumbar spine was reported in only one case.

Thermal injuries: Thermal injuries in the autopsy database have been classified as thermal 1 and thermal 2. Thermal burns 1 are burns sustained ante-mortem and were present in 3.6% (n = 3) of the cases, whereas thermal burns 2 (post-mortem burns) were present in 21.4% (n = 18) of the cases.

Crash and Environmental Conditions

The aircraft was destroyed in 91.8% (n = 68) of the accidents with substantial damage occurring in the remaining cases. Most of these accidents occurred during the maneuvering (31.1%, n = 23) phase of flight, followed by those in the cruise (22.9%, n = 17), and hover (16.2%, n = 12) phases of flight. There was no significant correlation between the phase of flight and commonly occurring injuries.

Most of the helicopters involved in these accidents (63.5%, n = 47) were operating under CFR Part 91 flying rules (i.e., general aviation) followed by 20.3% (n = 15) that were operating under CFR Part 135 flying rules (commercial). Of the accidents reported in the present database, 82.4% (n = 61) of the helicopters were flying under visual meteorological conditions (VMC), whereas only 13.5% (n = 10) of the accidents occurred in instrument meteorological conditions (IMC).

Information was also analyzed for the number of engines in the helicopter and the type of landing gear to examine any possible correlation between these and the nature of injuries. A total of 86.5% (n = 64) of the helicopters were equipped with a single engine, and the skid type landing gear was the most common on these

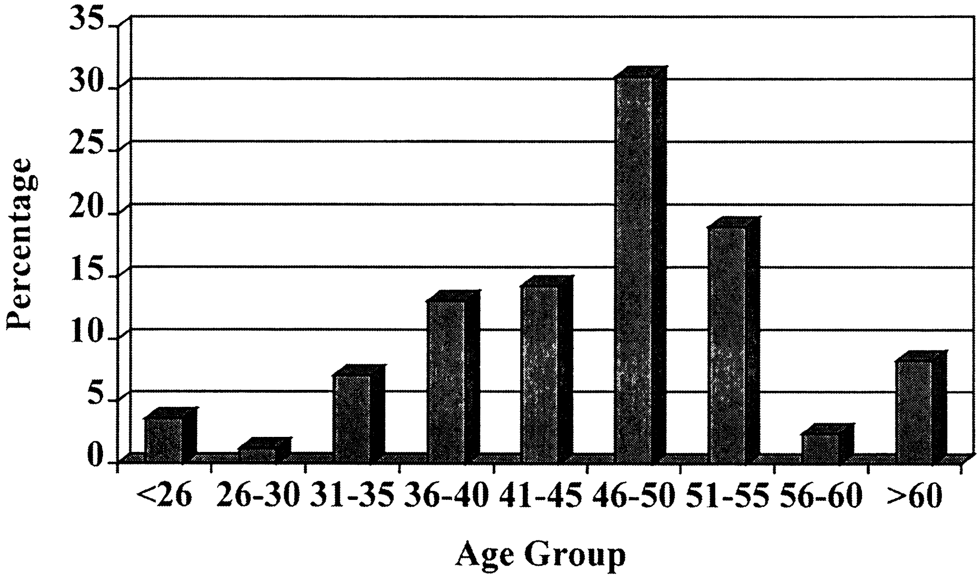

Fig. 1. Age distribution of pilots blocked across 5-yr age groups.

helicopters (82.4%, n = 61). There was no significant relation between the number of engines/landing gear and the nature of injuries.

Aircrew errors were cited as probable causes in 63.5% (n = 47) of the accidents; mechanical factors were considered probable causes in 22.9% (n = 17). The causes were not known in 14.9% (n = 11) of the cases, either because the reports were preliminary or because the causes were undetermined.

Demographic Information

All the pilots in the autopsy database were males. **Fig. 1** presents the age distribution of these pilots when grouped into 5-yr age groups. Approximately one third of the pilots were in the age group of 45–49 yr, whereas there were fewer pilots at either end of the age range. Of the pilots, 7 were over the age of 61. There was no significant correlation between the age of the pilots and the nature of the injuries.

Use of a Restraint System

Information on the use of a restraint system was not available in 17.9% (n = 15) cases. While 58.3% (n = 49) of the pilots were reportedly using a shoulder harness at the time of the accident, 10.7% (n = 9) were not using a shoulder harness. A statistically significant decrease in the incidence of sternum fractures and lung hemorrhages were found with the use of a shoulder harness. While pilots using their shoulder harness had sternum fracture in 20.4% cases, this increased to 33.3% in those not using a shoulder harness [χ^2 (n = 84,2) = 6.180, $p < 0.05$]. Similarly, the incidence of lung hemorrhage increased from 36.7% when using a shoulder harness to 66.7% when not using a shoulder harness [χ^2 (n = 84, 2) = 9.402, $p < 0.005$]. Though not statistically significant, a slight increase was observed in blunt trauma as the primary cause of death, as well as liver laceration and lung avulsion when not using a shoulder harness. The use of a shoulder harness did not appear to be a function of age.

DISCUSSION

Crash forces involved in helicopter accidents can produce a wide range in severity and pattern of injuries (8). In 88% of the cases (n = 74) the primary mechanism of death in the fatal accidents examined in this study was blunt trauma and expectedly corroborates findings from earlier studies (1). A recent study revealed that of all aviation fatalities in the U.S., 76% are due to blunt trauma (13). While ante-mortem burns were reported in only 3.6% of the cases, post- mortem burns were present in almost a fifth of the pilots. Burns were found to be the primary cause of death in 4.3% and 5.9% of cases as reported by Conroy (4) and Ast (1), respectively. Li and Baker also reported burns as a cause of death in 4% of all aviation fatalities (14).

The high incidence of injuries to the skull observed in this study parallels a similar finding of a study on U.S. Army fatal helicopter crashes (6,17). It has been estimated that 50% of fatalities in survivable U.S. Army helicopter accidents were caused by head strikes (17). Smith et al. (19) report that 62.5% of fatal injuries in rotorcraft accidents are head injuries. Skull fractures appear to be primarily a contact injury due to collapsing structure, intrusion of high mass items (rotor systems, transmission, engines), flailing of the head and upper torso, or a combination of the above (19). Head injury could, in itself, be fatal or severely impair the ability of the injured pilot to escape from the post-crash environment and hazards like fire; and hence, deserves utmost attention in any strategy to improve crash worthiness and survival.

Injuries to the ribs, sternum, and the intrathoracic contents also constitute a large percentage of injuries in these fatalities and corroborate finding of an earlier report (19). With the lungs being the most superficial in the thoracic cavity, it comes as no surprise that there were injuries to the lung in as high as 60.7% of the autopsies. A statistically significant relation was found between fractures of the ribs and lacerations of the lungs and heart in the present study. A significant correlation was also observed between fractures of the ribs and facial bones. The primary mechanism of injury in this region may be the direct compression and penetration by broken ribs and sternum. While no direct causal mechanism can be attributed to the relation between fractures of the facial bones and laceration of the heart as observed earlier, it is possible that fractures of the ribs and facial bones suggest common trauma patterns, subjecting the heart to direct compressive forces.

Despite the abdomen's comparative anatomical vulnerability, there is generally a lower incidence of injury observed in this area than in other bodily regions (7). Hill (7) has postulated various possible mechanisms for injury to the intra-abdominal organs. While compression of the viscera, probably remains the primary mechanism, other complex shear/rotational forces are also possible, thereby damaging the intra-abdominal organs. In the present study, a significant relationship was observed between fractures of the ribs and injuries to the liver and spleen, which seems to suggest that direct compression may be a primary mechanism of injury to these intra-abdominal organs. Although laceration of the abdominal organs can occur without impactment, the lack of autopsy details on the nature of the actual injury precludes support for such a conclusion.

It may be appropriate to mention possible implications of research on abdominal injury in automobile crashes. It has been shown that wheel stiffness, and not the column characteristics, may be the primary determinant of steering system-induced injury. Lau et al. (11) were able to demonstrate dramatic alterations in injury patterns by varying steering wheel stiffness, orientation, and column angle. It is likely that the abdominal injury patterns may vary between helicopter and fixed wing aircraft accidents, given the difference in the types of stick, yoke, and control wheels found in these aircraft. However, basic research is still needed to examine the injury-causing potential of various cockpit control characteristics in all aircraft.

Protection afforded by occupant restraint systems has always been a key issue in injury analysis. Certain researchers consider that improved restraints will provide the next major advancement in overall aircraft crashworthiness (19). However, this information was not available in 17.9% of the cases whereas 10.7% of the pilots were reportedly not using a shoulder harness. Also, in an earlier study, less than one half (48%) of pilots were reported to be wearing a shoulder restraint at the time of crash (14). Protective effects of shoulder restraints have been reported in studies of commercial aircraft and air taxi crashes (10,12). Although only fatal accidents were examined in this study, significant protection was provided by a shoulder restraint against fractures of the sternum and lung hemorrhage. A restraint system attempts to maintain the occupant within a known volume so that the crash forces may be minimized and movement of the occupant restricted to avoid secondary impacts with equipments such as displays and controls.

Aircraft variables such as the number of engines and landing gear did not seem to influence the nature of injuries sustained in these accidents. While a greater proportion of accidents occurred during VMC conditions, it is impossible to comment on any relation between weather conditions and injuries due to lack of information on flying rates under VMC/IMC. There was also no correlation with the phase of flight or the mechanism of death or pattern of injuries. In their analysis of helicopter fatalities, Conroy et al. found that 37% of crashes in their data occurred during cruise followed by 19% during maneuvers in flight, but do not mention anything about crashes occurring during the hover phase (4). Our data also revealed that 54.1% of the total accidents occurred during the maneuvering and cruise phase. The damage to the helicopters reflects the severe impact forces involved in these crashes.

What then are the implications of the above findings in terms of crash survivability? The nature and severity of injuries suggests that these crashes may have involved forces exceeding the tolerance limits of the occupants. While no study documents the proportion of survivable/non-survivable accidents in civil helicopter crashes, it has been consistently shown that up to 90% of Army helicopter crashes are potentially survivable (17). Protection of the occupants exposed to a crash is a realistic objective that can be achieved if crashworthiness becomes a primary element of initial helicopter design and future upgrade programs.

Basic theoretical principles of crashworthiness would point to two basic strategies at making crashes more survivable. Minimizing the energy transmitted to the occupant is one way and is usually achieved by energy attenuating landing gears and seats. This method has been employed to prevent vertebral injuries in crashes of Black Hawk helicopters in the U.S. Army (17). However, analysis of injuries in the reported data corroborates earlier reports that contact injuries may be more of a concern than acceleration injuries (19,20). Indeed, Shanahan reported that contact injuries exceeded accelerative injuries by a ratio of approximately five to one (17). Contact injuries to the skull have been of concern in potentially survivable helicopter accidents. A crash activated cockpit air bag system (CABS), placed strategically within the cockpit and cabin, appears to be a very promising option in reducing strike hazards within the cockpit (18). The proposed introduction of a CABS in UH-60 helicopters is projected to reduce pilot fatalities in UH-60A/L helicopters by 15% (18) and may reduce light civil helicopter fatalities by 30%. However, a thorough understanding of potential injury mechanisms, as well as the impact environment in civilian helicopter operations would be required. This will be possible when crash investigators classify the accident as survivable, partially survivable, or non-survivable and identify the sources of injuries. Only then will studies such as the present one be able to evaluate the protective effects of these safety modifications.

The autopsy database used in this study consisted of 74 accidents out of a possible 272 fatal accidents occurring from 1993 to 1999, reflecting an autopsy-reporting rate of about 27%. Ast et al. reported an autopsy rate of 50% in fatal aircrafts in Lower Saxony (Germany) for a 15-yr period (1). Wiegmann and Taneja observed an autopsy reporting rate of 44% in fixed wing airplane accidents in general aviation (20). Despite the existence of federal guidelines that state specific procedures for submitting these reports, aviation authorities in the U.S. have expressed concerns about the low percentage of autopsy reports reaching CAMI (2). Besides identifying important injury patterns, autopsy findings can provide significant inputs in the reconstruction of crash events in an accident. Attempts should therefore be made to increase the autopsy reporting rates. Nevertheless, given the fact that types of aircraft have remained relatively unchanged in the recent past, it is reasonable to assume that despite the low autopsy rate, the data would be a fair representation of the entire spectrum of fatal helicopter accidents. Additional research, however, is clearly needed.

CONCLUSIONS

Despite the shortcomings in the data, this study provides insight into the nature of injuries sustained in fatal helicopter accidents. It reinforces the fact that contact injuries may be of greater concern in survivable crashes than those caused by deceleration loading. It appears that the use of a shoulder restraint and some form of protection to the head can significantly influence the pattern of injuries in potentially survivable accidents. The proposed introduction of a CABS in military helicopters may be the next step toward a big reduction in fatalities in helicopter crashes. Recommendations have been made to modify the data collection process so that more quantifiable and standardized data is available to evaluate the beneficial effects of any future intervention strategies.

ACKNOWLEDGMENTS

This work was supported in part by a grant from the Federal Aviation Administration (DTFA 99-G-006). A grant from the R. D. Birla Smarak Kosh, Mumbai, India was also given to the first author. The views expressed in this article are those of the authors' and do not necessarily reflect those of the IAF or FAA. We acknowledge the assistance of Dr. Alex Wolbrink in data collection.

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