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Injury Patterns and Mechanisms in Medical Evacuation (MEDEVAC) Rotary-Wing Helicopter Crashes

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14. ABSTRACT
A review of injuries resulting from U.S. Army combat and non-combat rotary-wing medical evacuation (MEDEVAC) mishap events and civilian helicopter emergency medical services (HEMS) mishap events was conducted. Data related to U.S. Army rotary-wing MEDEVAC accidents was obtained from the U.S. Army Combat Readiness Center; injury data related to , U.S. Army MEDEVAC combat-related incidents (CRIs) was obtained from the Defense Casualty Informatin Processing System (DCIPS), and injury data from civilian HEMS accidents was obtained from an online aviation accident investigation database maintained by the National Transportation Safety Board (NTSB). Frequency of injuries, injury type, injury severity, and injury mechanism were calculated by body region for 184 mishap events that included 717 occupants; 196 occupants suffered 547 injuries of varying severities.

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14. Abstract (continued)
The core of the body (thorax and abdomen) was the most frequently injured body region followed by the extremities; internal organ injuries and fractures/dislocation/crush injuries were the two most common injury types; blunt force was identified as the most common injury mechanism. The primary aim of this study was to identify patterns of injury and associated injury mechanisms resulting from rotary-wing MEDEVAC mishap events to inform the design of future MEDEVAC aircraft that will support injury prevention for aircrew, cabin crew, and patients.

Executive Summary

A review was conducted of injuries resulting from U.S. Army combat and non-combat rotary-wing medical evacuation (MEDEVAC) and civilian helicopter emergency medical services (HEMS) mishap events between 2002 and 2018. Data related to U.S. Army rotary-wing MEDEVAC accident data was obtained from the U.S. Army Combat Readiness Center (USACRC). Injury data related to U.S. Army MEDEVAC combat-related incidents (CRIs) was obtained from the Defense Casualty Information Processing System (DCIPS). Injury data from civilian HEMS accidents was obtained from an online aviation accident investigation database maintained by the National Transportation Safety Board (NTSB). The frequency, type, severity, and mechanism of injuries were calculated by body region for 184 mishap events, which included 717 occupants; 196 occupants suffered 547 injuries of varying severities. Overall, the core of the body (i.e., thorax and abdomen) was the most frequently injured body region followed by the extremities. Internal organ and fractures/dislocation/crush injuries were the two most common injury types; blunt force was identified as the most common injury mechanism. The primary aim of this study was to identify patterns of injury and associated injury mechanisms resulting from rotary-wing MEDEVAC mishap events to inform the design of future MEDEVAC aircraft to support injury prevention for aircrew, cabin crew, and patients.

The following conclusions are based upon the results of this study:

- Results of this study are consistent with the higher level of crashworthiness required for Army Black Hawk MEDEVAC aircraft, compared to aircraft used for civilian HEMS. The lower proportions of fatalities and serious injuries seen in Army MEDEVAC aircraft accidents compared to civilian HEMS accidents are suggestive of the benefits of the higher level of crashworthiness required for the Army MEDEVAC aircraft. Army MEDEVAC aircraft should continue to be designed to the more stringent military crashworthiness standards.
- Improved occupant restraint and delethalization of the aircraft interior have been identified as means of mitigating blunt force injuries to the extremities, thorax, and head. Future Army MEDEVAC aircraft designs should investigate improved occupant restraint systems or leverage emerging data on occupant flail to design aircraft cockpits and cabins to minimize the placement of strike hazards within the flail envelope of the occupant's head.
- To mitigate the risk of spinal fractures, aircraft should continue to be equipped with energy-absorbing seating systems, as these systems are a mechanism to reduce the frequency of vertebral body fractures. Seat designs for future Army MEDEVAC aircraft, or upgrades to legacy aircraft, should meet new medically-based performance criteria that incorporate enhanced human spinal injury risk functions.

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Introduction

Although modern military helicopters used for medical transport have been designed to maximize occupant survival, mission needs often result in medical evacuation (MEDEVAC) crews being unable to use all available safety equipment. For example, flight medics do not remain in crashworthy medical attendant seats while treating patients; flight medics fly with inadequate restraints (e.g., “monkey harness”) to allow freedom of movement when treating patients; and patient movement items and litter systems are not adequately restrained, allowing them to displace during a mishap. It is important to document any increased crash injury risk to MEDEVAC aircraft occupants to determine if further research and development is warranted to design new safety features into MEDEVAC helicopters.

Dodd (1992) found that poor medical equipment retention is a major cause of injury in civilian medical helicopter crashes. Recent U.S. Army Aeromedical Research Laboratory (USAARL) crash tests conducted in collaboration with the National Aeronautics and Space Administration (NASA) have shown that transport litters and attachments can catastrophically fail and cause additional patient injuries (Weisenbach et al., 2017). Restrictive cabin dimensions limit patient positioning and allow for minimal space for setting up equipment. The mobile environment can expose aircraft occupants to sudden movements, which can cause injury to personnel or damage to equipment (Reksorprido et al., 2019). Civilian Helicopter Emergency Medical Service (HEMS) crashes share similar characteristics with U.S. military MEDEVAC crashes: weak litters, and unrestrained patients and medical attendants. Examining civilian HEMS crashes in conjunction with U.S. military MEDEVAC crashes provides additional indications of injury risks and potential crash safety countermeasures to occupants of U.S. military MEDEVAC aircraft.

Safety in aviation is a primary concern, including those in military and civilian aeromedical programs (Dodd, 1992; Dodd, 1994; De Lorenzo, 1999; Baker et al., 2006). While injury rates have decreased significantly since Vietnam, due in part to epidemiological studies conducted over the years, there is a continued need for studies that analyze injury patterns and potential causative factors, specifically in MEDEVAC crashes. While epidemiology studies do not reduce aviation crashes or accidental injuries, they can identify patterns of injuries and mechanisms in medical transport helicopter accidents through retrospective analysis that could have implications on overall helicopter design, equipment use and placement, or procedural changes important in mitigating future injuries and fatalities. This research is essential to the Future Vertical Lift (FVL) program, as well as to current MEDEVAC operations.

Multiple factors, including engineering mitigations to reduce impact forces, retain medical equipment, and improve performance of litter pans and stanchions, are safety-critical and represent potential prevention measures for likely causes of injury or death in military and civilian helicopter crashes. This epidemiological study of injuries in mishaps identifies important countermeasures for current helicopters, and reveals possible improvements and requirements for future helicopters (e.g., FVL).

Objective

The primary aim of this study is to identify patterns of injury and associated injury mechanisms resulting from U.S. Army combat and non-combat rotary-wing MEDEVAC crashes and civilian HEMS crashes. These data will provide necessary information to inform the design of future MEDEVAC aircraft that will support injury prevention for aircrew, cabin crew, and patients.

Methods

This study was conducted under a human subjects research protocol approved by the U.S. Army Medical Research and Development Command (USAMRDC) Office of Research Protections in accordance with 32CFR219 (Protection of Human Subjects, 2013) and met all requirements to waive the need to obtain informed consent from the individuals whose injury data were included in this study.

A retrospective study of injuries occurring during accidents and combat-related incidents involving U.S. Army rotary-wing MEDEVAC aircraft and accidents involving civilian HEMS aircraft during a 16-year period (January 1, 2002 through December 31, 2018) was conducted. Data for this study were obtained from the U.S. Army Combat Readiness Center (USACRC) aviation mishap database, the Defense Casualty Information Processing System (DCIPS), and the National Transportation Safety Board (NTSB) Aviation Accident Database. The USACRC aviation mishap database provided information related to military MEDEVAC accidents; data from the DCIPS database represented military MEDEVAC combat-related incidents (CRIs). The NTSB Aviation Accident Database provided information for civilian HEMS accidents.

Injury Severity Score Assignment

Whenever possible, injury data used in this study were coded using the Association for the Advancement of Automotive Medicine's (AAAM) Abbreviated Injury Scale (AIS). As described below, a subset of injury data used in the present study had been previously coded in accordance with AIS coding rules and descriptions. For injuries that were not previously AIS-coded, an AAAM-certified AIS coding specialist reviewed available injury descriptions and coded the injuries, if injury descriptions were sufficient to do so. For injuries without adequate injury descriptions, injury location, type, severity, and mechanism were coded as Unspecified.

AIS is an anatomically-based severity scale used to classify and describe individual injuries. AIS uses a pre-dot code, six digits to the left of a decimal point, as a numerical indicator of body region and location of the injury. A post-dot code, one digit from one to six to the right of the decimal point, is used to indicate injury severity (Table 1). This system is used to classify an individual injury relative to its importance to the whole body based off on several dimensions of severity. While factors such as threat-to-life, mortality, impairment, and quality of life are dimensions of severity, they are not sole determinants. Factors such as outcome and sequela are not considered in the dimensions of severity used to classify injuries. For example, while mortality (theoretical, expected, or actual) is considered a dimension of severity, death is not an inherent part of the injury scale (e.g., a post-dot six does not mean fatal and a post-dot one does not mean non-fatal) (Table 1).

Table 1. Abbreviated Injury Score (AIS) Severity Descriptions

AIS Severity	Injury Description
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximal
9	Unknown

Within the AIS, injury is defined as an anatomic lesion caused by a transfer of energy resulting from a mechanical, chemical, or thermal source. For the purpose of this study, AIS codes were assigned using the AIS established in 2005 and updated in 2008 (Gennarelli & Wadzin, 2008). This version was chosen for continuity because this version correlates with the date of injuries contained in the dataset that were previously coded. For the purpose of this study, codes were assigned according to information contained in a de-identified dataset, not from a comprehensive study of specific medical records. Codes were assigned based on broad categories of body regions, specific anatomical location of the injury, and injury descriptors contained in the full list of included case records. Codes were assigned according to specific coder instructions outlined by the AIS, including coding conservatively. Localizers were not used for coding this dataset (Gennarelli & Wadzin, 2008).

U.S. Army Combat Readiness Center (USACRC) Aviation Mishap Database

The USACRC is responsible for archiving aviation accident reports for all Army aviation accidents. Each aviation mishap report is also encoded into the aviation mishap database; the database can be analyzed for trends in materiel failures, accident causes, training deficiencies, and occupant injuries. A memorandum of agreement established 29 August 2016 between the USACRC and the USAARL enables USAARL to access historical accident data for safety and injury trend analysis. In addition to reviewing data contained within the USACRC aviation mishap database, electronic copies of Abbreviated Aviation Accident Reports (AAARs) (Department of the Army Form 2397-AB) were accessed using the USACRC Risk Management Information System (RMIS), which provides online access to the AAARs. As the aviation mishap database is populated using data from the AAARs, these reports were reviewed to confirm data extracted from the aviation mishap database.

All U.S. Army Class A and B, rotary-wing, in-flight mishaps occurring within the study timeframe were reviewed for this study. Class A mishaps are defined by regulation as accidents resulting in 1) property damage of $2,000,000 or more; 2) the destruction, loss, or abandonment of an Army aircraft; or 3) injury and/or occupational illness that results in a fatality or permanent total disability. Class B mishaps are defined as accidents resulting in 1) a total cost of property damage greater than $500,000 but less than $2,000,000; 2) injury and/or occupational illness resulting in permanent partial disability; or 3) three or more personnel hospitalized as inpatients as the result of a single occurrence (Department of Defense [DOD], 2011). Mishaps classified as

C, D, E, and F were not considered in this study because crashes falling under these classifications do not typically involve significant injury.

Each aircraft involved in a U.S. Army aviation mishap receives a classification of either survivable, partially-survivable, or non-survivable, based on two factors: aircraft kinematics and preservation of occupiable space per Department of the Army (DA) Pamphlet (PAM) 385-40 (DA, 2015). For instance, if multiple aircraft are involved in a mishap, each mishap aircraft receives a unique survivability classification. A mishap aircraft receives a survivable classification if the aircraft impact accelerations remained within human tolerance and the occupiable space around the occupants was not compromised for all seat and litter positions. A mishap aircraft receives a partially-survivable classification if impact accelerations remain within human tolerance and occupiable space is maintained for at least one seat or litter position. If no seat or litter positions meets these two criteria, the mishap aircraft receives a non-survivable classification (DA, 2015). All mishap aircraft survivability classifications were included in this analysis. In other words, mishap cases were not down-selected or filtered out according to mishap aircraft survivability classification.

To identify U.S. Army rotary-wing MEDEVAC mishaps, the USACRC aviation mishap database was queried to identify all U.S. Army, Class A and B, rotary-wing, in-flight mishaps cases occurring within the 16-year study timeframe. This subset of rotary-wing mishaps was filtered to identify cases that were coded as having “Medical Evacuation” as a mission type. Additionally, this subset of rotary-wing mishap cases was also searched to identify potential MEDEVAC mishap cases using the keywords: medical evacuation, MEDEVAC, casualty evacuation, CASEVAC, patient, HH-60A, HH-60L, HH-60M, HH-60G, and UH-72A. All mishap cases meeting these two criteria were reviewed by the study team for inclusion. Only cases involving aircraft on a mission to transport injured personnel to medical care at the time of the mishap were included; an aircraft was considered to be on a medical transport mission if it was en route to pick up a patient, transporting a patient, or returning from delivering a patient to medical care when the mishap occurred.

All database entries related to Class A and B, in-flight, rotary-wing mishaps involving U.S. Army aircraft determined to be on a MEDEVAC missions within the 16-year study timeframe were included in the analysis. Aircraft type and occupant information, including flight role (i.e., pilot, crew chief, medical attendant, or patient), injuries, and occupant disposition (i.e., fatal, disabling injury, non-disabling injury, etc.) were included in the study dataset for analysis. Within the database, some injuries had been previously coded in accordance with AIS rules and descriptions. Any injuries not previously coded were coded by a certified as an AAAM AIS coder; injuries were coded in accordance with the AIS 2008 coding rules and descriptions. USACRC database records were anonymized; individuals involved in the aviation mishaps of interest were identified by a unique combination of the mishap case number and personnel number assigned by the USACRC.

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Defense Casualty Information Processing System (DCIPS) Database

This study investigated mishaps from 2002 to 2018, and to do so, leveraged an existing, unclassified dataset of injuries resulting from CRIs involving U.S. Army UH-60 Black Hawk helicopters for period January 1, 2002 to December 31, 2014. Previous researchers (Dudek et al., 2018) reviewed each UH-60 Black Hawk combat incident and coded each aircraft's mission. Additionally, the previous research team had coded each occupant's flight role (i.e., pilot, medical attendant, patient), injuries, and disposition (i.e., fatally injured, seriously injured, suffered minor injury, and uninjured).

Injury information contained within the dataset were originally gathered from the DCIPS database, which is maintained by the Casualty and Mortuary Affairs Operations Division of the U.S. Army Human Resources Command (USAHRC). The DCIPS database contains data on DOD military and civilian casualties, which includes circumstantial information, injury and illness descriptions, as well as information on the cause and circumstances of the death, injuries observed post mortem, location of death, status, and treatment facility.

For the present study, data from occupants of aircraft previously coded as being on a MEDEVAC mission at the time of combat damage incident were extracted from the previous dataset and included in analysis dataset. The DCIPS database was further queried to determine if additional personnel had been injured during combat-related incidents involving U.S. Army rotary-wing MEDEVAC aircraft between January 1, 2015 and December 31, 2018, but no additional MEDEVAC CRIs were identified. No identifiable information was obtained. Occupant injuries were coded in accordance with AIS 2008 coding rules and descriptions.

Combat damage incidents associated with casualty information contained within the DCIPS database were not classified based upon accident class as defined by DOD (2011). Therefore, mishaps could not be filtered to include only Class A and B mishaps (DOD, 2011). All combat damage incidents meeting the inclusion criteria were considered in the analysis.

National Transportation Safety Board (NTSB) Aviation Accident Database

The NTSB maintains an online aviation accident database containing accident data from all civilian aircraft accidents. The NTSB database is available to the public without any need for registration or explanation of how the data will be used. The online NTSB aviation accident investigation data were accessed using two online portals.

- For civilian accidents occurring before calendar year 2009, accident investigation data were queried from the Aviation Accident Database and Synopses.
- For civilian commercial transportation mishaps occurring after 2009, investigation data were queried from the Case Analysis and Reporting Online (CAROL) page (National Transportation Safety Board, 2021).

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The NTSB online accident database was queried to identify mishaps involving civilian HEMS aircraft within the 16-year study timeframe. To search for accidents and investigations occurring before 2009 the following search parameters were entered.

- Event start and end dates, respectively: January 1, 2002 and December 31, 2009
- Aircraft category: Helicopter
- Operation: Part 135: Air Taxi and Commuter
- Keywords: Emergency medical
- All other search fields were kept at their default entries.

To search for accidents occurring after 2009 using the CAROL query page, four search rules were used:

- Rule 1:
    - Field type: Event date
    - Field condition: On or after
    - Query value: January 1, 2010
- Rule 2:
    - Field type: Event date
    - Field condition: On or before
    - Query value: December 31, 2018
- Rule 3:
    - Field type: Aircraft category
    - Field condition: Is
    - Query value: Helicopter
- Rule 4:
    - Field type: Air medical
    - Field condition: Is
    - Query value: True

Case files for each mishap meeting the search criteria above were reviewed for applicability to the study. All final case reports were reviewed to confirm that the aircraft was involved in a civilian HEMS mission; an aircraft was considered to be on a HEMS mission if it was en route to pick up the patient, transporting the patient, or returning from delivering the patient to medical care when the mishap occurred. Mishaps not meeting this definition, as determined by the study team, were excluded from the analysis. HEMS mishaps were not classified based upon accident class as defined by the DOD (2011). Therefore, HEMS mishaps could not be filtered to include only Class A and B mishaps, as defined by the DOD (2011). For this analysis, all civilian HEMS mishap events meeting the inclusion criteria were considered.

Each HEMS mishap investigation case file included a final case report and supporting documentation; the amount and type of supporting documentation varied with each HEMS investigation. For some HEMS cases, detailed injury information was provided in supporting case files. When available, injury information from these files, including AIS codes, was included in the analysis dataset. For those cases without detailed injury information, final case reports were reviewed to extract aircraft type, occupant flight roles, occupant injuries, and occupant dispositions. When possible, injuries described in the final reports or other supporting documentation were coded by a certified, in-house AIS coding specialist in accordance with AIS 2008 rules and descriptions. Some injury descriptions did not provide sufficient detail to allow AIS coding; for these injuries, injury locations, severities, and types were inferred, if possible, from the description.

For some HEMS mishaps, only occupant dispositions were provided. Individuals were identified as fatally injured, seriously injured, having minor injuries, or uninjured. Individuals with dispositions other than uninjured were assumed to have at least one injury that led to the reported disposition; this injury was coded in the analysis dataset as body region "unspecified" with injury type "unspecified;" these injuries were assigned an AIS severity of 9 (i.e., unknown, see Table 1). The NTSB aviation mishap database contained publicly available, identifiable data within the case files. None of the identifiable information was recorded or used by the study team; individual occupants were identified in the study dataset by a unique identifier, and no key was created to link identifiable information to the unique identifier.

Data Standardization

Data from each Army MEDEVAC accident, Army MEDEVAC combat-related incident, and civilian HEMS accident were examined to extract the following information:

- Number and type of aircraft involved in each crash event
- Number of occupants in the aircraft involved in each crash event
- Number of occupants injured in each crash event
- Flight role of each occupant
- Injury data for each injured individual
    - Injury location (body region)
    - Injury type (e.g., laceration, concussion, fracture)
    - Injury severity
    - Occupant disposition

Throughout the three databases, occupant flight roles were coded in multiple ways. To provide consistency, the multiple flight roles provided in the three databases were grouped into four major flight roles: pilot, crew, patient, and unknown. Table 2 summarizes the different flight role descriptions from each database that were grouped under each major role. Crewmembers and pilots were combined into a single overarching flight role, as both groups were occupants of the aircraft cabin. Patients were kept apart from other aircraft cabin occupants to allow them to be examined separately.

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Table 2. Flight Roles Associated with Aircraft Fuselage Section by Database

Flight Role Category	**Flight Role Description by Database**		
	USACRC (MEDEVAC Accidents)	**DCIPS (MEDEVAC CRIs)**	**NTSB (HEMS Accidents)**
Pilot	Pilot Pilot in Command	Pilot	Pilot
Crew/ Passenger	Passenger Combat Equipped Troop/Jumper Crew Chief/Flight Engineer Flight Surgeon/Medical Attendant Flight Engineer Instructor Gunner	Passenger Crew Flight surgeon Medic, NFS* MEDEVAC Crew, Flight Nurse	Passenger Crewmember, NFS* Crewmember, Medical flight Crewmember, Medical Medic, NFS* Medic, Flight Nurse, NFS* Nurse, Flight Nurse, Specialty Paramedic, NFS* Paramedic, Flight Mechanic Passenger
Patient	N/R†	Patient	Patient
Unknown	UFR**	UFR**	UFR**

*NFS = Not Further Specified; ** UFR = Unknown Flight Role; † N/R = Not Reported

Detailed injury information was not available for all occupants involved in the rotary-wing medical evacuation events included in this analysis. However, occupant dispositions were more consistently reported across the three independent datasets. For the MEDEVAC accident dataset, occupant disposition was coded categorically in terms related to return to duty (e.g., permanent disability, restricted workday, lost workday). For HEMS accidents, occupant dispositions were coded as fatal, severe, minor, and uninjured, based upon each occupant's highest severity injury. For MEDEVAC CRIs, occupant dispositions were coded as killed in action (KIA) or wounded in action (WIA).

To allow occupant disposition to be considered in this analysis, occupants were grouped into four general occupant disposition categories of fatal, serious, minor, and uninjured. For MEDEVAC CRIs, occupants listed as WIA were assigned dispositions by the study team based on the occupant's highest AIS severity. Table 3 shows which individual dispositions from each dataset were grouped into the four general disposition categories used in this study.

Table 3. Database-Coded Occupant Dispositions Mapped to General Occupant Disposition Categories Used in This Study

Disposition Categories	Disposition Description by Database		
	USACRC (MEDEVAC Accidents)	**DCIPS (MEDEVAC CRIs)**	**NTSB (HEMS Accidents)**
Fatal	Fatal	KIA	Fatal
Serious	Permanent total disability Permanent partial disability	AIS 3 or greater injury severity	Serious
Minor	Workday of restricted activity Lost workday Medical treatment beyond first aid	AIS 1 or 2 injury severity	Minor
Uninjured	No injuries reported	No injuries reported	No injuries reported

Occupant injuries were broken down by body region affected, injury type, and injury severity. Whenever possible, occupant injuries not previously coded in accordance with AIS 2008 rules and descriptions were AIS-coded by the AIS coding specialist on the study team. AIS codes were used to assign occupant injuries into the nine AIS body regions. Injury descriptions and AIS codes, if available, were used to determine injury types. For injuries that could not be coded in accordance with AIS 2008, or for which descriptions were insufficient for identifying injury location or severity, the injury was coded in the analysis dataset as body region "unspecified" with injury type "unspecified;" these injuries were assigned an AIS severity of 9 (unknown) (Table 1). Injury types were aggregated into a smaller number of overarching groups for simplification of presentation (Table 4).

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Table 4. Individual Injuries Included in Each Overall Injury Type

Overall Injury Type	Individual Injury Types
Amputation	Traumatic loss of a limb
Fracture/dislocation/crush	Fractures, fracture/dislocations, fracture with spinal cord involvement (SCI), decapitation, and crush
Internal organs	Brain injury including brain avulsion, concussion, contusion, laceration, and traumatic brain injury (TBI)
	Internal organ injuries including contusions and lacerations
	Blood vessel injuries including hemorrhage and transections
	Inhalation and drowning injuries due to the effects on the trachea and lungs
Burns	Thermal injures resulting from exposure to excessive heat or flame or caustic chemicals
Strain/sprains	Severe or excessive pulls on muscle tissue; wrench or twist of ligaments.
Open wounds/superficial	Abrasions, contusions, lacerations to skin and muscle tissue
	Penetrating and puncture wounds
Unspecified	Mishap documentation suggests that injuries occurred; however, no injuries were documented or coded
None	Mishap documentations indicates that the individual did not suffer any injuries

Data Analysis

For the Army MEDEVAC CRIs, the number of aircraft involved in combat-related events was known. For the incidents involving injury, the number of injured and uninjured personnel onboard the aircraft was known. For incidents that did not involve injuries, the total number of persons onboard the aircraft was not explicitly known; however, all Army aircraft involved in MEDEVAC CRIs within the study timeframe were variants of the UH-60 Black Hawk. The Black Hawk typically flies with two pilots and two crewmembers. This typical crew compliment was used to estimate the number of uninjured personnel aboard these aircraft. The estimated numbers of uninjured pilots and crewmembers from MEDEVAC CRIs are included in the occupant frequencies (counts) presented in this study.

Data from each Army MEDEVAC accident and CRI and civilian HEMS accident meeting study inclusion criteria were entered into a combined study dataset. The study dataset contained information on occupant injury status (i.e., injured or uninjured), injury descriptions to include body region injured, injury type, and AIS injury severity, occupant flight role, and occupant disposition. Insufficient data were available on the number of hours flown by all Army MEDEVAC and civilian HEMS aircraft within the study timeframe. Therefore, accident and injury rates could not be calculated as a function of total flight hours.

Sufficient data was available to calculate descriptive statistics for the study dataset. Frequency (counts) of total occupants, injured occupants, and uninjured occupants were calculated for each group. The proportions of injured and uninjured occupants were calculated relative to the total number of occupants within each rotary-wing medical evacuation event group (i.e., MEDEVAC accidents, MEDEVAC CRIs, and HEMS accidents). Group-level frequencies were totaled to provide an overall look at the proportions of injured and uninjured occupants across all rotary-wing medical evacuation events. Similarly, the frequency (counts) of injured and uninjured occupants within each flight role (Table 2) were calculated for each group and the combined dataset. The proportion of injured occupants within each flight role were computed based upon the total number of injured occupants within each group.

Occupant disposition (Table 3) was commonly reported for occupants of aircraft involved in Army MEDEVAC accidents, Army MEDEVAC CRIs, and civilian HEMS accidents. Frequency (counts) of occupants fatally injured, seriously injured, suffering minor injury, and sustaining no injuries (uninjured) were calculated and used to calculate the proportions of total personnel exposed within the three medical evacuation mishap groups and the dataset as a whole.

Frequency (counts) of injuries, injury type, and injury severity were calculated for each AIS body region and rotary-wing medical evacuation event group. The frequency of injury in each AIS body region was calculated for each rotary-wing medical evacuation event group; these frequencies were used to calculate the proportion of the total injuries occurring within each body region. The frequency of each injury type (Table 4) within an AIS body region was calculated and expressed as a proportion of the total number of injuries within a body region. Similarly, the frequency of each AIS injury severity (Table 1) within a body region was calculated and expressed as a proportion of the total number of injuries within a body region. Group-level frequencies were totaled to provide an overall look at the proportions of injuries by AIS body region, injury type, and AIS injury severity for the entire dataset.

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Results

Summary Data

Table 5 shows the number of Army MEDEVAC accidents, Army MEDEVAC CRIs, and civilian HEMS accidents. Within each group, the total number of aircraft involved are presented, as are the numbers of occupants of those aircraft. Occupants are further grouped into injured and uninjured categories. Total injuries experienced by occupants are presented for each group.

Nine (9) of 19 injured occupants were occupants of a single MEDEVAC CRI aircraft. These occupants were involved in the only MEDEVAC CRI within the study timeframe that resulted in an aircraft crash. The remaining injured personnel were occupants of MEDEVAC aircraft that were involved in CRIs that did not result in an aircraft crash.

Table 5. Overall Number of Events, Aircraft, and Occupants

	MEDEVAC Accidents		MEDEVAC CRIs		HEMS Accidents		All Events
	Freq.	Prop. (%)	Freq.	Prop. (%)	Freq.	Prop. (%)	
Total Events	12	7	98	53	74	40	184
Total Aircraft	12	7	98	53	74	40	184
Events/Aircraft with Injuries	8	13	9	14	46	73	63
Events/Aircraft without Injuries	4	3	89	74	28	23	121
Total Occupants	55	8	418	58	244	34	717
Injured	31	16	19	10	146	74	196
Uninjured	24	5	399	77	98	19	521
Total Injuries	64	12	270	49	213	39	547

Note. Proportions were calculated based on all events within each group.

The proportions of injured and uninjured occupants within the three medical evacuation incident groups are presented in Figure 1. Figure 1 also shows the proportions of injured and uninjured occupants for all rotary-wing medical evacuation events combined. Overall, 73 percent (%) (521/717) of rotary-wing medical evacuation event occupants were uninjured. When considered separately, MEDEVAC accidents and CRIs had the highest proportions of uninjured occupants at 44% (24/55) and 95% (399/418), respectively.

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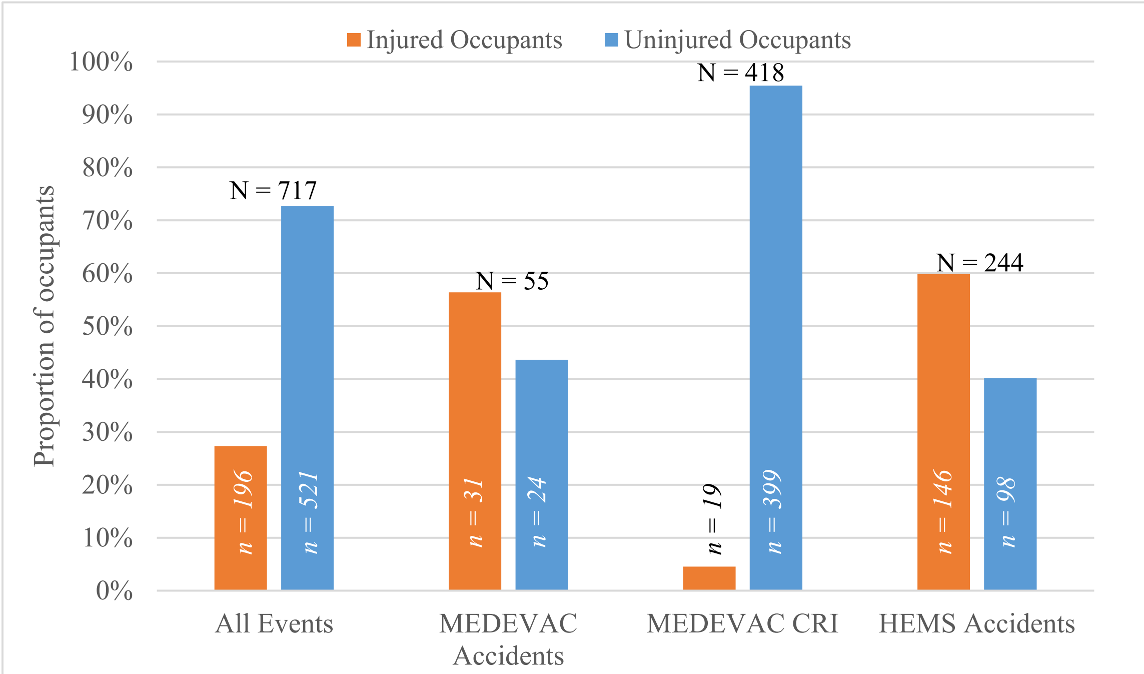

Figure 1. Proportion of injured and uninjured occupants involved in rotary-wing medical evacuation events. Data are presented for all groups combined, and each group individually. Proportions are expressed relative to the total number of occupants within each group.

Very few occupants were coded as being patients on board the rotary-wing medical evacuation aircraft considered in this study. Approximately 3% (22/717) of all occupants were coded as patients (Table 6). Thirteen (13) injured patients were occupants of HEMS accident aircraft. Detailed injury information for these 13 individuals was not available in the NTSB database; disposition information indicated that one patient received minor injuries, while the remaining 12 were fatally injured. The one patient involved in a MEDEVAC CRI (Table 6) was noted as being previously injured and receiving a minor injury because of the MEDEVAC CRI.

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Table 6. Injured and Uninjured Occupants by Flight Role and Rotary-Wing Medical Evacuation Event Group

	MEDEVAC Accidents		MEDEVAC CRIs		HEMS Accidents		All Events
	Freq.	Prop. (%)	Freq.	Prop. (%)	Freq.	Prop. (%)	
Total Pilots	24	8	196	67	74	25	294
Injured	14	22	5	8	46	71	65
Uninjured	10	4	191	83	28	12	229
Total Crew/Passenger	31	9	190	55	127	36	348
Injured	17	15	12	11	84	74	113
Uninjured	14	6	178	76	43	18	235
Total Patients	0	0	1	5	21	95	22
Injured	0	0	1	7	13	93	14
Uninjured	0	0	0	0	8	100	8
Unknown	0	0	31	58	22	42	53
Injured	0	0	1	25	3	75	4
Uninjured	0	0	30	61	19	39	49
Total Occupants	55	8	418	58	244	34	717
Injured	31	16	19	10	146	74	196
Uninjured	24	5	399	77	98	19	521

Overall, pilots accounted for 33% (65/196) of injured occupants (Figure 2). Within the individual medical evacuation incident groups, the MEDEVAC accident group had the largest proportion of injured occupants that were pilots (45%, [14/31]) (Figure 2). Within the HEMS accident group, the number of total pilots (74) (Table 6) equaled the number of aircraft involved in HEMS accidents (Table 5) indicating HEMS missions are typically flown with a single pilot. Crewmembers and passengers accounted for the largest proportion of injured occupants within each rotary-wing medical evacuation event group (Figure 2). Patients accounted for the lowest proportions of injured occupants with a known flight role within each rotary-wing medical evacuation event group (Figure 2).

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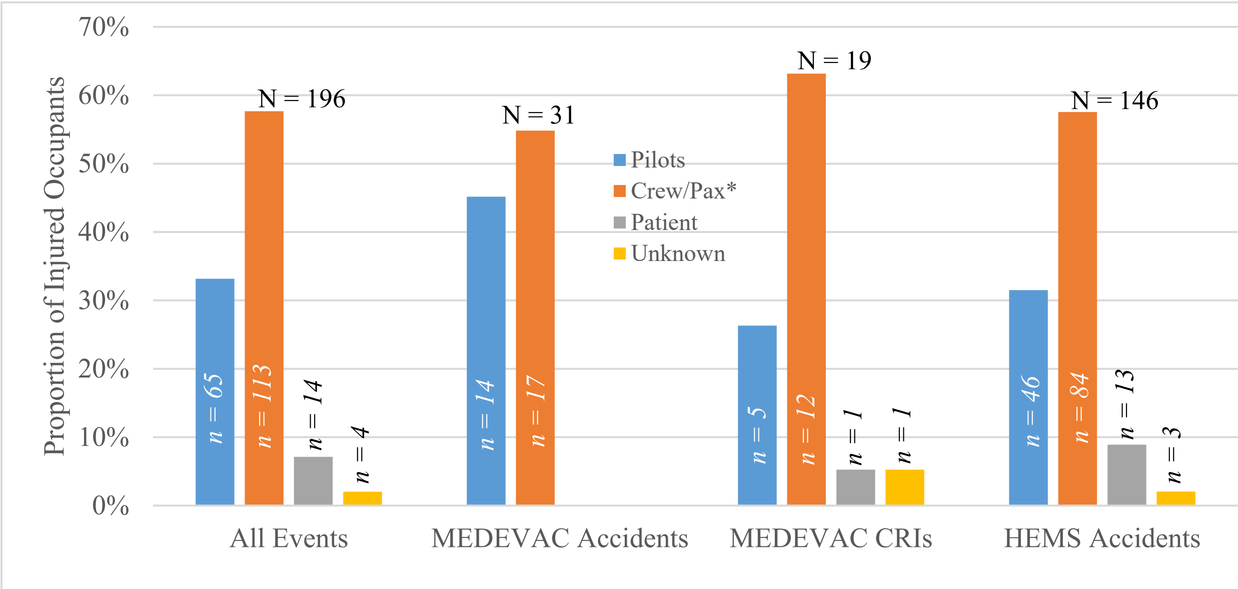

Figure 2. Proportion of injured occupants by flight role and rotary-wing medical evacuation event group. Proportions are expressed relative to the number of injured occupants within each group. *Pax = Passenger.

Detailed injury information was not available for all occupants involved in the rotary-wing medical evacuation events included in this analysis. However, occupant dispositions were more consistently reported for each occupant across all groups. Table 7 details the frequency of occupants fatally injured, seriously injured, suffering minor injuries, and uninjured for each rotary-wing medical evacuation event group and for the combined dataset; these data are represented graphically in Figure 3. Across all groups, 101 occupants were fatally injured with 81 fatal injuries occurring during HEMS accidents; HEMS accidents accounted for 32 of 38 seriously injured occupants and 33 of 57 occupants receiving minor injuries (Table 7).

Table 7. Frequency of Occupant Dispositions

Occupant Disposition	**MEDEVAC Accidents**		**MEDEVAC CRIs**		**HEMS Accidents**		**All Events**	
	Freq.	Prop. (%)	Freq.	Prop. (%)	Freq.	Prop. (%)	Freq.	Prop. (%)
Fatal	11	20	9	2	81	33	101	14
Serious	5	9	1	0	32	13	38	5
Minor	15	27	9	2	33	14	57	8
Uninjured	24	44	399	95	98	40	521	73
Total Occupants	55		418		244		717	

Note. Proportions were calculated based on total occupants within each group.

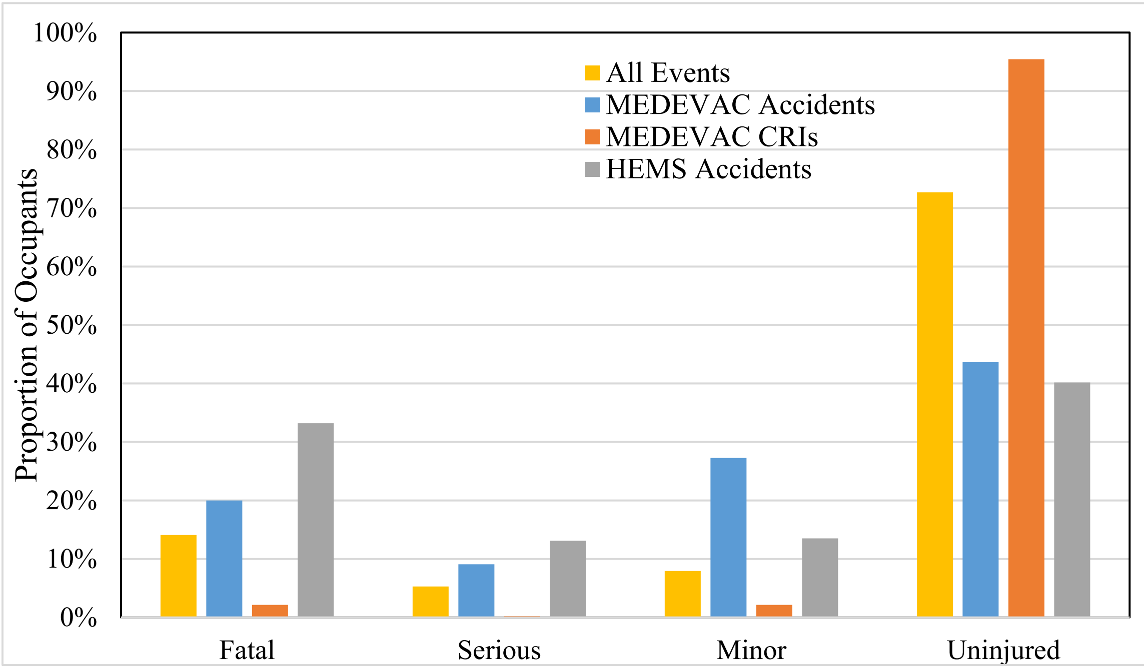

Figure 3. Proportion of occupants by disposition category. Data are presented for all groups combined and for each group individually. Proportions are expressed relative to the total number of occupants exposed to rotary-wing medical evacuation events within each group.

Injury Analysis

Nearly one-quarter (23%, [15/64]) of injuries incurred by occupants of MEDEVAC accident aircraft and 57% (122/213) of injuries to occupants of HEMS accident aircraft were not sufficiently described to allow injuries to be assigned to an AIS body region (Table 8). Overall, 26% injuries included in the study dataset could not be assigned to a specific AIS body region (Table 8). Injury frequencies in individual AIS body regions within these two groups may have been higher than the frequencies shown in Table 8. Figure 4 compares the proportion of total injuries sustained within each medical evacuation event group associated with each AIS body region.

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Table 8. Frequency of Injuries within Each Body Region by Rotary-Wing Medical Evacuation Event Group

Body Region	**MEDEVAC Accidents**		**MEDEVAC CRIs**		**HEMS Accidents**		**All Events**	
	Freq.	Prop. (%)	Freq.	Prop. (%)	Freq.	Prop. (%)	Freq.	Prop. (%)
Head	5	8	32	12	9	4	46	8
Face	5	8	15	6	3	1	23	4
Neck	4	6	7	3	1	0	12	2
Thorax	4	6	72	27	18	8	94	17
Abdomen	2	3	45	17	5	2	52	10
Spine	9	14	21	8	24	11	54	10
Upper Extremity	8	13	29	11	7	3	44	8
Lower Extremity	10	16	34	13	18	8	62	11
Whole-Body	2	3	12	4	6	3	20	4
Unspecified	15	23	3	1	122	57	140	26
Total Injuries	64		270		213		547	

Note (1). Proportions were calculated based on total number of injuries occuring within each group.
Note (2). A single occupant could have multiple injuries per body region.

Overall, injuries to the core of the body (thorax and abdomen combined) accounted for the highest proportion (27%, [146/547]) (Table 8) of total injuries. This proportion is due largely to the high proportions of thoracic (27%) and abdominal (17%) injuries reported the MEDEVAC CRIs. Collectively, the injuries to the extremities represented 19% (106/547) of the total injuries included in the dataset (Table 8). Twenty-nine (29) percent of injuries in MEDEVAC accidents and 24% of injuries in MEDEVAC CRIs were to the extremities (upper and lower extremities combined). Spinal injuries accounted for 10% of the total injuries within the study dataset (Table 8). Spinal injuries occurred in relatively similar proportions across the three rotary-wing medical evacuation event groups, accounting for 14% of total injuries in MEDEVAC accidents, 8% of total injuries in MEDEVAC CRIs, and 11% of total injuries in HEMS accidents. Injuries to the head also accounted for 8% of total injuries contained within the dataset (Table 8) with the largest individual group proportions occurring in MEDEVAC accidents and CRIs at 8% and 12%, respectively.

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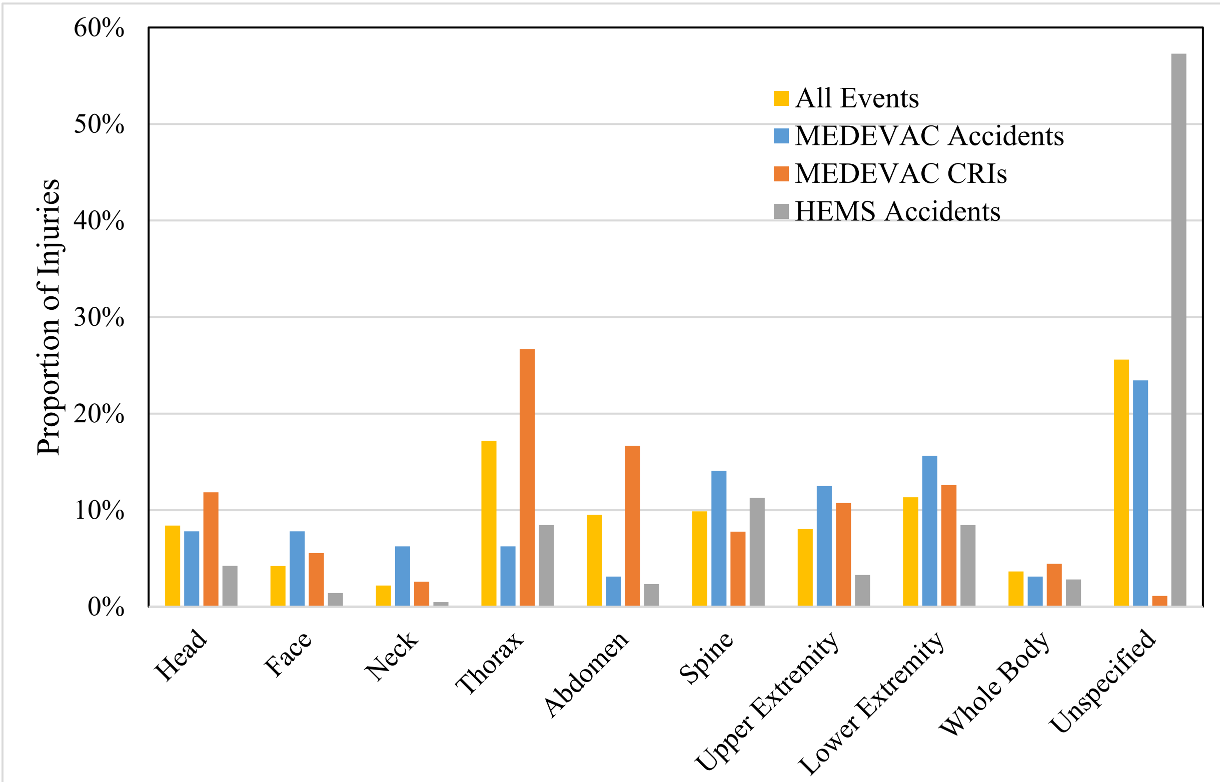

Figure 4. Proportion of total injuries by body region and rotary-wing medical evacuation event group. Proportions are expressed relative to the total number of injuries experienced by occupants of each rotary-wing medical evacuation event group. A single occupant could have multiple injuries per body region.

Injuries to the core of the body (thorax and abdomen combined) were primarily internal organ and fracture/dislocation/crush injuries (Figure 5). These two injury types accounted for 93% (136/146) of total thoracic and abdominal injuries contained in the study dataset (Table 9). Thoracic and abdominal injury severities ranged from AIS 1 to AIS 6 (Figure 6). The proportion of total thoracic and abdominal injuries (Table 10), as well as examples of injuries, associated with each AIS severity level are below:

- AIS 1 (10%): Contusions, abrasion, and hemorrhages;
- AIS 2 (18%): Lacerations of the liver, transection of the intercostal arteries, collapsed lungs, and sternal fractures;
- AIS 3 (36%): Lung aspiration, hemothoraces (not further specified [NFS]), and lung, splenic, liver, and kidney lacerations;
- AIS 4 (12%): Severe liver and kidney lacerations, hemothoraces with greater than one liter of blood loss on at least one side, and transections of the Vena Cava and Iliac artery;
- AIS 5 and AIS 6 (22% for both severities combined): Bilateral lung lacerations, bilateral flail chest, bilateral pulmonary artery transections, aortic transection, splenic avulsions, lacerations of the heart, and lung injuries resulting from drowning.

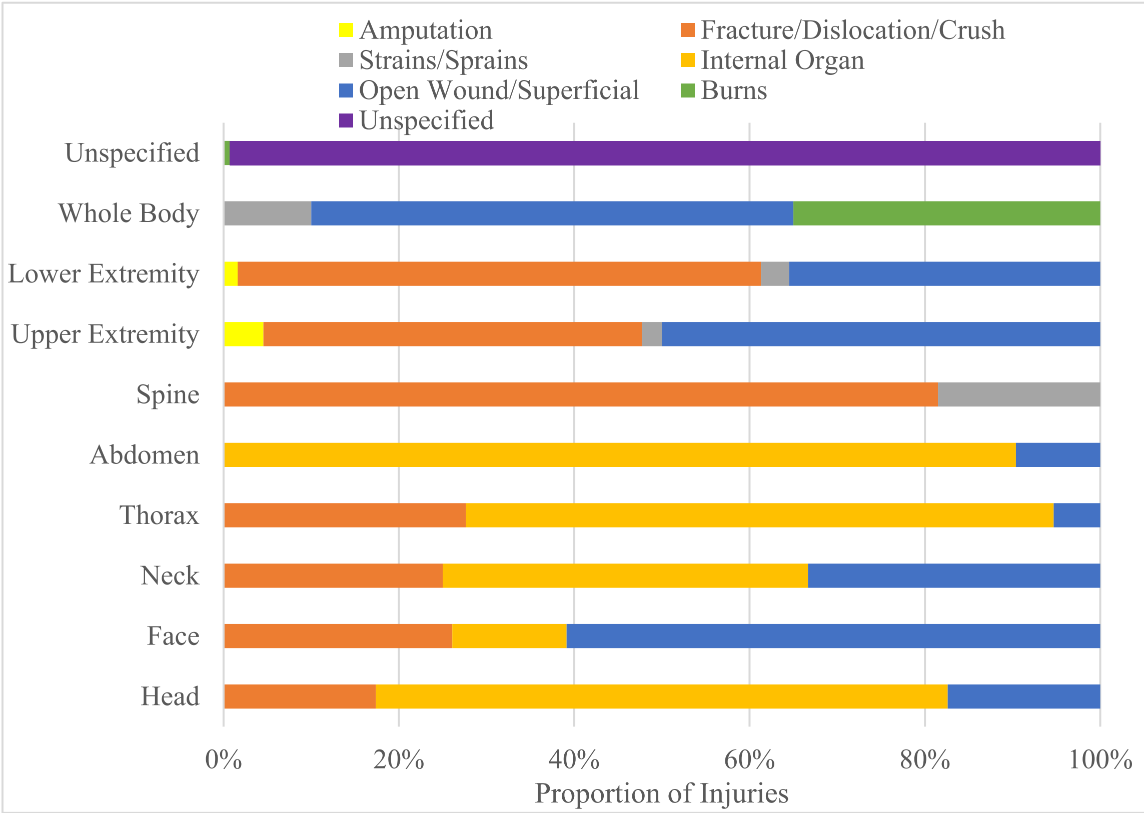

Figure 5. Injury type by body region for all events. Proportions are relative to total injuries within a body region.

Injuries to the extremities (upper and lower extremities combined) were primarily fracture/dislocation/crush type injuries and open wounds/superficial injuries (Figure 5). These two injury types accounted for 94% (100/106) of total extremity injuries contained in the study dataset (Table 9). A small proportion of total extremities injuries also included amputations and strains/sprains (Figure 5). Extremity injury severities ranged from AIS 1 to AIS 4 (Figure 6). The proportion of total extremity injuries (Table 10), as well as examples of injuries, associated with each AIS severity level are below:

- AIS 1 (42%): Strains, sprains, contusions, lacerations, and punctures;
- AIS 2 (29%): Fractures/dislocations of the lower legs (tibia and fibula) and wrist, clavicle, coccyx and pelvic girdle fractures;
- AIS 3 (8%): Fractures of the humerus and femur at various locations along the bones;
- AIS 4 (8%): Traumatic amputations above the elbow and pelvic ring fracture with disruption of pelvic floor and posterior arch;
- AIS 5 (0%): No reported injuries of this severity; and
- AIS 6 (0%): No reported injuries of this severity.

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Table 9. Frequency of Injury Type by Body Region and Rotary-Wing Medical Evacuation Event Group

	Body Region	**Amputation**		**Fx/Disloc/ Crush***		**Strain/ Sprain**		**Internal Organ**		**Open Wound/ Superficial**		**Burns**		**Unspecified**		**Total Injuries by Region**
		Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	
All Events	Head	0	0	8	17	0	0	30	65	8	17	0	0	0	0	46
	Face	0	0	6	26	0	0	3	13	14	61	0	0	0	0	23
	Neck	0	0	3	25	0	0	5	42	4	33	0	0	0	0	12
	Thorax	0	0	26	28	0	0	63	67	5	5	0	0	0	0	94
	Abdomen	0	0	0	0	0	0	47	90	5	10	0	0	0	0	52
	Spine	0	0	44	81	10	19	0	0	0	0	0	0	0	0	54
	Upper Extremity	2	5	19	43	1	2	0	0	22	50	0	0	0	0	44
	Lower Extremity	1	2	37	60	2	3	0	0	22	35	0	0	0	0	62
	Whole Body	0	0	0	0	2	10	0	0	11	55	7	35	0	0	20
	Unspecified	0	0	0	0	0	0	0	0	0	0	1	1	139	99	140
	Total by Injury Type	3	1	143	26	15	3	148	27	91	17	8	1	139	25	547
MEDEVAC Accidents	Head	0	0	1	20	0	0	4	80	0	0	0	0	0	0	5
	Face	0	0	0	0	0	0	0	0	5	100	0	0	0	0	5
	Neck	0	0	2	50	0	0	1	25	1	25	0	0	0	0	4
	Thorax	0	0	1	25	0	0	2	50	1	25	0	0	0	0	4
	Abdomen	0	0	0	0	0	0	2	100	0	0	0	0	0	0	2
	Spine	0	0	1	11	8	89	0	0	0	0	0	0	0	0	9
	Upper Extremity	0	0	1	13	0	0	0	0	7	88	0	0	0	0	8
	Lower Extremity	0	0	2	20	1	10	0	0	7	70	0	0	0	0	10
	Whole Body	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	Unspecified	0	0	0	0	0	0	0	0	0	0	0	0	15	100	15
	Total by Injury Type	0	0	8	13	11	17	9	14	21	13	0	0	15	23	64

Table 9. Frequency of Injury Type by Body Region and Rotary-Wing Medical Evacuation Event Group, Continued

	Body Region	Amputation		Fx/Disloc/ Crush*		Strain/ Sprain		Internal Organ		Open Wound/ Superficial		Burns		Unspecified		Total Injuries by Region
		Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	
MEDEVAC CRIs	Head	0	0	5	16	0	0	23	72	4	13	0	0	0	0	32
	Face	0	0	6	40	0	0	3	20	6	40	0	0	0	0	15
	Neck	0	0	0	0	0	0	4	57	3	43	0	0	0	0	7
	Thorax	0	0	18	25	0	0	51	71	3	4	0	0	0	0	72
	Abdomen	0	0	0	0	0	0	41	91	4	9	0	0	0	0	45
	Spine	0	0	21	100	0	0	0	0	0	0	0	0	0	0	21
	Upper Extremity	2	7	14	48	0	0	0	0	13	45	0	0	0	0	29
	Lower Extremity	0	0	24	71	0	0	0	0	10	29	0	0	0	0	34
	Whole Body	0	0	0	0	0	0	0	0	10	83	2	17	0	0	12
	Unspecified	0	0	0	0	0	0	0	0	0	0	0	0	3	100	3
	Total by Injury Type	2	1	88	33	0	0	122	45	53	20	2	1	3	1	270
HEMS Accidents	Head	0	0	2	22	0	0	3	33	4	44	0	0	0	0	9
	Face	0	0	0	0	0	0	0	0	3	100	0	0	0	0	3
	Neck	0	0	1	100	0	0	0	0	0	0	0	0	0	0	1
	Thorax	0	0	7	39	0	0	10	56	1	6	0	0	0	0	18
	Abdomen	0	0	0	0	0	0	4	80	1	20	0	0	0	0	5
	Spine	0	0	22	92	2	8	0	0	0	0	0	0	0	0	24
	Upper Extremity	0	0	4	57	1	14	0	0	2	29	0	0	0	0	7
	Lower Extremity	1	6	11	61	1	6	0	0	5	28	0	0	0	0	18
	Whole Body	0	0	0	0	0	0	0	0	1	17	5	83	0	0	6
	Unspecified	0	0	0	0	0	0	0	0	0	0	1	1	121	99	122
	Total by Injury Type	1	0	47	22	4	2	17	8	17	8	6	3	121	57	213

Note (1). Proportions were calculated based on total number of injuries occurring within body region.
Note (2). A single occupant could have multiple injuries per body region.
*Fx/Disl/Crush = Fracture/Dislocation/Crush as shown in Table 4.

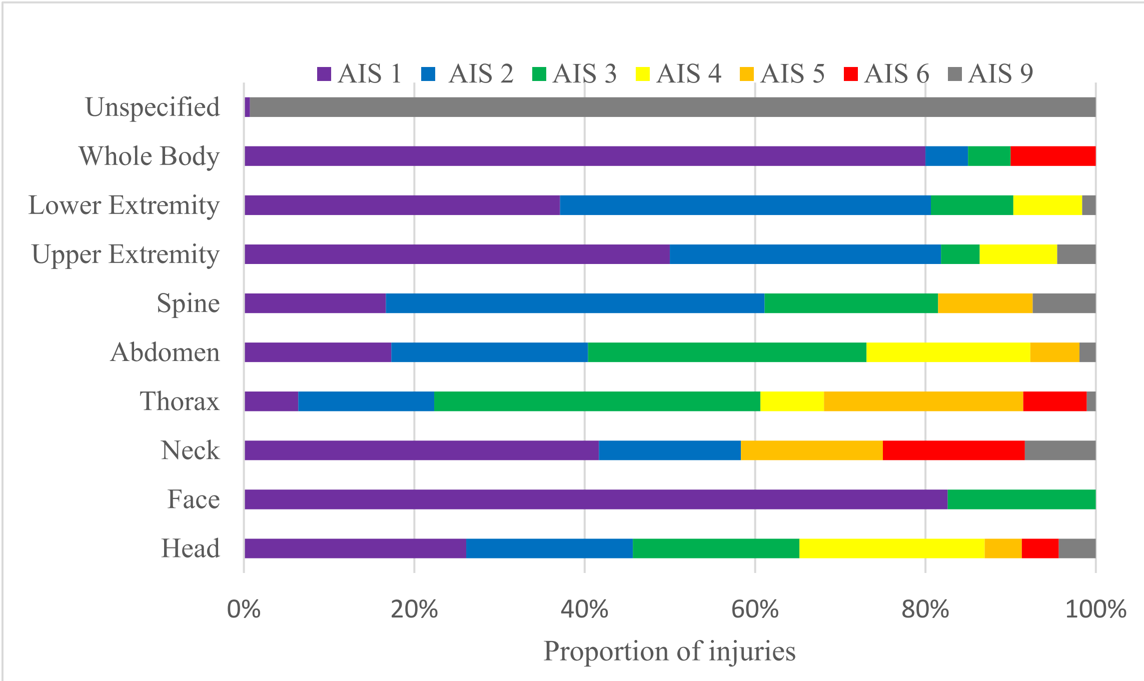

Figure 6. Injury severity by body region for all events. Proportions are relative to total injuries within a body region.

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Table 10. Frequency of AIS Severity by Body Region and Rotary-Wing Medical Evacuation Event Group

	Body Region	**AIS 1** Freq	**AIS 1** Prop (%)	**AIS 2** Freq	**AIS 2** Prop (%)	**AIS 3** Freq	**AIS 3** Prop (%)	**AIS 4** Freq	**AIS 4** Prop (%)	**AIS 5** Freq	**AIS 5** Prop (%)	**AIS 6** Freq	**AIS 6** Prop (%)	**AIS 9** Freq	**AIS 9** Prop (%)	**Total Injuries per Region**
All Events	Head	12	26	9	20	9	20	10	22	2	4	2	4	2	4	46
	Face	19	83	0	0	4	17	0	0	0	0	0	0	0	0	23
	Neck	5	42	2	17	0	0	0	0	2	17	2	17	1	8	12
	Thorax	6	6	15	16	36	38	7	7	22	23	7	7	1	1	94
	Abdomen	9	17	12	23	17	33	10	19	3	6	0	0	1	2	52
	Spine	9	17	24	44	11	20	0	0	6	11	0	0	4	7	54
	Upper Extremity	22	50	14	32	2	5	4	9	0	0	0	0	2	5	44
	Lower Extremity	23	37	27	44	6	10	5	8	0	0	0	0	1	2	62
	Whole Body	16	80	1	5	1	5	0	0	0	0	2	10	0	0	20
	Unspecified	1	1	0	0	0	0	0	0	0	0	0	0	139	99	140
	Total by Injury Type	122	22	104	19	86	16	36	7	35	6	13	2	151	28	547
MEDEVAC Accidents	Head	3	60	0	0	2	40	0	0	0	0	0	0	0	0	5
	Face	5	100	0	0	0	0	0	0	0	0	0	0	0	0	5
	Neck	1	25	0	0	0	0	0	0	0	0	2	50	1	25	4
	Thorax	1	25	0	0	2	50	0	0	0	0	1	25	0	0	4
	Abdomen	0	0	1	50	0	0	0	0	0	0	0	0	1	50	2
	Spine	8	89	1	11	0	0	0	0	0	0	0	0	0	0	9
	Upper Extremity	7	88	0	0	1	13	0	0	0	0	0	0	0	0	8
	Lower Extremity	8	80	1	10	1	10	0	0	0	0	0	0	0	0	10
	Whole Body	2	100	0	0	0	0	0	0	0	0	0	0	0	0	2
	Unspecified	0	0	0	0	0	0	0	0	0	0	0	0	15	100	15
	Total by Injury Type	35	55	3	5	6	9	0	0	0	0	3	5	17	27	64

Table 10. Frequency of AIS Severity by Body Region and Rotary-Wing Medical Evacuation Event Group, Continued

	Body Region	**AIS 1**		**AIS 2**		**AIS 3**		**AIS 4**		**AIS 5**		**AIS 6**		**AIS 9**		**Total Injuries per Region**
		Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	
MEDEVAC CRIs	Head	4	13	7	22	6	19	10	31	2	6	2	6	1	3	32
	Face	11	73	0	0	4	27	0	0	0	0	0	0	0	0	15
	Neck	4	57	1	14	0	0	0	0	2	29	0	0	0	0	7
	Thorax	3	4	11	15	25	35	7	10	20	28	5	7	1	1	72
	Abdomen	8	18	9	20	15	33	10	22	3	7	0	0	0	0	45
	Spine	0	0	9	43	6	29	0	0	6	29	0	0	0	0	21
	Upper Extremity	13	45	10	34	1	3	4	14	0	0	0	0	1	3	29
	Lower Extremity	9	26	16	47	3	9	5	15	0	0	0	0	1	3	34
	Whole Body	11	92	0	0	1	8	0	0	0	0	0	0	0	0	12
	Unspecified	0	0	0	0	0	0	0	0	0	0	0	0	3	100	3
	Total by Injury Type	63	23	63	23	61	23	36	13	33	12	7	3	7	3	270
HEMS Accidents	Head	5	56	2	22	1	11	0	0	0	0	0	0	1	11	9
	Face	3	100	0	0	0	0	0	0	0	0	0	0	0	0	3
	Neck	0	0	1	100	0	0	0	0	0	0	0	0	0	0	1
	Thorax	2	11	4	22	9	50	0	0	2	11	1	6	0	0	18
	Abdomen	1	20	2	40	2	40	0	0	0	0	0	0	0	0	5
	Spine	1	4	14	58	5	21	0	0	0	0	0	0	4	17	24
	Upper Extremity	2	29	4	57	0	0	0	0	0	0	0	0	1	14	7
	Lower Extremity	6	33	10	56	2	11	0	0	0	0	0	0	0	0	18
	Whole Body	3	50	1	17	0	0	0	0	0	0	2	33	0	0	6
	Unspecified	1	1	0	0	0	0	0	0	0	0	0	0	121	99	122
	Total by Injury Type	24	11	38	18	19	9	0	0	2	1	3	1	127	60	213

Note (1). Proportions were calculated based on total number of injuries occuring within each body region.
Note (2). A single occupant could have multiple injuries per body region.

Strains/sprains and fracture/dislocation/crush type injuries were the two injury types associated with spinal injuries (Figure 5). Fracture/dislocation/crush injuries made up the largest proportion of spinal injuries contained in the study dataset (Figure 5), accounting for 81% of total spinal injuries (Table 9). Strains/sprains accounted for 19% spinal injuries (Table 9). Spinal injury severities included AIS 1 through AIS 3 and AIS 5 (Figure 6). The proportion of total spinal injuries (Table 10), as well as examples of injuries, associated with each AIS severity level are below:

- AIS 1 (17%): Cervical and thoracic muscle strains and sprains;
- AIS 2 (44%): Transverse process fractures of various vertebral bodies and vertebral body fractures NFS;
- AIS 3 (20%): Burst fractures in the thoracolumbar spine, intervertebral disc ruptures, contusions of the spinal cord and cauda equina, and atlanto-axial dislocation without fracture;
- AIS 4 (0%): No reported injuries of this severity;
- AIS 5 (11%): Spinal cord lacerations in the presence of fractures and dislocation; all AIS 5 spinal injuries were associated with MEDEVAC CRIs (Table 11); and
- AIS 6 (0%): No reported injuries of this severity.

Head injuries included injuries to internal organs, open wounds/superficial injuries, and fracture/dislocation/crush injuries (Figure 5). Internal organ injuries accounted for 65% of total head injuries, while fracture/dislocation/crush injuries and open wounds/superficial injuries each accounted for 17% of total head injuries (Table 9). Head injury severities included AIS 1 through AIS 6 (Figure 6). The proportion of total head injuries (Table 10), as well as examples of injuries, associated with each AIS severity level are below:

- AIS 1 (26%): Superficial lacerations and contusions and diagnosed concussions;
- AIS 2 (20%): Hemorrhage in various regions of the brain, concussion with brief loss of consciousness, and simple vault fractures;
- AIS 3 (20%): Contusions of the cerebrum NFS, subdural hematomas, fractures of the base of the skull;
- AIS 4 (22%): Brain lacerations, bilateral subdural hematomas, complex basilar skull fractures, and massive vault fracture;
- AIS 5 (4%): Contusions of the brain stem NFS; and
- AIS 6 (4%): Lacerations of the brain stem NFS.

The largest proportions of specified injuries in the study data set were fracture/dislocation/crush injuries, open wounds/superficial injuries, and internal organ injuries (Figure 5 and Table 9). Burns made up 1% of total injuries but accounted for 35% of injuries to the whole body (Table 9). Burns occurred most frequently in the HEMS accidents, accounting for 83% of injuries to the whole-body (Table 9) occurring within that group.

Injuries with severities of AIS 1 through AIS 3 occurred most often within all rotary-wing medical evacuation events (Figure 6). AIS 1 injuries accounted for 22% of total injuries, and AIS 2 and 3 injuries accounted for 19% and 16% of the total injuries sustained in all rotary-wing medical evacuation events, respectively (Table 11). The neck sustained the lowest frequency of injury among all AIS body regions (12 of 547 injuries) (Table 11). The AIS 6 neck injuries were decapitations.

The most common injury mechanism within the study dataset was blunt force (Table 11). Blunt force was identified as the injury mechanism associated with 68% of the total injuries within the study dataset (Table 11). Penetrating injuries accounted for 4% of total injuries; this injury mechanism was associated primarily with MEDEVAC CRIs (Table 11).

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Table 11. Frequency of Injury Mechanism by Body Region and Rotary-Wing Medical Evacuation Event Group

		Blunt Force		**Burns**		**Inhalation**		**Penetrating**		**Unspecified**		
	Body Region	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Freq	Prop (%)	Total
All Events	Head	46	100	0	0	0	0	0	0	0	0	46
	Face	22	96	0	0	0	0	1	4	0	0	23
	Neck	12	100	0	0	0	0	0	0	0	0	12
	Thorax	91	97	0	0	3	3	0	0	0	0	94
	Abdomen	52	100	0	0	0	0	0	0	0	0	52
	Spine	54	100	0	0	0	0	0	0	0	0	54
	Upper Extremity	30	68	0	0	0	0	14	32	0	0	44
	Lower Extremity	54	87	0	0	0	0	8	13	0	0	62
	Whole Body	13	65	7	35	0	0	0	0	0	0	20
	Unspecified	0	0	1	1	0	0	1	1	138	99	140
	Total by Mechanism	374	68	8	1	3	1	24	4	138	25	547
MEDEVAC Accidents	Head	5	8	0	0	0	0	0	0	0	0	5
	Face	5	8	0	0	0	0	0	0	0	0	5
	Neck	4	6	0	0	0	0	0	0	0	0	4
	Thorax	4	6	0	0	0	0	0	0	0	0	4
	Abdomen	2	3	0	0	0	0	0	0	0	0	2
	Spine	9	14	0	0	0	0	0	0	0	0	9
	Upper Extremity	7	11	0	0	0	0	1	2	0	0	8
	Lower Extremity	8	13	0	0	0	0	2	3	0	0	10
	Whole Body	2	3	0	0	0	0	0	0	0	0	2
	Unspecified	0	0	0	0	0	0	0	0	15	0	15
	Total by Mechanism	46	72	0	0	0	0	3	5	15	23	64
MEDEVAC CRIs	Head	32	12	0	0	0	0	0	0	0	0	32
	Face	14	5	0	0	0	0	1	0	0	0	15
	Neck	7	3	0	0	0	0	0	0	0	0	7
	Thorax	72	27	0	0	0	0	0	0	0	0	72
	Abdomen	45	17	0	0	0	0	0	0	0	0	45
	Spine	21	8	0	0	0	0	0	0	0	0	21
	Upper Extremity	16	6	0	0	0	0	13	5	0	0	29
	Lower Extremity	28	10	0	0	0	0	6	2	0	0	34
	Whole Body	10	4	2	1	0	0	0	0	0	0	12
	Unspecified	0	0	0	0	0	0	1	0	2	1	3
	Total by Mechanism	245	91	2	1	0	0	21	8	2	1	270

Table 11. Frequency of Injury Mechanism by Body Region and Rotary-Wing Medical Evacuation Event Group, Continued

	Body Region	**Blunt Force** Freq	**Blunt Force** Prop (%)	**Burns** Freq	**Burns** Prop (%)	**Inhalation** Freq	**Inhalation** Prop (%)	**Penetrating** Freq	**Penetrating** Prop (%)	**Unspecified** Freq	**Unspecified** Prop (%)	Total
HEMS Accidents	Head	9	4	0	0	0	0	0	0	0	0	9
	Face	3	1	0	0	0	0	0	0	0	0	3
	Neck	1	0	0	0	0	0	0	0	0	0	1
	Thorax	15	7	0	0	3	1	0	0	0	0	18
	Abdomen	5	2	0	0	0	0	0	0	0	0	5
	Spine	24	11	0	0	0	0	0	0	0	0	24
	Upper Extremity	7	3	0	0	0	0	0	0	0	0	7
	Lower Extremity	18	8	0	0	0	0	0	0	0	0	18
	Whole Body	1	0	5	2	0	0	0	0	0	0	6
	Unspecified	0	0	1	0	0	0	0	0	121	57	122
	Total by Mechanism	83	39	6	3	3	1	0	0	121	57	213

Note (1). Proportions were calculated based on total number of injuries occurring within each group.
Note (2). A single occupant could have multiple injuries per body region.

Discussion

The study dataset included data from Army MEDEVAC accidents, Army MEDEVAC CRIs, and civilian HEMS accidents. All MEDEVAC CRIs and HEMS accidents that occurred during the study timeframe were included in the study; no attempt was made to exclude MEDEVAC CRIs or HEMS accidents from the study based on event severity (DOD, 2011) or aircraft survivability (DA, 2015). For this study, only class A and B MEDEVAC accidents were included in the study (DOD, 2011), class C, D, E, and F accidents (DOD, 2011) were not considered since accidents falling under these classifications do not typically involve significant injury. Therefore, all three datasets contained injury data from events falling within all levels of survivability.

MEDEVAC CRIs had the highest proportions of uninjured occupants at 95% (399/418) (Figure 1). MEDEVAC CRI events involved the aircraft being engaged by enemy weapon systems (Dudek et al., 2018). Nine (9) of 98 aircraft (Table 5) involved in MEDEVAC CRI events were involved in an aircraft mishap as a result of these engagements. The low number of injured occupants is likely due to the low number individuals that exposed to a mishap event as a result of a MEDEVAC CRI.

Only three percent (3%) of all rotary-wing medical evacuation aircraft occupants included in this study were coded as being patients (Table 6). The small proportion of patients contained within the study dataset could indicate that most rotary-wing medical evacuation events occurred while en route to pick up patients or upon return from the medical evacuation mission. Another potential reason for the low proportion of patients may be that patients were being mistakenly coded as passengers or other flight roles at the time information was entered into the three databases used in this study. No matter the reason, an insufficient amount of patient-specific information was contained in the study dataset to allow any patient-specific recommendations to be made regarding improving patient safety during medical evacuation events.

Direct comparisons of injury risk between the three study groups cannot be made due to the lack of crash severity data (i.e., aircraft kinematics, magnitude of impact). Nonetheless, the injury data are consistent with the enhanced crashworthiness mandated for Army MEDEVAC aircraft, compared to design requirements for civilian HEMS aircraft. When considering all rotary-wing medical evacuation events together, 73% of occupants were uninjured as a result of events (Figure 1); this high proportion of uninjured occupants in the overall dataset is driven by the proportion of uninjured occupants involved in MEDEVAC CRIs (95%) (Figure 1). Additionally, MEDEVAC accidents resulted in a slightly higher proportion of uninjured occupants (44%) than HEMS accidents (40%) (Figure 1). Twenty-seven percent (27%) of all occupants considered within the study were either fatally injured, seriously injured, or suffered minor injuries (Table 7); within this cohort, more occupants of HEMS accident aircraft were fatally or seriously injured than in MEDEVAC accidents and CRI aircraft (Figure 3).

The UH-60 Black Hawk is the Army's primary rotary-wing MEDEVAC aircraft. The Black Hawk was designed using principles of crashworthiness described in the Aircraft Crash Survival Design Guide (DesJardins et al., 1989), MIL-S-58095 (DA, 1986), and Shanahan (1993). The aircraft was designed from its inception to protect the occupants during severe but survivable aviation accidents. MEDEVAC-specific variants of the Black Hawk (e.g., HH-60A, HH-60L) were built using the same crashworthiness principles to protect Army MEDEVAC aircrew and patients during aircraft mishaps.

Additionally, all Army aircraft, including MEDEVAC aircraft, require two pilots to be in the cockpit during a mission. Analysis of the HEMS accident dataset indicates that HEMS aircraft are flown by a single pilot (Table 5 and Table 6). Having two pilots in the cockpit provides for better situational awareness during an emergency and the capability of one pilot to fly the aircraft in the event of in-flight incapacitation of the other due to medical emergency, disorientation, etc. The requirement to have two pilots in the cockpit provides improved flight safety.

Previous research has shown that the core, extremities, and head have been the most injured regions of the body in Army rotary-wing mishaps. Shanahan and Shanahan (1989) reported injuries from survivable, partially survivable, and non-survivable, Class A and B, Army rotary-wing mishaps occurring during a six-year period (October 1, 1979 through September 30, 1985). Shanahan and Shanahan (1989) found that the core of the body (thorax and abdomen combined), extremities, and head accounted for approximately 26%, 34%, and 24% of overall injuries, respectively. Shanahan and Shanahan (1989) attributed the torso, extremities, and head injuries to contact forces resulting from occupant flail that resulted in impact with aircraft structures.

In the current study, the same body regions showed large proportions of overall injuries: core of the body (thorax and abdomen) (27%), extremities (19%), and head (8%) (Table 8). The mechanism of injury to these regions was blunt force (Table 13). Contact with aircraft structures, as mentioned by Shanahan and Shanahan (1989), would produce blunt force trauma. Thus, it is conceivable that the injuries observed in the present study were likely also be the result of excessive occupant flail and contact between the occupant and aircraft structure. Shanahan and Shanahan (1989) identified improved restraints and delethalization of the aircraft interior as a means for reducing contact injuries caused by flail of the torso, extremities, and head.

Shanahan and Shanahan (1989) identified the head as the body region receiving the third-highest proportion of total injuries. In the present study, the spine was shown to be the body region with the third-highest proportion of overall injuries (Table 8). Spinal injury proportions were similar between the two studies; Shanahan and Shanahan (1989) reported that injuries to the spine accounted for nearly 9% of all injuries, while the present study showed that injuries to the spine accounted to 10% of all injuries (Table 8). The similar proportions of spinal injuries indicates that risk of spinal injury has not changed considerably since 1985. This finding is consistent with the results of epidemiological review of spinal injuries occurring in U.S. Army rotary-wing mishaps conducted by Brozoski and colleagues (2020).

Future designs of Army rotary-wing aircraft, including MEDEVAC variants, should maximize occupant restraint. Currently, four- and five-point restraint systems with auto-locking inertial reels are used in Army rotary-wing aircraft to restrain passengers and pilots, respectively. Five-point restraint systems with auto-locking inertial reels provide improved restraint over four-point restraints, as five-point restraints include a tie-down strap to eliminate the occupant submarining and sliding out of the restraint. To further enhance the restraint of cockpit occupants, multiple types of inflatable restraint systems have been investigated (Crowley & Dalgard, 2000), and cockpit air bags were developed for the OH-58D Kiowa Warrior and UH-60A and UH-60L Black Hawk variants (Shanahan et al., 1993; Crowley et al., 2000; Brozoski et al., 2000a; Brozoski et al., 2000b). To improve restraint of MEDEVAC crewmembers, multifunctional medical attendant seats have been developed. These seats are intended to allow the attendant more mobility while caring for the patient; the medical attendant, who is tied to the seat with a four-point restraint system, can move the seat longitudinally along the aircraft floor and pivot the seat 360 degrees. The four-point restraint system allows the medical attendant to lean forward or stand while remaining restrained to the seat. Although the data available for the present study lacked sufficient detail to allow correlation of restraint type with injury risk, these well-researched crash survival design principles should be considered.

In addition to improving occupant restraint, the aircraft cockpit and cabin should be delethalized to the greatest extent possible. Delethalizing entails moving potential strike hazards out of the occupant's potential flail corridors. Historically, occupant flail corridors described in the ACSDG (Desjardins et al., 1989). The legacy flail corridors were based on anthropomorphic test device flail (e.g., crash test dummy) during a dynamic sled test. More recent research has been conducted by USAARL in support of the FVL modernization priority. This work has resulted in head flail corridors for well-restrained vehicle occupants; the head flail corridors were developed from analysis of human volunteer exposures to accelerative loads from anterior-posterior, lateral, vertical, and oblique impact orientations (Olszko et al., 2021). The new head flail corridors can be employed for reducing occupant strike hazards in the cockpits and cabins of future FVL aircraft designs.

Injuries to the thorax and abdomen could also be caused by objects within the aircraft impacting the occupants. Impacts from these objects, which could be pieces of aircraft structure or medical equipment that has broken free during the accident, could cause blunt force injuries. The study dataset did not contain sufficient information to determine whether injuries to the thorax and abdomen resulted from impacts by medical equipment displaced during the mishap event.

With the exception of injuries with an unknown severity (i.e., AIS 9), AIS 1 and AIS 2 severity injuries were shown to make up the largest proportion of injuries across the entire dataset (22% and 19%, respectively) (Table 10). AIS 1 and 2 injuries are the lowest AIS severity levels (Table 1). However, several of the injuries associated with these injury severities can be painful and immediately debilitating, particularly those in the head, thorax, extremities, and spine. AIS 1 and AIS 2 head injuries included concussions with and without loss of consciousness; within the thorax, lower severity injuries included collapsed lungs and sternal fractures. Fractures/dislocations of the lower legs (tibia and fibula), as well as fractures of the wrist, clavicle, coccyx and pelvic girdle were among AIS 1 and AIS 2 extremity injuries. AIS 2 spinal injuries including transverse process fractures and vertebral body fractures (NFS). While the AIS severity level for these injuries is among the lowest possible, these AIS 1 and 2 injuries can be extremely painful and immediately debilitating (e.g., concussion, collapsed lung, fractured pelvic girdle); injuries such as these can have immediate effects on the occupant's ability to self-egress from the aircraft and have long-term effects such as chronic pain.

AIS 3 spinal injuries including burst fractures in the thoracolumbar spine, disc ruptures, and spinal cord contusions made up 20% of all spinal injuries (Table 11). Fractures to the thoracolumbar spine occur more frequently than fractures to any other portion of the spine (Brozoski et al., 2020). AIS 3 spinal injuries can have immediate and long-term effects on the occupant similar to, or potentially more severe than, as those associated with AIS 2 spinal injuries. One design strategy intended to reduce the frequency of spinal injuries is the use of energy-absorbing crew seats; recent evidence suggests that seat designs for future Army MEDEVAC aircraft, or upgrades to legacy aircraft, should meet new medically-based performance criteria that incorporate enhanced human spinal injury risk functions (Lafferty et al., 2020).

Limitations

MEDEVAC accidents were down-selected to include Class A and B mishaps. No equivalent categorization existed for the MEDEVAC CRIs or HEMS accidents; therefore, all MEDEVAC CRIs and HEMS accidents were considered in this analysis. This might suggest that more minor accidents could have been included in the MEDEVAC CRI and HEMS accident groups, which could have allowed low severity injuries to be overrepresented in the dataset. Despite this possibility, our analysis did not reveal a disproportionate number of minor or AIS 1 injuries in the MEDEVAC CRI or HEMS accident groups (Table 7 and Table 10).

The present study was a database review. The three databases contained sufficient information to determine basic mechanisms of injury (e.g., blunt force, penetrating injury); however, there was insufficient information available in the databases to indicate the cause of the basic injury mechanism or the impact severity. For example, insufficient information was available to determine if a blunt force injury resulted from impact by medical equipment that had become dislodged during an accident. Future work should be conducted to expand upon this effort and include detailed case reviews for the medical evacuation events included in the study dataset. Detailed reviews of USACRC and NTSB case files may provide additional information on the circumstances leading to an occupant's injuries, allowing additional conclusions to be drawn.

For the Army MEDEVAC CRIs that did not involve injuries, the total number of persons onboard those aircraft was not explicitly known; however, all Army aircraft involved in MEDEVAC CRIs within the study timeframe were variants of the UH-60 Black Hawk, which typically flies with a crew complement of two pilots and two crewmembers. Numbers of pilots and crewmembers for MEDEVAC CRIs were therefore estimated based on the typical Black Hawk crew complement.

The total numbers of occupants and injuries for the Army MEDEVAC groups were potentially under-reported. Twelve MEDEVAC accident cases met the inclusion criteria for the study with eight of those accidents involving occupants with injury (Table 5). The USACRC aviation mishap database contained injury information for occupants of five of these eight accident aircraft. For MEDEVAC CRIs, 418 total occupants were reported as being involved in these events. However, the DCIPS database has been noted previously to under-report numbers of injured occupants involved in CRIs (Dudek et al., 2018).

Conclusions and Recommendations

Results of this study are consistent with the higher level of crashworthiness required for Army Black Hawk MEDEVAC aircraft, compared to aircraft used for civilian HEMS. Mishap data available for this analysis did not contain sufficient detail to determine specific actions or circumstances (e.g., unrestrained medical equipment) that led to each injury, although different injury patterns were noted between the Army MEDEVAC and civilian HEMS groups. Army MEDEVAC aircraft should continue to be designed to the more stringent military crashworthiness standards. Further review of detailed accident investigation files may allow comparisons of impact severity and injury-producing mechanisms, leading to more specific recommendations.

Improved occupant restraint and delethalization of the aircraft interior have been identified as means of mitigating blunt force injuries to the head, thorax, and extremities. Future Army MEDEVAC aircraft designs should investigate improved occupant restraint systems or leverage emerging data on occupant head flail to design aircraft cockpits and cabins to minimize the placement of strike hazards within the flail envelope of the occupant's head.

To mitigate the risk of crash-related spinal fractures, rotary-wing aircraft should be equipped with energy-absorbing seating systems, as these systems are a mechanism to reduce the frequency of vertebral body fractures. Seat designs for future Army MEDEVAC aircraft, or upgrades to legacy aircraft, should meet new medically-based performance criteria that incorporate enhanced human spinal injury risk functions.

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