Aircraft Mishap Investigation With Radiology-Assisted Autopsy: Helicopter Crash with Control Injury

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Folio LR, Harcke HT, Luzi SA. *Aircraft mishap investigation with radiology-assisted autopsy: helicopter crash with control injury.* **Aviat Space Environ Med 2009; 80:400–4.**

Radiology-assisted autopsy traditionally has been plain film-based, but now is being augmented by computed tomography (CT). The authors present a two-fatality rotary wing crash scenario illustrating application of advanced radiographic techniques that can guide and supplement the forensic pathologist's physical autopsy. The radiographic findings also have the potential for use by the aircraft mishap investigation board. Prior to forensic autopsy, the two crash fatalities were imaged with conventional two-dimensional radiographs (digital technique) and with multidetector CT. The CT data were used for multiplanar two-dimensional and three-dimensional (3D) image reconstruction. The forensic pathologist was provided with information about skeletal fractures, metal fragment location, and other pathologic findings of potential use in the physical autopsy. The radiologic autopsy served as a supplement to the physical autopsy and did not replace the traditional autopsy in these cases. Both individuals sustained severe blunt force trauma with multiple fractures of the skull, face, chest, pelvis, and extremities. Individual fractures differed; however, one individual showed hand and lower extremity injuries similar to those associated with control of the aircraft at the time of impact. The concept of "control injury" has been challenged by Campman et al., who found that control surface injuries have a low sensitivity and specificity for establishing who the pilot was in an accident. The application of new post mortem imaging techniques may help to resolve control injury questions. In addition, the combination of injuries in our cases may contribute to further understanding of control surface injury patterns in helicopter mishaps.

Keywords: radiology-assisted autopsy, helicopter mishap, control injury, virtual autopsy, aircraft mishap investigation.

MAJOR OBJECTIVES in the medical investigation of an aircraft mishap are to identify victims, reconstruct crash sequence, determine contributing medical factors, and analyze survivability (4). Particular importance is given in multiple-occupant crashes when determining the person in control of the aircraft at the time of the accident. Campman and Luzi (1) have recently challenged the traditional thinking concerning the sensitivity and specificity of control injuries. They showed such injuries to be poor predictors of a pilot attempting to control an aircraft, but suggest that study of combinations of injuries, particularly those involving both the upper and lower extremities, may improve sensitivity and specificity.

Radiographs have been employed in forensic investigation since their discovery and traditionally have been an important part of aircraft crash investigations. The radiographic examination traditionally has been "plain film-based," with standard two-dimensional images recorded on film. Digital technology is now replacing film, and advanced imaging techniques such as computed tomography (CT) are now being used to augment plain films. This technique, sometimes referred to as "virtual autopsy," enables improved visualization of pathology through the ability to create two-dimensional and three-dimensional (3D) reconstructed images of injury. The cases presented are from a two-fatality rotary wing aircraft crash. This report illustrates the application of advanced radiographic techniques that can guide and supplement the forensic pathologist's physical autopsy. The radiographic findings also have the potential for use by the aircraft mishap investigation board. We offer this incident analysis as a model for future radiographic evaluation of aircraft mishaps.

SCENARIO

These two individuals were the aircrew on an Apache (AH-64) aircraft that impacted the ground for unknown reasons.

Occupant 1

This adult male died of multiple blunt force injuries. Lethal injuries included skull fractures, pulpifaction of both cerebral hemispheres, atlanto-occipital and atlanto-axial dislocations, bilateral rib fractures (flail chest), lacerations of the heart, and lacerations of the liver and left kidney. The plain radiographs, CT, and physical autopsy revealed severe blunt force injuries to the head, face, chest, abdomen, and pelvis. Fractures of the skull and facial bones showed disrupted fragmentation consistent with blunt force impact and analogous breaks in the

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This manuscript was received for review in October 2008. It was accepted for publication in December 2008.

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DOI: 10.3357/ASEM.2445.2009

helmet. Three-dimensional CT reconstructions clarified fragment positions and facial bone disruption. Chest fractures were evident on the plain radiographs and CT. These included bilateral fractured clavicles and ribs and a dislodged sternum.

The lower extremities had comminuted tibia and fibula shaft fractures bilaterally (**Fig. 1**). The left foot had a navicular fracture and comminuted fracture of the calcaneus. Pelvic fractures involved sacroiliac joints and acetabuli bilaterally, and the right femoral head was dislocated.

There was a severely displaced dorsal fracture/dislocation of the left wrist. **Fig. 2**, an oblique 3D reformatted CT image (GE Advantage Workstation 4.2, GE Healthcare, Milwaukee, WI), illustrates the intact ulna with complete dislocation from the carpals. The comminuted distal radial fracture has fragments displaced posteriorly. On the right hand, there was a posteriorly angulated and displaced transverse fracture of the fifth metacarpal. A subtle lucency seen on the radiograph of the first metacarpal was suspected to be a nondisplaced transverse fracture. This finding was supported with associated ecchymosis as well as palpable signs of fracture at autopsy.

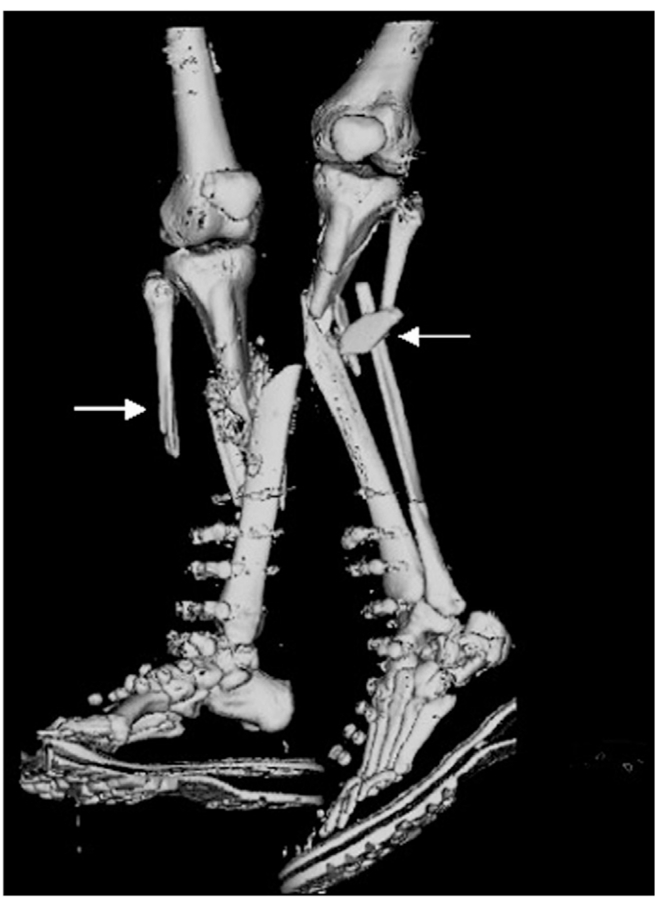

Fig. 1. Three-dimensional computed tomography of lower legs in Occupant 1 demonstrating bilateral tibia-fibula fractures. The fractures are bilaterally comminuted, segmental, angulated, and displaced (overlapping) shaft fractures (arrows). This fracture pattern has been previously described by Dummit and Reid (3) as likely due to having feet firmly on pedals and flying at time of crash.

Occupant 2

This adult male also died of multiple blunt force injuries. Lethal injuries included ponto-medullary transection, fracture-dislocation of the cervical spine with underlying transection of the spinal cord, bilateral rib fractures, lacerations of the lungs, multiple lacerations of the heart, transection of the aorta, and lacerations of the liver and right kidney. The plain radiographs, CT, and autopsy revealed severe blunt force injuries to the

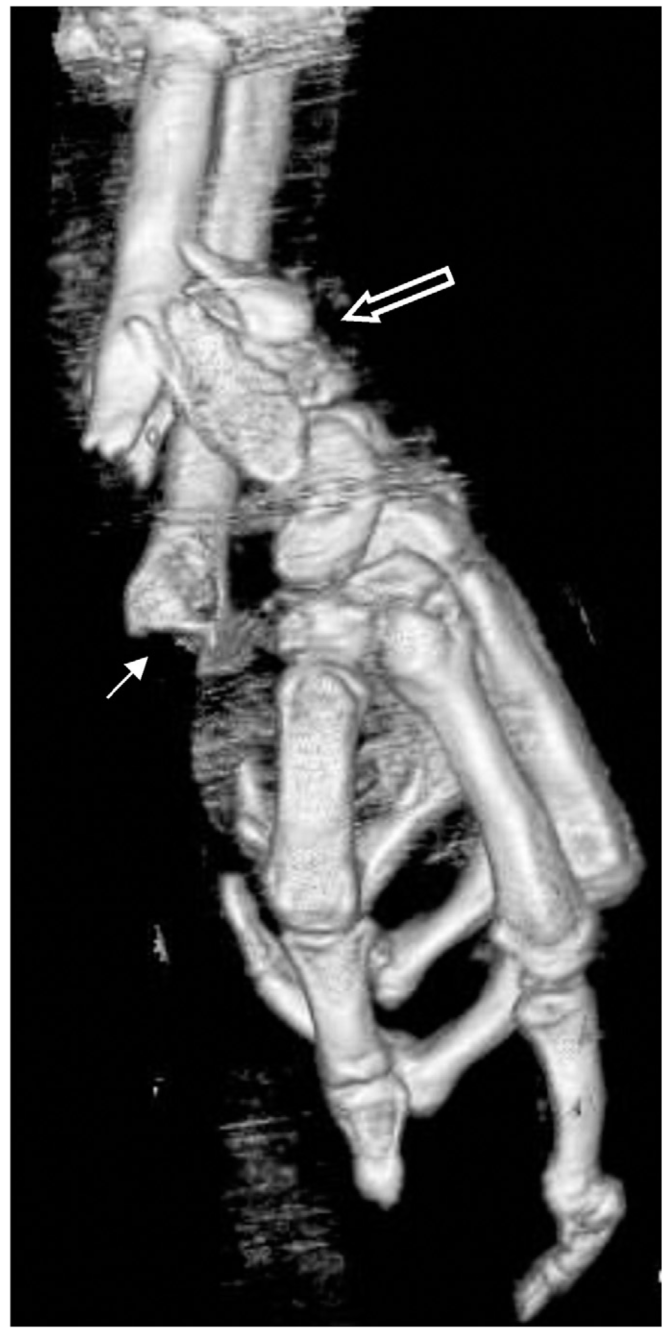

Fig. 2. Collective control injury pattern on the left hand and wrist. The three-dimensional reconstruction shows a severely displaced open fracture-dislocation of distal radius and ulna. The three-dimensional format better illustrates intact distal ulna (closed arrow), with complete dislocation from carpals, and comminuted distal radius fragments severely displaced posteriorly (open arrow).

head, face, chest, abdomen, and pelvis. Fractures of the skull and facial bones showed disrupted fragmentation. Thoracic injuries were evident on the radiographs and CT. They included bilateral fractured clavicles and ribs and a dislodged sternum.

Lower extremity fractures included two comminuted, displaced, angulated right femoral shaft fractures and a midshaft fracture of the left femur. The distal right tibia was fractured at the ankle joint. On the left, a proximal fibular fracture and comminuted calcaneal foot fracture were present. Upper extremity fractures were noted in the distal right radius and ulna and the mid shaft of the left radius and ulna.

Aircraft-Specific Analysis

Helicopters are defined as an aircraft in which all flight attitudes are supported in the air wholly or in part by a rotor or rotors (10,12). Familiarity of rotary-wing specific flight controls is important in that the pilot flying has both hands occupied, each on separate controls. Whether the pilot is in the pilot or copilot seat (whether side-by-side or tandem seating) at the time of impact does not matter from a control point of view in helicopters. This is different from fixed-wing because fixed-wing aircraft hand positions are often reversed depending on which seat the pilot or copilot is sitting in. Hand dominance is not a factor for position on controls in fixed-wing aircraft. It is more dependent upon what seat the person is sitting in since one hand is on the yoke, the other on the throttle. It should be mentioned here that many helicopters fly with two pilots. However, only one is typically on the controls at a time. There is always a designated pilot in charge of the mission ("pilot in command"); however, the pilot in command does not necessarily always have the controls.

In helicopters, the collective (which controls elevation) is always controlled with the left hand, the cyclic (which controls pitch, roll, bank, and turn) is always controlled with the right hand (**Fig. 3**). The actual hand positions do not vary between military services, country of manufacture, and airframes. It also does not matter if a pilot is left- or right-handed or is flying a U.S. military or general aviation helicopter. There are times in transition of controls that both pilots' hands are on both controls. This is more common in training, when the student pilot has their hands on the controls to go through the motions without actually being in control; in other words, to get a "feel" for the movements.

The upper-extremity injuries found in Occupant 1 can be evaluated in accordance with control position. **Fig. 4** is a drawing of the fracture, with the likely mechanism of fracture dynamics of the hand and collective at impact. Fig. 3 demonstrates the typical left hand position of a flying pilot. The correlative autopsy finding showed the open ulna dislocation and associated ecchymosis from the radial fracture proximally. We feel the dorsal dislocation of forearm is a significant indicator that the left hand was on the collective.

The right hand findings match a pattern of energy transfer to the right hand from the cyclic at impact. At time of autopsy, the radial side of the hand showed

Fig. 3. Cockpit side view shows typical left hand position on the collective. Note the right hand position on the cyclic.

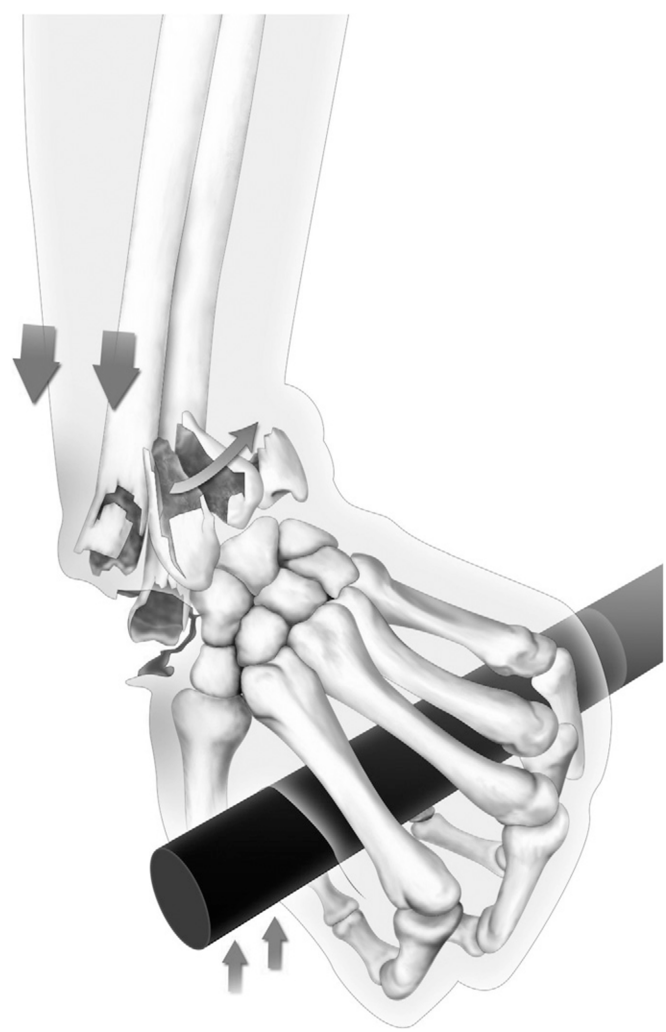

Fig. 4. Artist's mechanistic illustration of collective control injury showing direction of forces upon impact (arrows) that result in the described fracture-dislocation.

bruising over the first metacarpal. Likewise, the ulnar side showed bruising in the region of the fifth metacarpal. The cyclic rest in contact with the fifth metacarpal region might cause this type of fracture upon impact. We feel the combination of left and right hand injuries is important in this scenario.

Both pilots had pelvic fractures and dislocated right hips, consistent with downward, rightward impact forces. A possible mechanism where knee impact with the cockpit panel or pedal drives the flexed femur/hip posteriorly, causing dislocation, would be similar to motor vehicle impact accidents (9). Both pilots had foot fractures; however, Occupant 1 had bilateral midtibia and fibula fractures that differed from the distal tibia fracture noted in Occupant 2. We believe the difference in fracture pattern is relevant considering Occupant 1 was also the pilot with the significant hand injuries.

DISCUSSION

To our knowledge, this is the first description of the application of post-mortem CT imaging to the investigation of an aircraft mishap. It is anticipated that multiplanar and 3D imaging will provide the medical examiner with information that can augment the physical autopsy. In addition, this type of imaging can be correlated with the crash scene situational environment. The cases presented highlight several findings supporting mechanism of injuries combined into one incident, and this report illustrates how this may be accomplished.

Of particular interest is the issue of "control injuries." In the past, control injuries have been reported with the implication of specificity (5,6). Coltart (2) presented a control injury so specific that the fracture developed its own name: "aviator's astragalus." Two things have changed since that landmark article, however. First, that article was published when it was more common to have rudder bars rather than the current-day pedals for rudders, and second, the astragalus (Greek) is now referred to as the talus (Latin). In older aircraft, the pilot's feet would position the arches over the rudder bars, and direct pressure was applied to the talus, bypassing the calcaneus in deceleration mishaps. The calcaneous usually absorbs most of the impact in falls, hence the discovery of the unusually high rate of talus fractures in aircraft mishaps in the 1940s and 1950s. In the late 1960s, Dummit and Reid (3) reported on injuries to helicopter pilots and noted comminuted fracture of the midshaft of the tibia to be a consistent finding. It is notable that the example case shown by Dummit and Reid (3) is very similar to our Occupant 1.

The recent work of Campman and Luzi (1) challenges the conventional teachings about fracture pattern and control injury. They found a high incidence of control injury-like patterns in passengers as well as pilots. Statistically, the control-injury type injuries had unacceptably low sensitivity and specificity for establishing that a pilot had attempted to control an aircraft. Their study contains a mix of fixed and rotary wing mishaps, and determinations were made from a review of mishap reports and autopsies. While this study did not specifically mention radiography as part of the autopsy, we assume that conventional anteroposterior radiographs were a part of the autopsy in most or all cases. There would not have been multiple views or the spatial resolution advantage CT now affords.

In our analysis, we relate more completely defined fracture characteristics to the specific instrumentation of rotary wing aircraft and the cockpit configuration of the crashed airframe. By this type of correlation, combinations of injury such as right and left hand-specific fracture in rotary wing aircraft can increase confidence in identifying control surface injury. The fact that helicopters are more "hands-on" than fixed-wing aircraft may lead to more conclusive evidence of control surface injuries in the future. The combination of injuries in our report helps support that Occupant 1 was the pilot in control of the aircraft at time of impact. Furthermore, multiplanar and 3D CT reconstruction permits mechanisms of injury to be studied on an aircraft-specific basis.

The cause of death in most fatal aircraft accidents is blunt trauma (13). Military aviation crash survivability and crashworthiness have received more attention than general aviation. The most common cause of injury in a study of U.S. Army helicopters was "secondary impact" caused by collapse of structure into occupied areas, by inadequate restraint, or both (11). It has been shown that pilot fatality correlates to variables likely related to increased impact forces (7). Our report follows these basic premises of fatal aircraft mishaps in general. The Office of the Armed Forces Medical Examiner consults the National Transportation Safety Board in aiding the review of aviation fatalities (8).

This mishap analysis has several limitations: foremost is that speculation is necessary, and no definitive conclusion is possible. In mishap investigation, the autopsy is subject to permutations of possibilities of events as the scene is recreated. Another limitation is our current radiation-assisted autopsy protocol, which does not maximize use of CT. Current protocol calls for anteroposterior digital radiographs and total body CT. The CT field of view does not always include all of the extremities (as was case in our report). For three of the four upper extremities, the anteroposterior view was all we had available. Adding CT scanning specific for extremities is recommended when arms and legs are not included on the total body scan, and 3D images are needed for analysis.

Conclusion

We present this report as the first description of radiology-assisted autopsy with use of 3D CT and to introduce a new concept for the study of control injury in aircraft accident investigation. The specific fracture detail afforded by CT allows correlation with mechanism of injury. This is particularly valuable when considered in an aircraft-specific environment. While we can reach no definitive conclusion as to which pilot was in control in this mishap, the combination and type of bilateral hand injuries, coupled with the bilateral midtibia and fibula fractures described by Dummit and Reid (3), should be considered when determining which pilot was actively flying at the time of impact. Such injuries, however, need to be related to situation and environment, such as cockpit configuration and position in dual control rotary wing aircraft. Radiology-assisted autopsy that includes 3D CT can provide the opportunity for better recognition and analysis of number and type of injury.

ACKNOWLEDGMENTS

The opinions and assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the view of the Departments of the Army, Navy, Air Force, or Defense.

The authors acknowledge the contributions of Sofia del Castillo, Audio Visual Center of Uniformed Services University, who provided the drawing, and Michelle Stofa, who provided editorial assistance.

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