Postmortem Computed Tomography in Victims of Military Air Mishaps: Radiological-Pathological Correlation of CT Findings

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Abstract

A thorough medical inquiry is included in every aviation mishap investigation. While the gold standard of this investigation is a forensic pathology examination, numerous reports stress the important role of computed tomography in the postmortem evaluation of trauma victims. To characterize the findings identified by postmortem CT and compare its performance to conventional autopsy in victims of military aviation mishaps, we analyzed seven postmortem CT examinations. Musculoskeletal injuries accounted for 57.8% of the traumatic findings identified by postmortem CT. The most frequent findings were fractures of the rib (47%), skull (9.6%) and facial bones (8.6%). Abnormally located air accounted for 24% of findings, for which CT was superior (3.5% detected by autopsy, 100% by postmortem CT, $P < 0.001$). The performance of autopsy in detecting injuries was superior (autopsy detected 85.8% of all injuries, postmortem CT detected 53.9%, $P < 0.001$), especially in the detection of superficial lesions (100% detected by autopsy, 10.5% by postmortem CT, $P < 0.001$) and solid organ injuries (100% by autopsy, 18.5% by postmortem CT, $P < 0.001$). Performance in the detection of musculoskeletal injuries was similar (91.3% for autopsy, 90.3% for postmortem CT, P = not significant). Postmortem CT and autopsy have distinct performance profiles, and although the first cannot replace the latter it is a useful complementary examination.

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In air forces around the world, aviation mishaps are investigated thoroughly. The main goal of a mishap investigation is to identify the causes of the accident in order to prevent future recurrence. A scrupulous medical investigation is an essential part of the accident inquiry. It may uncover a medical cause of the accident, for instance the presence of an underlying disease that could have resulted in sudden incapacitation of the pilot [1]. Another role of the medical investigation is to assess the nature of injuries sustained by aircrew and passengers in order to unveil downsides of aircraft and personal safety equipment design such as helmets and harnesses [2,3]. In certain cases the medical findings may shed light on the mechanism whereby the accident occurred [4-6].

The primary tool of the medical inquiry, considered to be the gold standard, is a forensic pathological postmortem examination. In a series of 559 autopsies of pilots involved in general aviation (non-military) fatal accidents published by Weigmann and Taneja [7], blunt trauma was the most frequent cause of death (86%). The most commonly occurring bony injuries were fractures of the ribs (72.3%), skull (55.1%), facial bones (49.4%), tibia (37.9%) and pelvis (36%). Common organ injuries were lacerations of the liver (48.1%), lung (37.6%), heart (35.6%) and spleen (30.1%). Hemorrhage of the brain and lung occurred in 33.3% and 32.9%, respectively.

There are numerous reports in the literature on the usefulness of postmortem computed tomography in assessing injuries and determining the probable cause of death in trauma victims. Some researchers claim that PMCT has an advantage over autopsy due to its ability to image organs *in situ* and to perform multi-planar and three-dimensional reconstructions [8-14].

In recent years PMCT examinations were performed in the Israeli Air Force on victims of military aviation mishaps as part of the medical investigation. In light of the numerous publications that support the role of PMCT in trauma victims, we postulate that CT could successfully identify injuries in this unique setting, contribute some information and confirm autopsy findings. The objectives of the current study were to characterize injuries of fatalities of aviation mishaps diagnosed by PMCT and to compare findings on PMCT to conventional autopsy.

Methods

The study is a retrospective analysis of seven military fatalities that occurred in our Air Force between the years 1992 and 1995, for whom a PMCT examination was performed. The Defense Forces Medical Corps institutional review board approved the study. The fatalities were the result of two helicopter accidents. Four of the victims were pilots, one was an airborne technician

PMCT = postmortem CT

and two were passengers. The remains of the victims were flown by helicopter immediately (within one hour) after the mishap to the hospital (blinded) where the PMCT examination was carried out. The remains were then transported to the National Center of Forensic Medicine where forensic examinations were performed by experienced forensic pathologists. The autopsy included an external forensic inspection and a full invasive dissection.

CT technique and image analysis

The studies were carried out on a dual-slice scanner (Elscint CT Twin, Haifa, Israel) and included a scan of the head, neck, abdomen and pelvis. Slice collimation and increment were 10 mm for the chest, abdomen and pelvis scans, 5 mm for the head scan and 2.5 mm for the neck scan. Head scans were performed by the axial method; all other scans were spiral. Typical Kv and mas values were 120 and 200–275, respectively. The PMCT scans were carried out within 10 hours after the accident. Interpretation was performed by two certified radiologists in consensus, using a comprehensive list of anatomic systems, organs and injuries. The head CT examination was interpreted by neuroradiologists and the chest and abdomen examinations by body CT specialists. The examinations were read using hard copy and conventional screens.

Statistical analysis

One of the seven cases was excluded from analysis due to an incomplete PMCT examination. The injuries diagnosed by PMCT in the remaining six cases were summarized and analyzed using descriptive statistics. In two cases a quantitative comparison of the findings at PMCT examinations and the findings at autopsy was performed. These were the most severely injured cases and since they also had very detailed autopsy reports they were chosen for quantitative comparison. Results were checked for statistical significance using a modified chi-square statistic. For the purpose of comparison, both the diagnoses from the PMCT examinations and the autopsies were considered to be the gold standard representing the true amount of injuries present. Each of the two modalities (PMCT and autopsy) was compared to this gold standard and to the other modality.

Results

Altogether, 303 traumatic findings were diagnosed by PMCT in the six cases that were included in the study [Figure 1]. Musculoskeletal injuries accounted for 175 (57.8%) of all traumatic findings. Among these, the most common diagnoses were factures of the rib (47.3%), cranial bones (9.6%), facial bones (8.6%), pelvis (7.5%) and lumbar spine (6.5%). Central nervous system injuries accounted for 17 (5.6%) of the total traumatic findings. Solid organ injuries accounted for 7 (2.3%), lung injuries for 4 (1.3%) and heart injuries for 2 (0.6%). Abnormally located air collections accounted for 73 (24.1%) of all injuries and were readily diagnosed by PMCT. As a group, air collections were the second most frequent traumatic finding. The most frequent abnormal air locations were: intracranial (25%), in the thorax (pneumothorax, 14.3%), the subcutaneous tissues (emphysema,

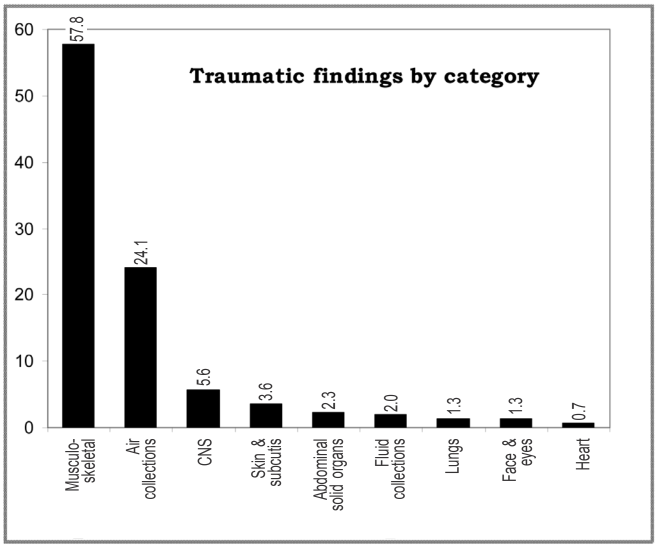

Figure 1. Injuries diagnosed by PMCT according to anatomic system or organ. The prevalence of abnormal air and fluid collections is also depicted.

10.7%), the spinal canal (10.7%), the abdomen (pneumoperitoneum, 7.1%), and the mediastinum (pneumomediastinum, 7.1%).

In the two cases for which a pathological radiological correlation was performed, a total of 267 discrete traumatic findings were diagnosed by either PMCT or autopsy. This number was considered to be the gold standard representing the true amount of traumatic findings present in these two cases [Table 1]. A total of 229 (85.7%) and 144 (53.9%) traumatic injuries were identified at autopsy and PMCT, respectively. Of the total 267 traumatic findings diagnosed by either PMCT or autopsy, 57 (21.3%) were superficial lesions of the skin or subcutaneous tissues. These injuries were identified on an external forensic inspection prior to invasive dissection. Excluding these superficial lesions, the autopsy examination revealed 81.9% and PMCT examination 65.7% of the 210 traumatic findings. PMCT was more sensitive than autopsy in detecting abnormally located air collections. PMCT identified 100% of 28 air collections and autopsy identified only 3.5% of these. The performance of the two modalities in

Table 1. Performance of PMCT versus autopsy in detection of injuries

Type of injury	No. of injuries	Detected by autopsy (%)	Detected by PMCT (%)	*P*
All injuries	267	229 (85.8)	144 (53.9)	< 0.001
All injuries, excluding superficial	210	172 (81.9)	138 (65.7)	< 0.001
Musculoskeletal	93	85 (91.3)	84 (90.3)	NS
Central nervous system	16	14 (87.5)	10 (62.5)	NS
Solid organs	27	27 (100)	5 (18.5)	< 0.001
Heart	4	4 (100)	1 (25)	< 0.05
Lungs	9	9 (100)	1 (11.1)	< 0.001
Abnormal air collections	28	1 (3.5)	28 (100)	< 0.001
Fluid collections	10	10 (100)	5 (50)	< 0.01
Superficial lesions	57	57 (100)	6 (10.5)	< 0.001

identifying bone injuries was similar. Autopsy was more sensitive than PMCT in detecting soft tissue injuries.

Forty-six percent of findings were detected solely by autopsy (34.2% excluding superficial injuries) while 14.2% of findings (18.1% excluding superficial injuries) were identified solely by PMCT.

Discussion

Recently there have been increasing reports on the usefulness of advanced imaging modalities in the postmortem assessment of trauma victims [8-14]. In many cases the purpose of the postmortem investigation is primarily academic and serves as a tool to assess the reasons for failure of therapeutic efforts by the hospital trauma team. In the aviation milieu however,

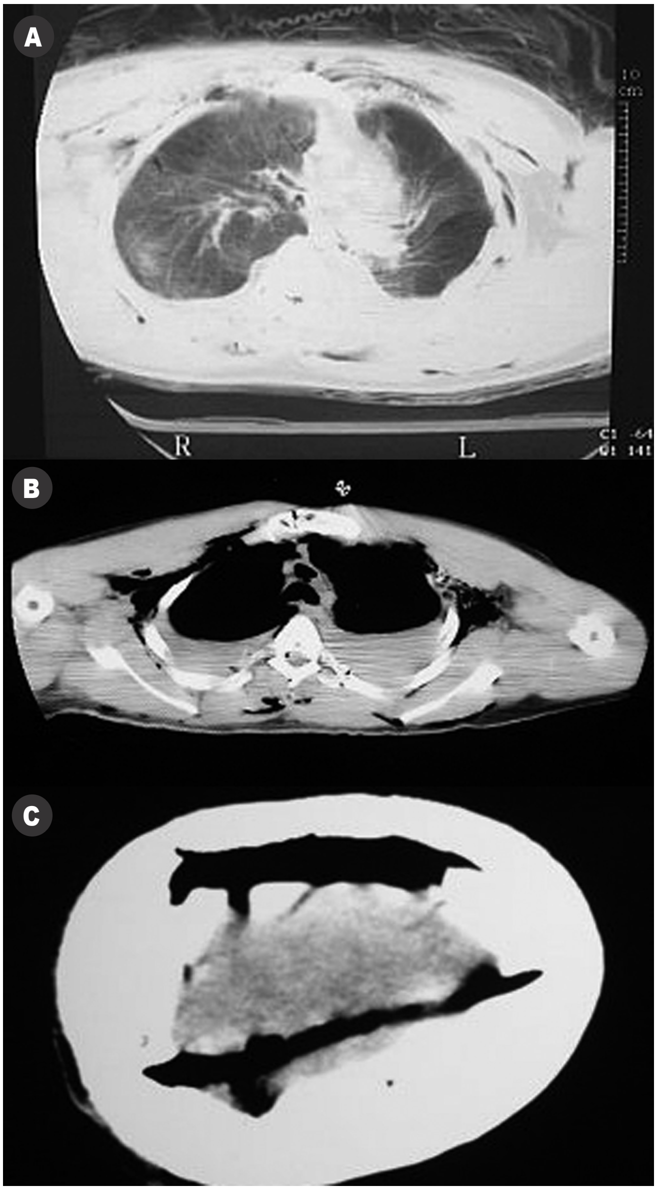

Figure 2. Organs appear differently postmortem. **[A]** Lungs, showing ground-glass opacities. **[B]** Contracted, air-filled aorta. **[C]** Air-filled sagittal sinus. Images are from separate cases.

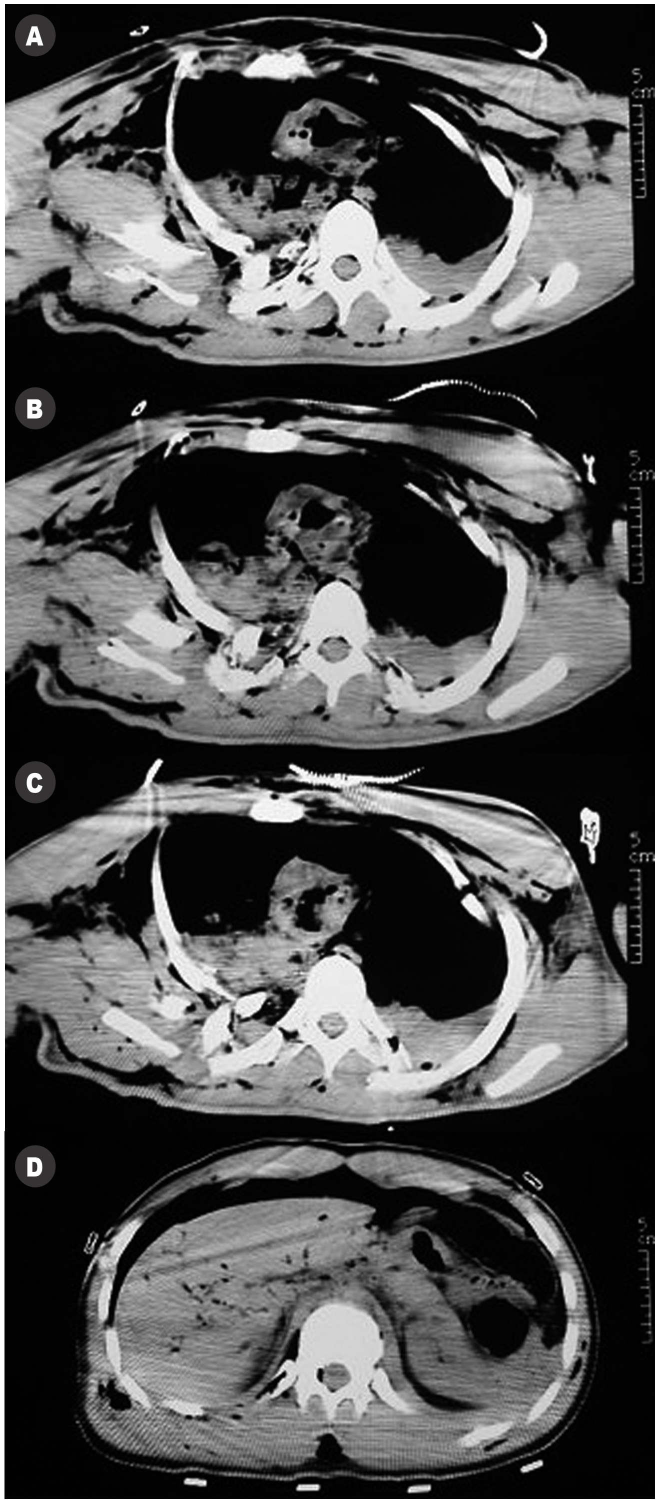

Figure 3. Underestimation of injury severity by PMCT.
[A-C] Consecutive sections through the chest. The interpreting radiologist used the term "collapsed heart." At autopsy, the pericard was found torn and the heart was not present within it. Fragments of it were identified in the pleural and peritoneal spaces. **[D]** Section through the liver and spleen (different case). Air-filled vessels are readily identified and some parenchymal damage is evident. However, the pathologist's description was of completely shattered organs, as in a "post-explosion" state.

the postmortem evaluation of mishap victims is more important and serves other functions as well, including evaluating for the presence of a medical precipitating condition, relating injuries to specific aircraft and safety equipment design, and contributing information towards a comprehensive understanding of the accident's chain of events. The medical investigation, therefore, is crucial in this setting, and decisions regarding which tools and modalities are to be used in the investigation should rely on sound scientific evidence.

The most prevalent traumatic findings, identified by PMCT in our series, were musculoskeletal, especially bone injuries. This is consistent with published data from autopsies of general aviation mishaps [7,15]. It is interesting to note that this predominance of skeletal injuries exists even though extremity injuries were not included in the present study as the PMCT scans did not include the extremities.

The performance of PMCT in comparison to autopsy in our study was lower and our hypothesis was rejected. As many as 34–46% of all traumatic findings were missed by PMCT, depending on whether superficial lesions, discovered on the external forensic inspection, were included in the comparison. This result might be explained by certain disadvantages that CT is subjected to in evaluating fatalities. The CT suite, machine and team are engineered and trained to serve living patients. CT technicians are not accustomed to dealing with cadavers and this may lead to less than optimal examinations technically, often due to suboptimal positioning. The examinations are obviously performed without oral or intravenous contrast material, a fact that has a drastic influence on the diagnostic yield of the examinations. In addition, organs such as the brain, lungs and blood vessels often change their appearance postmortem [Figure 2], while radiologists evaluating the CT scans are not trained regarding the normal postmortem appearance of organs. On top of that, tremendous tissue damage is often encountered in the aviation accident setting, including a disruption of normal anatomic relationships and locations. The combination of these factors renders the radiological interpretation less effective when compared to living patients and may often lead to underestimation of the severity of injuries [Figure 3].

Nevertheless, PMCT did make a unique contribution to the detection of traumatic findings. As many as 18% of injuries (excluding superficial findings detected on external inspection) were diagnosed solely by PMCT. This contribution involved mainly the detection of abnormally located air as a sign of injury, an area in which PMCT was superior to autopsy. PMCT was also effective in evaluating for the presence of bone injuries, although its performance in this field was similar to that of autopsy.

Two limitations of our study must be acknowledged. The earliest PMCT scans included in this study took place a decade ago. They were performed on a dual-slice scanner and were regularly filmed. Hence, this study does not demonstrate latest generation multi-detector CT technology that may be more accurate and useful. Secondly, comparing such very distinct modalities involves a certain degree of subjective interpretation. We tried to minimize this by using specially designed forms as well as consensus reading.

In conclusion, PMCT and autopsy are distinct investigative modalities in the setting of an aviation accident inquiry, with different profiles of performance. PMCT plays a unique role in the diagnostic investigation and may be considered complementary to autopsy. Further research is needed to evaluate possible advantages of multi-detector CT with planar reconstructions in postmortem evaluation.

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