Chapter 14

AVIATION PATHOLOGY

In the investigation of aircraft accidents, the contributions of the Medical Member of the Aircraft Accident Investigating Board, in association with the Pathologist, are firmly established as a significant part of the total inquiry. The close cooperation of these medical specialists is recognized as essential for thorough evaluation of human factors in terms of physical, physiologic, and psychologic processes and their role in the disruption of the man-aircraft unit. Medical findings have, in some instances, ruled out "pilot error" or "undetermined" as the cause of an accident when a careful autopsy has proved the existence of some specific physical ailment, such as coronary artery disease. Thorough medical analyses ultimately bring about improvement in pilot selection processes and enhancement of personnel safety features of aircraft and spacecraft.

Strong impetus was given to the application of pathology to aircraft accident investigation in 1955, when the Department of Defense issued a directive establishing the Joint Committee on Aviation Pathology (JCAP), composed of representatives from the military medical services of the United States, Great Britain, and Canada. The Armed Forces Institute of Pathology (AFIP), Washington, DC, is JCAP Headquarters and has been further designated as the central coordinating facility for investigation of the pathology of aircraft accident fatalities. The Aerospace Pathology Branch has the prime responsibility for this mission and utilizes the full consultant, histopathologic, and toxicologic facilities of the AFIP in analyzing both military and civilian cases collected.

Pathology Support

The authority for providing a pathologist at the scene of an aircraft accident is AFR 160-109. Pathology support from the Military Consultant Centers is authorized and outlined in AFR 160-51. Most of the toxicologic analyses (*i.e.*, carbon monoxide, lactic acid, and alcohol) are to be performed by the designated Class A Laboratories per AFR 160-109, with additional support provided as required by the Epidemiological Laboratory at Lackland AFB, by the AFIP, and by other histopathology centers. Unusual or difficult analyses, such as those involving drugs, are referred directly to the AFIP.

With the active participation of more consultants, the number of Air Force pathologists with experience in aircraft accident investigation will increase at an appreciable rate. A Flight Surgeon or a Flight Medical Officer may be exposed to only a few accidents during his entire tour of duty in the Air Force, but a Pathologist at a Military Consultant Center will often participate in many investigations, at several bases, in his area during a 2 or 3-year tour. By approaching each accident investigation as a team, the Flight Surgeon or Flight Medical Officer and the Pathologist can pool their experiences and more effectively discharge their responsibilities.

Basic Procedures

Experience has proven that each investigation varies slightly from the next. There are, however, a few basic procedures which will aid the Flight Surgeon in carrying out an efficient and thorough investigation. These are discussed below. Problems not covered in this discussion may be referred, day or night, to the Officer-On-Call at the

Aerospace Pathology Branch, AFIP, Washington, DC.

First Step:

This is the most important phase of every aircraft accident investigation. It requires the medical officer to obtain immediate transportation to the crash site and exercise authority to prevent disturbance of the fatally injured victims *in any way* until after they and the scene of the accident have been thoroughly documented in photographs, preferably in color. While this requirement should not be interpreted as preventing firefighters from determining the presence of signs of life, the fact remains that valuable evidence is frequently distorted or destroyed by well-meant rescue operations. Photographs will, at least, partially preserve these details for later analyses by pathologists and flight surgeons.

The rapid reaction time required for this initial phase, obviously, demands a prearranged disaster plan. To provide medical coverage for a crash site distant from the base, it is strongly urged that each Flight Surgeon establish arrangements for immediate air transportation as an integral part of the disaster program.

A compact flyaway kit should be available for unscheduled emergencies. In addition to personal gear, other useful equipment should include a 35 mm camera, color film, flash unit, tags, waterproof marking pen, a 50-foot steel tape, compass, paper, pencils, rubber bands, and polyethylene bags.

Second Step:

When the general wreckage distribution has been photographed from all angles, and the casualties have been photographed and examined in their original positions, the remains should be tagged with an identifying number and moved, and the original location then marked by an identically numbered tag or stake. At the time of removal of the remains, it is important to note all environmental features which may have contributed to the injury pattern, such as seat belt failure or possible traumatizing control knobs. It is imperative that suspected evidence be documented by photographs.

After the casualties have been moved to the mortuary and refrigerated, pending the arrival of the pathologist, the numbers should be plotted on a scale diagram indicating the wreckage distribution. Photos of the flight path and aerial views of the crash site are frequently helpful in determining force vectors producing certain injuries and in ascertaining specific traumatic agents in the cockpit or cabin environment.

Although examination of the site is an essential part of the pathologist's examination, the medical officer should examine the wreckage as early as possible for trace evidence. The canopy or tail surfaces may reveal fabric, tissue smudges, or blood which will enable the correlation of injuries with the time and place of occurrence, such as in the cockpit, in the air, or on the ground. Scrapings of such materials can usually be identified under a microscope.

Additional significant data may often be obtained from careful examination and photographic documentation of the casualty's personal equipment to ascertain its condition and functional status. Tears of flying clothing and direction of blood flow from lacerations may be integrated with injuries found at autopsy. Marks and other damage to the helmet and oxygen equipment must be evaluated. Every aspect of ejection failure must be checked, and an attempt at reconstruction of the sequence of events of the ejection must be made.

Because of his intimate knowledge of operational activities, the Flight Surgeon should be able to provide the pathologist with details of personal equipment, ejection seats, and cockpit configurations with which the latter may not be familiar.

Third Step:

AFM 168-4 requires that an autopsy be performed when death occurs while the person is serving as an aircrew member in a military aircraft. The Base Commander may authorize an autopsy when the accident occurs within his jurisdiction.

However, when the accident occurs outside the base perimeter, the local coroner or medical examiner exercises legal authority over the accident site and the remains. Depending on local statutes, permission must be obtained from the coroner or medical examiner before the casualty is removed from the crash site and before an autopsy may be performed.

If the local legally constituted authority is unwilling or unable to make such an authorization, permission must be sought from the next of kin. Merely transporting the remains to a military base does not permit the Base Commander to authorize the autopsy.

In some instances, the coroner or medical examiner may insist on performing the post mortem examination himself. An interested party, such as a medical officer, is usually welcome as an observer.

In the same general area of legal requirements is the necessity to establish positive identification of the remains. Such identification may be established by reference to the personal belongings that are carefully tagged and transported with each victim, by jewelry, metal identification tags, fingerprints, footprints, and dental records, and, occassionally, by blood type, hair type, or comparison of clinical and post mortem X-rays. Local law enforcement agencies are usually unskilled in this work, but can obtain assistance through the Base Mortuary Officer (AFM 143-1). If necessary, the services of the Federal Bureau of Investigation may be requested.

Although some of these legal requirements may lie within the province of the pathologist, the Medical Member of the Accident Investigating Board, who is aware of these requirements, can expedite the investigation by proper preplanning.

Fourth Step:

At the mortuary facility, it is desirable that the casualty be photographed again, both clothed and unclothed, from all angles, and preferably in color. Additional photographs of major lesions should be taken as indicated during the course of the autopsy.

It is also desirable that X-rays of the entire body be taken, using fixed radiographic facilities. This is most conveniently accomplished by scheduling such procedures after normal hospital duty hours. Occult fractures and foreign bodies are thus easily detected prior to autopsy, and the poor quality and artefacts of portable equipment can be avoided.

Fifth Step:

To be of value, the pathologic investigation must be approached from the forensic viewpoint. Trauma should be related to the causative agent. The medical officer should recognize that the "case history" includes personal and family backgrounds, interpersonal relationships, occupational stresses, and the history of the last flight. The unique relationship that existed between the Flight Surgeon and the flying personnel will provide the pathologist with much of the information he seeks. Medical and personnel records should be thoroughly reviewed for additional data before the autopsy.

Post Mortem Examination:

On rare occasions, the Flight Surgeon may find himself without assistance to perform an autopsy. To be prepared for such a contingency, the Flight Surgeon must familiarize himself with the essential techniques in AFM 160-19.

When an Air Force pathologist is not available, it may be desirable to seek the assistance of a civilian consultant or a Navy or Army pathologist. In all instances, specimens and reports should be submitted per AFR 160-109.

FACTORS FOR CONSIDERATION

Experience in evaluating Aviation Pathology cases has yielded three broad categories of data that encompass most of the pathological information, namely, environmental conditions, traumatic aspects, and pre-existing disease.

Environmental Factors

Altitude:

a. *Hypoxia:*

One of the most important and least readily solved problems confronting aircraft accident investigators is the detection of acute ante-mortem hypoxia. Histopathologic changes are of little or no value in its diagnosis, and chemical tests are reliable in only a low percentage of cases.

Through the joint efforts of the RCAF Institute of Aviation Medicine and the USAF School of Aeroscape Medicine, a colorimetric test on frozen, unfixed, central nervous system tissue obtained at autopsy, was devised to measure the lactic acid concentration. This intermediate metabolic product accumulates in significant quantities in neural tissues when glycogen levels in the blood increase as a response to stress. A decrease in aerobic metabolism, as might occur under hypoxic conditions, also causes the lactic acid level to rise.

Lactic acid concentrations over 200 mg% in gray matter are indicative of stress, although the elevated level does not differentiate the cause of the stress. Therefore, a variety of conditions—such as lack of oxygen attributed to altitude, drowning or strangulation, ingestion of certain drugs, and shock—may produce an elevated lactic acid value in the brain or spinal cord. It is worthwhile to note that, if an individual survives an injury long enough to receive medical treatment, intravenous administration of dextrose and water or of citrated blood may produce misleading elevated lactic acid levels.

Among 1,219 aircraft accident cases in which this test was routinely performed at the AFIP, there were 141 instances in which a value over 200 mg% was obtained. In nine cases, there was definite evidence that the elevation was due to altitude hypoxia; the available history supported the chemical findings. In 66 cases, there was a history of the casualty's brief survival in a state of clinical shock, following the accident. Four cases were attributed to altitude, strangulation, or hyperventilation; 11 cases to suffocation; and 26 cases to drowning. In 16 cases, the cause of the elevated values could not be determined, and in nine others, no history was available.

On the other hand, it must be admitted that there are a certain number of cases in which the available facts appear to indicate a stressful circumstance, but in which the lactic acid is not significantly elevated. Thus, it can be seen that this test is reliable only when central nervous system lactic acid is significantly elevated (above 200 mg%), and this elevation correlates positively with the history of the accident.

b. *Decompression Sickness:*

The post mortem findings in these cases are thought to be due, at least in part, to fat embolism secondary to a decrease in ambient barometric pressure. Intravascular fat has been found in the lungs, brain, and kidney in some of these cases, and areas of cerebral ischemic necrosis have been noted to be indistinguishable from those caused by aero-embolism.

The pathogenesis of this condition is not clearly defined, but it has been postulated as follows: Adipose tissue contains a supersaturation of nitrogen; upon decompression, the dissolved nitrogen forms expanding bubbles which rupture the cell membranes and release both fat and gas into the vascular system.

This simple explanation of embolism may actually reflect a more fundamental change in the tissues. The problems of decompression sickness and the causes of its various manifestations deserve considerably more fundamental investigation.

Speed:

a. *Spatial Disorientation.* Spatial disorientation is difficult to prove because, as far as is known at present, there is no demonstrable pathologic lesion. It is significant to note, however, that inner ears are seldom examined in suspected cases, although their removal should be routine in every aircraft accident fatality. The occult nature of spatial disorientation taxes the ingenuity of all aircraft accident investigators.

b. *Windblast.* In an attempt to prevent "windblast" injuries resulting from high-speed ejections, experiments have been conducted using primates as subjects on rocket sleds at speeds exceeding Mach 1. The exposed skin surfaces showed a number of changes, including separation of the superficial epidermis into a distinct layer, compression of the remaining epidermis into a thin, leathery structure, epilation, and focal hemorrhages. The windblast and high dynamic air pressure resulted in a thermal elevation to about 300° F. As a result of this and other studies, the designing of protective clothing and equipment has played a major role in the prevention of injuries to flying personnel, the most advanced development of which is the closed-environment, self-sustaining escape capsule for high-performance aircraft.

Toxins:

a. *Carbon Monoxide:*

Much work has been devoted to the environmental problem of toxins, especially carbon monoxide. Although carbon monoxide has been one of the more commonly incriminated toxins associated with aircraft accidents, a careful study reveals that significant carboxyhemoglobin values are usually associated with viability and a history of fire, either in flight or following ground impact. Therefore, the practical value of a post mortem carbon monoxide level lies in its assistance in establishing the sequence of events—*i.e.*, whether the person was alive or dead at the time the fire ensued.

An aircraft accident investigation routinely includes the analysis of unfixed tissues for carbon monoxide. If blood is not available, the laboratory can utilize aqueous extracts from blood-containing organs. The extracts are analyzed in the same manner as whole blood, preferably by gas chromatography, and the results are reported as percent carboxyhemoglobin saturation. Levels less than 10% are considered insignificant because heavy smokers may attain values as high as 8 or 9%.

Of 1,904 cases analyzed by this method at the AFIP, 198 demonstrated an elevation (over 10% carbon monoxide saturation), and all of these correlated with a history of fire. The magnitude of carboxyhemoglobin concentration does not, necessarily, reflect the length of exposure to the gas because the tissue level attained depends upon the integrity of the individual's circulatory and respiratory systems, on the concentration of carbon monoxide in the products of combustion, and on the availability of ambient oxygen to dilute the carbon monoxide.

b. *Alcohol:*

Unfixed tissues are also routinely examined for the presence of ethanol, because of its well-known depressant effect and the fact that many of the casualties show varying degrees of fatty metamorphosis of the liver. Positive results for alcohol, however, are rare among military personnel.

Putrefactions may produce artefactual ethanol concentrations in some instances, usually detected together with acetone and acetaldehyde by gas chromatography. A delay of as little as 8 hours before refrigeration of urine, kidney, brain, or other parenchymatous organs may result in a misleading positive alcohol test. Alcohol is also a common constituent of embalming fluid.

c. *Drugs.* When clinical evidence indicates that a search for drugs might be worthwhile, this analysis becomes a part of the toxicologic evaluation. Practically no medication can be considered completely harmless to personnel flying high-performance aircraft under operational stresses. Antihistamines and ataractics have been implicated in a few accidents as contributing causes. Liver, bile, stomach contents, kidney, and urine are useful for this type of analysis. Because of the complexity of the method and the manhours involved, drug analysis should not be requested routinely.

Temperature. In spite of well-regulated air conditioning systems, the present-day pilot must be prepared to encounter an extreme temperature range within a single flight. The severe cold experienced at high altitudes has been sufficient to produce serious thermal injuries in ejection cases. Therefore, for survival, it is necessary that flying personnel be furnished with adequate personal equipment. It is even more important that fliers be trained in the use of this equipment and that they apply their training to practice. Aircraft accident investigators should determine what effect the personal and survival equipment has had on the fates of both the victims and survivors, and they should not hesitate to make pertinent recommendations.

In addition to the above, other environmental factors that should be considered are the effects of noise, vibration, and stress.

Traumatic Factors

The second broad group of pathologic changes studied in aircraft accident fatalities focuses on traumatic lesions. In many instances, these injuries appear so extensive and, obviously, the immediate cause of death that even medical personnel unfamiliar with Aviation Pathology techniques raise the question as to why an autopsy should be performed when the cause of death is so apparent.

In aircraft accident investigations, however, it is insufficient to state the immediate cause of death, such as crushed chest, fractured skull, or injuries, multiple, extreme. To achieve the goals stated at the beginning of this chapter, it is necessary to pinpoint the objects and/or forces producing the injuries that resulted in the lethal lesions. *For example,* if the cause of the accident is clearly established as mechanical failure of the aircraft, the investigator should devote his efforts primarily to determining how the crew member sustained his specific injuries by relating them to known mechanisms of the accident, such as angle of descent, force vectors at impact, and the physical nature of the traumatizing agent. From this integration, aerospace architects and engineers may learn how to improve their designs to prevent the recurrence of similar injuries.

On the other hand, if the cause of the accident is unknown, the prosector should learn all the available facts about the circumstances of the accident before he begins the post mortem examination. Without this background, he may waste much time and effort in irrelevant work. The autopsy should then be conducted in a careful and meticulous manner, employing an inductive reasoning approach, and using as many adjunctive studies as possible, such as X-rays and chemical and bacteriological studies.

The correct interpretation of certain pathologic findings will frequently lead to invaluable clues in unraveling the sequence of trauma. *For example,* when examining the heart and lungs, it is important to determine whether lacerations were actually compression ruptures or were made by fractured ribs, and if the latter, by which ones. If there was a laceration of the aorta, it should be determined whether it was produced by a fractured bone or was the result of impact deceleration, each of which shows characteristic lesions. (Ruptures of the aorta in the arch or just distal to the left subclavian artery are characteristic deceleration injuries.)

In analyzing a laceration of the liver, it would be helpful to know if it was due to rib fractures or to a crushing injury compressing the liver against the vertebral column. The question of viability during a fire can be resolved by demonstrating soot, either grossly or microscopically, within the respiratory tract, indicating that the subject inhaled smoke and, thus, was alive in the presence of a fire.

It is well to remember that heat alone can produce epidural hemorrhage and fractures of the skull and extremities.

Preexisting Disease

Coronary atherosclerosis is probably the most frequent preexisting disease among fliers of all ages, and its pathophysiology offers much room for speculation. A coronary attack in the pilot of a single-place aircraft could well result in another unexplained accident. (Predictions of the importance of coronary disease among pilots were made by Benson and White in 1937 and 1940.) Although many of the coronary arteries of deceased pilots show moderate to marked coronary sclerosis, the significance of such findings must be interpreted with caution. The failure of histology to parallel physiology is well known.

Other types of preexisting disease have been responsible for sudden incapacitation of a crewmember with or without a resultant accident. Nelson and Haymaker have described three cases of sudden incapacitation caused by a colloid cyst of the third ventricle. An astrocytoma was responsible for the first onset of unconsciousness in one pilot, which would have resulted in an accident had a copilot not been present. Sudden crew incapacitation has occurred as the result of sickle cell anemia. Certainly, any disease that can produce sudden death at ground level can similarly produce sudden death at altitude, and can best be detected by a skilled pathologist.

SUBMISSION OF SPECIMENS

Toxicologic Analysis

Routine Analyses: Routine analyses include determinations of carboxyhemoglobin, lactic acid, and ethanol. The optimum tissue quantities include 50 ml blood; all urine; 250 gm lung; 500 gm liver; ½ of each kidney; 1 cerebral hemisphere or, if brain is not available, 6 inches of spinal cord.

Lesser quantities may be submitted if they are the maximum available but, in that event, the spleen, bone marrow, and skeletal muscle should be included to assure sufficient blood-containing tissues for carboxyhemoglobin determination. Lactic acid levels are only of significance when determined from relatively untraumatized central nervous system tissue.

Organs for toxicologic analysis should be heat-sealed individually in the bottom half of standard-issue plastic bags. An identifying card marked with the casualty's name and rank, autopsy number, date of accident, submitting base, and type of tissue should be sealed into the upper half of each bag. Liquids, such as blood and urine, are most conveniently transported in latex bags (condoms) tied with a firm knot, inclosed within a second firmly tied latex bag, and labeled with an attached tag. Glass jars and small, capped tubes should not be used for shipping frozen specimens because of their tendency to shatter when the contents are frozen.

It is essential that specimens for chemical analysis be kept free of contamination. Tissues removed after embalming are unsatisfactory, and traces of formalin fixative will interfere with the analysis. *Fresh tissue must not be transmitted to the laboratory in the same package with fixed specimens under any circumstances.*

Specimens must be frozen by any method available (usually dry ice) as soon as possible after the accident, to prevent putrefaction. A brief period of refrigeration is acceptable only if freezing facilities are not available. Without thawing, the tissues should be packed for shipment in an insulated cardboard container with sufficient dry ice to maintain the frozen state for 48 hours. If only a metal, vacuum-type container is available, it must be punctured to prevent accumulation of CO_2 under pressure and possible explosion. A copy of DD Form 1322, "Aircraft Accident Autopsy Report," sealed in a separate plastic bag, should also be inclosed for identification and information purposes.

The packaged specimens should be addressed to the Chief, Clinical Laboratory Service of the regional Class A Laboratory (*not* to the Military Consultant Center unless these facilities coincide), and labeled as follows: "FRAGILE, RUSH, FROZEN SPECIMEN FOR TOXICOLOGIC EXAMINATION (AIRCRAFT ACCIDENT). DRY ICE ADDED AT ____ HOURS; RE-ICE IF NOT DELIVERED WITHIN 36 HOURS." (See AFR 160–109.)

Tissue shipments of this nature should be transmitted by air freight or by military carrier, and the addressee should be notified of the carrier, flight number, estimated time of arrival, and bill of lading number by the fastest means possible.

Special Studies:

When special toxicological examination is required, specimens should be transmitted directly to the AFIP, inclosing a copy of DD Form 1322 and any data pertinent to the tests requested. All specimens should be prepared for shipment in the same manner as those destined for the Class A Laboratory, and similar advance notification provided the Director of AFIP.

Such investigations might include an analysis of unlabeled medications or tissue for drugs (500 gm liver; 250 gm lung; ½ each kidney; 50 ml blood; all urine; all bile; and all gastric contents are required). In suspected drownings, one complete lobe of each lung and at least ½ kidney will be submitted for diatom determination.

The laboratories will send written reports of both routine and special determinations to the investigating base. Assistance by phone may be obtained at any hour from the Aerospace Pathology Branch, AFIP.

Histopathologic Examination

Representative specimens from all organs should be fixed in 10% neutral formalin for 18 to 24 hours. Tissue slices should measure not more than 5 mm in thickness to permit thorough fixation.

After preliminary examination of the unfixed heart, including serial cross sectioning of the coronary arteries at 5 mm intervals, the entire heart should be immersed in formalin. Remaining portions of the brain and spinal cord should be thoroughly fixed in a similar manner. Because the brain requires several days for adequate formalin penetration, the heart may remain in fixative for a similar period. Specimens for histopathologic examination should *never* be frozen, either before or after fixation.

After adequate fixation, the specimens should be wrapped in cheesecloth moistened with formalin and heat sealed in plastic bags. These tissues, properly identified, may then be transmitted to the regional Class A Laboratory by the most practical means. They should be accompanied by a copy of DD Form 1322, along with any descriptions, X-rays, photographs, or other materials not forwarded previously. *Fixed tissues should not be transported in the same container with specimens for toxicological examination.*

When the histopathologic examination has been completed, a written report and case analysis will be returned to the investigating base, and the case materials, including autopsy report, accident report, slides and/or paraffin blocks or tissue, will be forwarded *in toto* to the AFIP for review, coding, filing or further distribution.

REPORTS REQUIRED

For each casualty, the Medical Member of the Accident Investigating Board will complete the Aircraft Accident Autopsy Report, DD Form 1322, or its equivalent, in cooperation with the pathologist. A copy of this form will accompany all shipments of materials to the Class A Laboratory or the AFIP for purposes of identification and information.

Supplemental materials include photographs of the crash site and wreckage, victims *in situ* and at autopsy, and interesting or unusual lesions. A diagram or labeled photograph of the wreckage distribution and body positions is a useful adjunct to a detailed narrative of the accident sequence.

Upon conclusion of the investigation, the Flight Surgeon should forward to the Class A Laboratory and the AFIP, a summary of the Board's findings, together with his analysis of the human factors data and personal recommendations.

Additional reports required under AFR 127–4 are not to be submitted with the autopsy material unless specifically requested.

REFERENCES

The reader should insure the currency of listed references.

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AFM 143–1, *Mortuary Affairs.*

AFM 160–19, *Autopsy Manual.*

AFM 168-4, *Administration of Medical Activities.*

AFR 127-4, *Investigating and Reporting USAF Accidents/Incidents.*

AFR 160-109, *Medical Investigation of Aircraft Accident Fatalities.*

AFR 160-127, *Joint Committee on Aviation Pathology.*