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Part IV

MANUAL OF CIVIL AVIATION MEDICINE
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PART IV. AVIATION PATHOLOGY

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INTERNATIONAL CIVIL AVIATION ORGANIZATION

Part IV
Chapter 1. MEDICAL FACTORS IN AIRCRAFT ACCIDENT INVESTIGATION

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INTRODUCTION

This chapter of the Medical Manual is intended as a general guide to a medical examiner appointed as a member of the accident investigation team. It outlines how specialists in aviation medicine, pathology and human engineering may contribute to an accident investigation and the nature of the work involved in their contribution. It supplements guidance material for the conduct of an investigation given in the *Manual of Aircraft Accident and Incident Investigation* ("AIG Manual", Doc 9756).

The Standards and Recommended Practices for Aircraft Accident Investigation contained in Annex 13 to the Convention on International Civil Aviation have been adopted by the ICAO Council as the procedure to be followed by Contracting States for inquiries into accidents involving death or serious injury and instituted in accordance with the provisions of Article 26 of the Convention. Annex 13 to the Convention, Chapter, 5 deals with the investigation and refers also to the AIG Manual.

The fundamental purpose of inquiry into an aircraft accident is to determine the events, conditions and circumstances pertaining to the accident so that appropriate steps may be taken to prevent a recurrence of the accident and the factors that led to it. An equally important purpose is to determine the facts, conditions and circumstances pertaining to the survival or non-survival of the occupants and to the crashworthiness of the aircraft.

The prime object of the human factors investigation is to obtain evidence (related to the sequence, cause and effect of the accident) through an examination of the flight crew, the cabin crew and the passengers. Coincidentally with the investigation, evidence as to identification will automatically emerge - particularly if each examination is assisted by the co-ordinated efforts of a Human Factors Group that includes aviation medicine specialists, pathologists and human engineering experts.

Aircraft accident investigation is a highly specialized task which should only be undertaken by personnel trained in investigation techniques and with a sound working knowledge of aviation and professional skill in their specialities. To achieve its purpose an investigation should be properly organized, carried out, co-ordinated and supervised by qualified personnel. It is essential that the magnitude and scope of the task is assessed at an early stage so that the size of the investigation team may be planned, the appropriate skills marshalled and individuals allotted their various tasks.

The Investigator-in-Charge, or in certain countries a Board of Inquiry, is appointed to be responsible for the organization, conduct and control of the investigation and for co-ordinating the activities of all personnel associated with it. It is the responsibility of the Investigator-in-Charge to review the evidence as it is developed and from this initial evidence, make decisions that will determine the extent and depth of the investigation. It should be recognized that the precise extent and depth of a particular investigation will be contingent upon the nature of the accident, and possibly also upon the availability of investigative resources.

The Investigator-in-Charge should establish working groups as required to cover various aspects of the investigation. The Group System as described in the AIG Manual is an excellent method of conducting an extensive investigation into major accidents. The decision to employ such an organization does depend, however, on the size and complexity of the task, the nature of the accident and the investigative skills available. The location of the accident may also be a deciding factor. The primary purpose of the Group System is to establish the facts pertinent to an accident by making use of the specialized knowledge and practical experience of the participating individuals with respect to construction and operation of the aircraft involved in the accident and of the facilities and services that provided service to the aircraft prior to the accident. It also ensures that undue emphasis is not placed on any single aspect of the accident to the neglect of other aspects that might be significant to the investigation and that, whenever it is possible to verify a particular point by means of several methods, all those methods have been employed and the

co-ordination of results has been ensured. Thus the investigation effort may require participation of some or all of the following groups: operations; meteorology; air traffic services; witness statements; flight recorders; maintenance records; and specialists in structures, power plants, systems, aviation medicine, human factors, evacuation, search and rescue or fire fighting, as detailed in the AIG Manual. It is emphasized that the medical and human factors contributions to the investigation are as important as the efforts of the other investigative groups in the team. Therefore it can be expected that the participating aviation medicine and psychology specialists will be supervised and controlled by an Investigator-in-Charge in the same manner.

GENERAL

The Human Factors Group is responsible for the aeromedical, crash injury and survival aspects of the investigation with regard to the events and the cause of the accident. The Human Factors (or Medical) Group will be concerned with:

a) establishing the presence of any physical or psychological disorder which may have contributed to impaired function of the flight deck crew;
b) discovering any specific environmental factors which may have similarly affected the crew;
c) searching for items in the medical, paramedical and psychological background of the flight crew which might indicate or explain a decrement in its function or efficiency;
d) identifying the flight crew, and cabin crew, if relevant, their location at the time of the accident by review of their injuries and activities at the time of the impact.

Bio-engineering aspects will include, among other things, an attempt to establish the relationship of damage received by cockpit or cabin structures, seat orientation, harness restraint and so on; and to identify factors that may have affected evacuation of the aircraft and escape. The efficiency of survival aids will come under scrutiny. The pattern of injuries may provide sound evidence as to the sequence of events or even the cause of the accident.

The concept that the pilot-in-command or other flight crew members might precipitate an accident by being less than usually efficient (though suffering neither from organic disease nor impairment due to drugs) and that this could influence or cause an accident is rather intangible and is likely to be difficult to prove. It will normally be least difficult in the investigation of a non-fatal accident when the crew can be interviewed and medically examined, or when cockpit voice and flight data recordings are available. Regarding bio-engineering aspects, the non-fatal accident is also easier to investigate in that injuries will be fewer and less severe than when an accident is fatal and their precise cause and mode of production will be more obvious. The human factors investigation of a non-fatal accident essentially calls for a specialist in aviation medicine and such specialists are available in many Contracting States.

The totally fatal accident is a rather different proposition. This is a problem in deductive reasoning from the outset and the approach and expertise of a forensic pathologist are generally required. Few forensic pathologists have had much experience in investigating aircraft accidents, and these accidents pose problems that are quite distinct from those encountered in routine medico-legal pathology practice. It is largely by personal experience that expertise in this field is acquired. The appointment in each Contracting State of a relatively small number of pathologists, one of whom could be called to participate in the investigation of every fatal accident in that State, would be a positive step towards establishing a source of such expertise for the future. Many articles have been published in appropriate journals and there are also a few books available dealing specifically with this subject, which will be of help to a pathologist inexperienced in this work (See further reading list at the end of this Chapter). Some States offer courses of varying lengths for medical officers wishing to specialize in aircraft accident investigation.

It is the purpose of this chapter to summarize the potential value of medical investigation of aircraft accidents, and to detail some of the important steps in the approach to the various aspects of the task. Some material is a repetition of the material in the AIG Manual where the subject is presented for the non-medical accident investigator; the rest consists of material more properly the concern of the medical investigator.

DISASTER PLANNING

Human factors evidence will vary mainly in emphasis, rather than substance, depending upon whether the accident involves large or small aircraft. In either case its full value will not be achieved unless there has been pre-planning by aviation authorities and accident investigation units. It is to be expected that one or more of the aviation medicine specialists or pathologists designated to assist in aircraft accident investigation will be called upon to help in such pre-planning. This pre-planning should be based on the supposition of the largest likely disaster; a small accident merely means using fewer of the resources provided. The matters to be considered are detailed either in the AIG Manual or in subsequent sections of this chapter, but may be summarized as follows:

a) the large aircraft, non-fatal accident: the plans are concerned with the provision of rescue equipment, the availability of hospital facilities and the interview and examination of the crew to determine possible medical and psychological factors, and of both crew and passengers regarding injuries and their causes, and escape and survival aspects;
b) the major fatal accident: the disaster plan will include training in the mapping and recovery of bodies, the provision of mortuary and refrigeration facilities, and the establishment of a medical team of investigators together with an identification secretariat or commission.

RECONSTRUCTION

The circumstances and cause of the accident

Some medical evidence relating to the reconstruction of the circumstances of the accident may come from surviving crew members or passengers. In the main, however, medical evidence related to the reconstruction of the accident circumstances is associated with the autopsy of the victims of the accident.

In fatal light aircraft accidents the examination of the pilot is likely to contribute most. Here the medical investigations should be directed towards determining or excluding disease and its possible association with the accident and towards such aspects as alcohol, drugs and toxic substances as possible accident causes. However, in light aircraft with dual controls, one cannot be certain that a “passenger” was not actually flying the aircraft. Additionally, toxicological examination of passengers’ tissues may validate findings in the pilot’s body such as raised carbon monoxide levels.

The presence of two or more pilots on the flight deck of larger aircraft makes pilot incapacitation from disease or drugs as a cause of a major accident unlikely. This is, however, not entirely true when the accident has occurred at a critical phase of flight, such as take-off or landing. Nevertheless, the pathologist may often find it appropriate in a large accident to concentrate on the search for evidence of conditions likely to affect all members of the flight crew - in particular carbon monoxide or other noxious fumes that may have contaminated the cockpit air. He must also seek evidence to eliminate or confirm the involvement of a criminal act such as unlawful interference with the operation of the aircraft. A full examination of the

flight crew may give valuable evidence about who was controlling the aircraft at the time of the crash. In this respect, identification has direct technical value to the investigation as distinct from judicial value.

In the major fatal aircraft accident, however, there is the possibility of deriving evidence from the cabin crew and passengers. A main concern of this chapter is to illustrate why this opportunity must not be lost. A full examination, particularly when it can be based upon previous experience, may reveal evidence as to the sequence of events, the stage of flight and the degree of emergency anticipated. The pattern of injuries may indicate clearly the type of accident - fire in flight, structural failure in flight, sudden or gradual deceleration at impact, etc. An examination of the passengers may be the prime method of demonstrating sabotage as an accident cause.

Human engineering and survival

The Human Factors Investigation may provide medical evidence of great value in relation to human engineering and survival. Such evidence will be equally relevant in both fatal and non-fatal accidents but again there may be a difference of emphasis according to whether the accident involves a large or small aircraft.

In the case of a small aircraft accident, the examination will generally be directed to the pilot(s); however, whether the aircraft is large or small, one should consider such factors as the relevance of the type of harness restraint in use, the provision or lack of other items of safety equipment, and the injury-producing potential of the controls, instruments and other cockpit structures.

In the case of a transport aircraft accident, interest will inevitably include the passengers. The Human Factors Group will be searching for evidence of injury resulting from seat structures - with or without adequate harness restraint - and the missile effect of the various contents of the cabin. Medical or pathological evidence will also be available as to the adequacy or inadequacy of walkways, exits and survival equipment.

Identification

Clearly the useful interpretation of human factor findings is dependent upon accurate identification of the casualties involved. Identification is, therefore, pre-eminently a tool of investigation but it also has major medico-legal significance and judicial application. The head of the Human Factors Group must be prepared for any evidence determined by members of his group, particularly the pathologist, to be used for medico-legal purposes. The Human Factors Group will, therefore, have special needs for co-ordination with local or national authorities with particular regard to identification. These needs should be recognized during the pre-planning and should not be overlooked during the investigation. There is, however, no conflict of interests - investigation and identification are interdependent as recognized in Annex 13. In the following sections of this chapter, they are discussed together under the same headings, in particular:

a) tasks at the accident site;
b) tasks at the mortuary;
c) evidence to be derived from the pathological examination;
d) consideration of the medical history of the crew and, where appropriate, interrogation of surviving crew and passengers.

THE STATUS OF THE PATHOLOGIST; LIAISON WITH THE INVESTIGATOR-IN-CHARGE

The Investigator-in-Charge may appoint as head of the Human Factors Group a specialist in aviation medicine with experience in aircraft accident investigation. In the event that there are fatalities, he may also appoint a pathologist, ideally with experience in aviation pathology or at least in forensic pathology, to perform necessary full autopsy examinations on all those victims killed. If the pathologist has experience in aviation pathology, he may be appointed as head of the Human Factors Group but this will depend on the type of accident being investigated and on human factor considerations. The fatal accident is, generally, more difficult to investigate than the non-fatal accident and it is for this reason that the role of the pathologist is stressed in this chapter. In the event that no pathologist experienced in aircraft accident investigation is available in the State investigating a major fatal accident, the Investigator-in-Charge should consider requesting other States to provide the necessary specialist(s).

Ideally, the appointed pathologist would obtain a complete "case history" before beginning the examination: he should acquaint himself with the details of the circumstances of the accident, details of the operating crew's medical and personal histories, familiarize himself with the internal layout of the cockpit and passenger compartments of the aircraft type concerned, and make a thorough examination of the accident site - all before commencing the examination of the bodies. Such an approach is rarely, if ever, practicable. The pressures that exist following most fatal aircraft accidents are such that examination and disposal of the bodies must be handled as quickly as practicable and any delay avoided. Many factors may demand speed; the extreme example is that of a tropical climate with no refrigeration facilities.

A practical approach has been found to be for the pathologist to be briefed at the outset by the Investigator-in-Charge concerning the salient features of the accident and to be informed whether any particular ideas as to the type of accident may have been aroused. This does not have to be a lengthy or detailed briefing but sufficient only to allow the pathologist an opportunity to make a special point of searching, during the course of the normal complete examination, for supporting or contradictory evidence relative to any other evidence which may already be available to the Investigator-in-Charge. At frequent intervals during the investigation, the pathologist and the head of the Human Factors Group, or the Investigator-in- Charge as appropriate, should confer. The pathologist can thus get an up-to-date picture and learn of developments that may bear upon his work; he in turn can report any of his findings that could provide a lead for members of other groups. This is the principle of the Group System in which it is essential that the human factors team play a full part.

Tasks at the accident site

Authorities differ in opinion as to the extent to which the pathologist should be personally involved in the tasks at the accident site. He must, of course, be aware of all that has to be done there and the evidence he may expect to be collected or preserved by others. He will have to utilize and correlate this evidence with his own findings. These tasks are discussed in the AIG Manual.

As is implied in that manual, it is probably ideal that the pathologist goes to the accident site as soon as possible - certainly this is so in the accident involving many fatalities. It is always a great advantage to the pathologist to be aware from the beginning of the general situation at the accident site. His presence and interest are likely to ensure that the procedures (outlined in Chapter 18 of the AIG Manual), designed essentially to preserve all evidence of possible value in the medical investigation, are carefully and satisfactorily carried out.

The tasks at the mortuary

Whether or not the pathologist visits or works at the scene, he must be intimately aware of conditions in the local mortuary for it is there that his main pathological duties will be carried out. For this reason it is highly desirable that authorities involved in the pre-planning of an aircraft disaster situation should be advised by a pathologist on the matters referred to in Chapter 18 of the AIG Manual with special reference to the suitability, and the methods of adaptation, of any buildings proposed for use as main or temporary mortuaries.

The tasks in the mortuary cover both the search for evidence relating to accident investigation and identification of the bodies of the dead. The general principles of the identification of the dead will be known to most physicians and certainly to all pathologists. They are outlined for the information of non-medical accident investigators in the AIG Manual, Chapter 18 and subsequent appendix.

It is difficult, if not impossible, to design the perfect form to document something so variable as the findings arising from the examination of a body from an aircraft accident. It is necessary to record details about a body relating to its identification, the cause, and the circumstances of its death. Since ever-increasing numbers of persons may be killed in a given accident, it is expedient to reduce the number of forms for each body as far as possible, to reduce their complexity, and to provide forms that can be used and handled with ease. They should be at once simple yet comprehensive; they must be appropriate whether a body is substantially intact and fully clothed, or naked and partially disintegrated. Thus any form to be of value in an aircraft accident must be a compromise between a many-paged document, comprehensively listing every feature that might need to be recorded with ample space for their descriptions and, at the other end of the scale, an essentially plain piece of paper with minimum headings, placing upon the examiner the burden of remembering every detail to which attention should be given and recordings made. The International Police Organization, INTERPOL, has designed a Disaster Victim Identification Form that is available in English, French, Spanish and Arabic. It can be downloaded from INTERPOL's website (see further reading list).

Equipment

A list of instruments and equipment suitable for autopsy procedures in the mortuary is not given here. Only normal standard items are required and pathologists who become involved in the work of aircraft accident investigation will ensure that arrangements are made for the particular instruments they favour to be made available.

Teamwork in the mortuary

The work in the mortuary is most efficiently carried out as a team operation, such a team comprising the aviation accident investigation personnel and the judicial personnel. Both of these groups should co-operate as a team and their actions should be interrelated. It is preferable that the pathologist is in charge of this team since the examination of bodies is obviously his prime responsibility. The procedures to be undertaken will be enumerated as they would be undertaken in the event.

The pathologist must select those to be examined first from the packaged remains housed in the temporary mortuary. The work is often eased if complete and readily identifiable bodies are examined first; these may be followed by whole bodies mutilated beyond recognition or by remains constituting more than half a body; the examination of detached members and body fragments is conveniently undertaken last. It cannot be overemphasized that seriously incorrect deductions may result from the examination of only a

single class of injury. The remains selected for examination should be transferred to the mortuary table, removed from the container at the table and the container checked for any loose fragments or material that might have become detached during transit.

The series of numbers used for labelling the human remains at the accident site will bear no relationship to the total number of victims when there has been severe mutilation and fragmentation of bodies. Experience has shown that in such cases it is expedient to commence a new and distinct series of numbers to be used as cadaver numbers; in these circumstances the first thing to be done when the body is placed on the mortuary table is to give it a new cadaver number. The decision whether or not it is necessary to adopt this procedure must be made at the outset, and when it is adopted written and photographic records should be made as soon as a body is given its cadaver number so that the remains, the site number and the new cadaver number can be related.

In addition to a general photograph showing these two labels on the body, further photography should be carried out at this stage as considered necessary, either for identification purposes or to record unusual damage or features about the clothing (e.g. stains), which could be of significance to the accident investigation. Only rarely will there be such features whose likely importance is obvious at this stage but it is a good rule to take too many photographs rather than too few and to be as comprehensive in written record as the size of the whole task load will allow.

The next step is for clothing and personal possessions on the body to be removed, examined and catalogued. Jewellery and other personal possessions should be preserved for further examination and ultimate disposal to relatives; other items may need to be preserved as evidence. Much of this task is for identification purposes. It is desirable to examine and keep fragments of any distinctive garment, laundry marks, manufacturers' labels and so forth. The pathologist will examine the garments before, as, and after they are removed for evidence significant to the accident investigation; such evidence will generally be either unusual staining or damage that can be related to injury to the body and which may have arisen in some unusual way, e.g. from an explosive device in a case of sabotage.

The unclothed body must now be carefully examined externally by the pathologist. All external features of possible help in identification of the body must be observed and recorded. A general assessment of injuries can be made with particular attention being given to any that appear unusual. Any that could be due to fragments of an explosive device should be examined with special care and samples taken from around and within the wound for a later search for trace evidence. The method of preservation of such samples will depend upon what is being sought. If, for example, a body has a number of tiny puncture wounds that could have been caused by small fragments of shrapnel, an excision of tissues around several such fragments should be made. Some of the specimens should be preserved in 10 per cent formol saline[1] for histological examination while those for metallurgical study should be deep frozen. Should a body have what appears to be a gun-shot wound, which could have been inflicted by a weapon fired at close quarters, it would be better for the excised tissues around the wound to be preserved deep frozen so that there could be later analysis of any chemical deposits on the skin. Of course, in such an instance a search for the missile deep in the tissues would be undertaken and it would be preferable for a radiograph to be taken before this search is commenced.

It is at this stage that the whole question of radiography must be considered. Its use will depend on the availability of suitable apparatus and technicians. If equipment is readily available, full body radiographs of all fatalities would be ideal. They will provide a permanent record of all major skeletal damage and detect any unexpected metallic foreign bodies that may be present. Such foreign bodies may contribute also to identification. In children, ossification centres in particular would be included in the radiographic survey.

[1] Formol saline: a 10 per cent solution of formalin in 0.9 per cent aqueous NaCl, used as a general fixative for histologic and histochemical preparations.

If radiography is not readily available, the pathologist may have to decide whether to press for it to be made available for some or even all bodies. This decision can only be made on his assessment of the probability of its value in a given instance. If sabotage were strongly suspected, radiography would be very important. In instances where identification is difficult, or likely to be difficult, radiography is important as it might be the only source of evidence.

At the stage when the pathologist has completed his external examination of the hands and the head, he should allow the judicial team to proceed with finger-printing and the dentist with the examination of the jaws and teeth. The pathologist will continue with his internal autopsy with the cranial cavity being examined possibly as the last procedure when the dental records are finished. These minutiae are unimportant as a team will rapidly develop a rhythm and routine of working together.

The comprehensiveness of the internal autopsy must be a matter for the pathologist to decide on the basis of the-total volume of work, the probable identity of the body (i.e. flight crew, cabin crew or passenger), and his briefing by the Investigator-in-Charge. As a guide, the following should generally be regarded as a minimum requirement for all casualties:

a) establishment of the cause of death;
b) discovery of major disease likely to influence life expectancy;
c) assessment of deceleration force and direction based on injury to:
    1) cardiovascular system, liver and diaphragm
    2) head, sternum, spine and pelvis
d) collection of specimens for carboxyhaemoglobin studies;
e) collection of lung specimens for estimation of the agonal period.

If the body is that of a member of the flight crew or could be that of a member of the flight crew, specimens of all major organs should be taken for histological examination, including the whole heart or at least a very large sample of myocardium from the interventricular septum and the ventricular walls. All these samples should be preserved in 10 per cent formol saline.

Specimens of tissue should be collected for toxicological examination for drugs, alcohol and carboxyhaemoglobin. It should be noted that carbon monoxide poisoning from exhaust fumes is unlikely from the exhaust of gas turbine engines, whereas its concentration is much higher in the exhaust from reciprocating engines. The possibility of a post-mortem alcohol production in tissues demands that some thought be given to the matter of appropriate samples for this purpose. If available, urine is the best material to preserve for alcohol estimation. If available, blood should also be collected from the heart and from deep vessels at two peripheral sites as well. When mutilation results in blood and urine not being available, it will often be possible to obtain a vitreous humour or bile specimen. Cerebrospinal fluid is also a suitable material for analysis for alcohol, but it will be very rarely obtainable when the other body fluids mentioned are not. If no fluid sample can be obtained, muscle from three widely separated sites should be taken. Fluid samples should be preserved in l per cent sodium fluoride; samples of solid tissues must be deep frozen.

The samples of urine, blood and muscle may also suffice for toxicological examination for drugs. However, when specimens are being collected for drug analysis, it is advisable that at least 200 grams of liver tissue are preserved. It is also desirable to retain the whole of one kidney and at least one lobe of lung, particularly if blood and urine are not available. Tissues such as these may produce adequate blood for gas/liquid chromatographic techniques. All these samples should be preserved in the deep frozen state.

Glass jars are too heavy and cumbersome for the preservation of the numerous specimens collected during autopsy examinations following a large aircraft accident. Plastic bags are recommended as suitable containers for specimens taken for histological examination. They must be of a standard or heavy gauge plastic and be adequately sealed. A single size, 25 x 36 cm, will be found suitable for most specimens and

the stocking of many sizes can be avoided. These plastic bags are also suitable for samples collected for toxicological examination except that it should be noted that volatile substances can pass through plastic. It is necessary therefore to put samples for analysis for alcohol or other volatile substances into glass containers, which should be filled as completely as possible to minimize contact with air.

On completion of the joint examination of all whole bodies and all remains making up more than half a body, it will be necessary to examine the fragments. The possibility of important evidence concerning the accident investigation itself being present in a dismembered part must not be overlooked. Commonly the examination of the fragments will be of most value with regard to the final count of victims and with regard to the individual identification of a major fragment. Since clues to identity may be present in a separated part, the whole body may be identified when the various fragments can be associated on anatomic comparison.

Provided that the judicial team and pathologists have carried out a thorough comprehensive examination including making a full record of findings, and fully labelling and carefully preserving all suitable material evidence for further reference and for laboratory tests or analysis, the bodies may then be casketed and, if required, embalmed. It is, however, advised that individual bodies should not be released until the pathological processes of investigation and identification are complete with respect to the accident as a whole. In view of the possible need to re-examine bodies, the caskets should be left in such a state that they can be re-opened if necessary.

The accurate identification of the bodies that the pathologist has examined can be essential to the interpretation of his findings in the context of the accident investigation. His medical evidence may contribute significantly to the identification in many instances. Some authorities regard his involvement as very important in the assessment of all the evidence about the identity of a body and in the decision about whether the evidence is conclusive. However, it would be superfluous to repeat here details of the contribution of others in this field since it is discussed in Chapter 18 of the AIG Manual. Advice on an expeditious way to deal with the comparison of records in which the pathologist may or may not find himself involved is given in Chapter 18 and subsequent Appendix of that manual.

SUBSEQUENT LABORATORY INVESTIGATIONS

Histology

There are many reasons for performing histological examinations on tissues of air accident victims, including the detection of pathology:

a) indicating the presence of causal or contributory disease states in flight crew;
b) influencing survivability or egress;
c) providing possible indication of drug usage through fixed tissue reactions;
d) corroborating evidence of severe artefactual change such as putrefaction and fermentation with bacterial growth producing or reducing ethanol;
e) providing an indication of disease prevalence for research

Emphasis should be placed on obtaining well-labelled samples from the major organ systems and well-documented specimens of specific lesions or areas of artefactual change. Precise descriptions are extremely important. All specimens should be immediately placed in a container of 10 per cent buffered formalin solution for preservation.

While it is beyond the scope of this section to comprehensively review the broad field of histology, the

necessity to sample specific sites or organs must be emphasized.

The main cardiac vessels should be serially sectioned to detect the presence of occlusal disease. Similarly, the detection of cardiomyopathy requires multiple cardiac sections.

Histological examination of the liver may reveal a variety of conditions ranging from fatty liver to cirrhosis. Microscopic changes in this organ could provide the only indication of ethanol abuse or drug use.

Pulmonary embolization may provide vital information concerning survivability and the timing of death. Soot in the airways and the alveoli will indicate survivability in conditions of post-impact fire.

As well as taking specimens from all major organs, any suspected abnormality, including tumour growth, should automatically be sampled.

Toxicology

The adequate toxicological investigation of tissue and fluid specimens from air accident victims requires a careful examination for the presence of prescription and over-the-counter medicines and illicit drugs, substances of social use and abuse, environmental contaminants and toxins as well as the detection and discrimination of artefactual changes such as the production of ethanol due to post-impact fermentation. The range of tests will ideally be broad and the sensitivity at the therapeutic and subtherapeutic level. Since in many instances, physical trauma is severe, toxicological examination may provide the only evidence of the existence of disease states that could produce insidious or sudden incapacitation such as hypertension, epilepsy, etc.

If possible, examinations should be carried out by a central reference laboratory which will have developed methods specific for air accident services as opposed to general forensic testing (see Attachment A)

A variety of tissues and fluids are required for successful testing. Due to the high impact forces often involved, fluids may not be available, but adequate quantities of blood from three separate sites, sterile urine from an unpunctured bladder, bile and vitreous humour are all extremely useful to the toxicologist. The tests commonly performed on usually available fluids and liver tissues are as follows:

Blood

Qualitative and quantitative analyses for:

a) ethanol
b) other alcohols, solvents, fuels, hydraulic fluids, etc.;
c) carbon monoxide;
d) hydrogen cyanide;
e) delta-9-THC (tetrahydrocannabinol) and metabolites (“marijuana”);
f) gas chromatography-mass spectrometry (GC-MS) screen and quantitation for medicines and drugs and their metabolites
g) GC-MS screen and quantitation of pesticides and herbicides;
h) High Performance Liquid Chromatography (HPLC) screen and quantitation of medicines and drugs;
i) Radioimmunoassay (RIA) analyses when indicated;
j) Enzyme-multiplied immunoassay technique (EMIT) analyses of medicines.

Urine

Qualitative and quantitative analyses for:

a) ethanol;
b) other alcohols and solvents;
c) GC-MS screen for medicines, drugs and their metabolites
d) GC-MS screen for pesticides, herbicides, etc.;
e) HPLC screen for medicines and drugs;
f) RIA screen of digoxin, various antibiotics, THC metabolites, amphetamines, barbiturates, morphines and cocaine;
g) EMIT screen for illicit drugs.

Liver fluid extracts

See blood tests.

The following table indicates the optimum sample size required for specific types of testing by most laboratories:

Specimen	**1% Fluoride/Oxalate Preservative**	**EDTA Anticoagulant**	**Plain No Preservative**	**Frozen**
Blood	2mL from 2 clean sites	5mL	10mL	*******
Urine	2mL	*******	Remainder	*******
Bile	2mL	*******	Remainder	*******
Vitreous Humour	2mL	*******	*******	*******
Stomach Contents	*******	*******	All	*******
Liver	*******	*******	*******	200g
Lung	*******	*******	*******	100g
Kidney	*******	*******	*******	100g
Brain	*******	*******	*******	100g

Specimens should be uncontaminated if possible and preserved as indicated. Prevention of bacterial or fungal growth is especially important in the examination for the presence of ethanol.

The rationale behind toxicological testing should not require much elaboration. However, some pertinent points will be emphasized.

The detection of some classes of medicines such as tranquillizers and illicit compounds may indicate the need to investigate the victim's psychological status. Psychomotor, perceptual or judgemental performance decrements may result from drug ingestion or accidental exposure to a variety of environmental toxins.

Samples should be obtained from all accident victims, if possible. Specimens from passengers may function as controls for samples obtained from flight crew and provide valuable evidence as to, for example, the presence of fermentation producing ethanol.

Fire patterns may be discerned through the detection of distribution patterns in the levels of hydrogen cyanide or carbon monoxide in cabin crew and passengers. Carbon monoxide in flight crew may suggest a causal contamination problem due possibly to faulty heat exchangers.

Victims of crop-spraying accidents should be screened for the presence of pesticides or herbicides and the inhibition of cholinesterase. Accident investigators should be warned of the dangers of contamination in investigating agricultural accidents and be given adequate protective suits and equipment. They too should be tested if they experience symptoms.

Post-mortem biochemistry

Apart from those post-mortem biochemistry tasks normally part of forensic toxicology, other tests are generally not useful in air accident investigations owing to the length of time elapsing from time of death to discovery and autopsy.

THE INTERPRETATION AND VALUE OF THE PATHOLOGICAL EVIDENCE

The determination of the cause of death of each person

Many bodies from an air crash will be extensively damaged by mechanical forces and by burns. It is tempting for those not aware of the value of the pathological contribution to an aircraft accident investigation to ascribe death to burning or to multiple injuries based on a superficial external post-mortem examination. A fire produces so many additional factors that such an analysis represents little more than guess work; moreover, a superficial examination fails to distinguish between ante-mortem and post-mortem injury. The investigator must keep in mind the differences between ante-mortem and post-mortem injuries particularly in the flight crew; it is important to establish whether death occurred in flight and led to the accident or whether death was the result of the accident.

It is important to determine, if it is at all possible, the precise cause of death in each case in relation both to the technical aspects of the accident investigation and to later medico-legal problems.

The careful external post-mortem examination and internal autopsy and the laboratory investigations referred to earlier will frequently allow a precise diagnosis of the cause of death to be made as in the following examples:

a) following the death from heart disease of a pilot at the controls of an aircraft, the resultant crash could cause multiple injuries to his body which external examination alone might suggest were the cause of his death. Internal examination supplemented by histology may reveal severe coronary artery disease, coronary artery thrombosis, recent silent myocardial infarction, or myocarditis - whichever heart disease had caused his death at the controls;

b) if a passenger had sustained head injury of lethal severity, important conclusions could be drawn as to the survivability of the accident. Internal and subsequent laboratory examination, however, showing swallowed carbon in the oesophagus and stomach, inhaled carbon in the trachea and bronchi, congested oedematous lungs and a raised carboxyhaemoglobin level in the blood, would show the true cause of death as burning. The head injury might then be ascribable to heat and its interpretation would be quite different;

c) a husband and wife might both appear to have sustained multiple injuries and incineration. Detailed autopsy and laboratory examinations might show the one to have died as the passenger referred to in b) above while the other having a ruptured aorta and no evidence of survival during the post-crash fire had died from injury. It could then be held that the former had survived the latter with far-reaching medico-legal implications regarding the disposal of estates.

The nature and cause of injuries and their timing

This refers in particular to a single major lethal injury sustained by a victim or to potentially incapacitating injuries that would have prevented a conscious and otherwise capable person from effecting his own escape. An assessment of the nature and cause of injuries is required so that consideration can be given to appraising safety features within the aircraft and to improving them. Examples include penetrating head injuries or crushing fractures of the lower legs. Both of these may suggest an unsatisfactory design of the back of the seats in relation to those situated immediately behind them.

The causes of unusual types of injury need to be fully examined. On more than one occasion conclusions have been reached as to which pilot was actually at the controls of an aircraft when it crashed, based upon the nature of the injuries to the hands and wrists or feet and ankles as determined both by naked eye examination at autopsy and by radiographs.

Sabotage and the possible injuries due to blast or shrapnel from explosive devices must not be missed. Tissues from around any such suspect wounds should be preserved by the pathologist for laboratory analysis for the appropriate trace evidence. Injuries so caused will be reflected in damage to the clothing; the dangers of premature removal of clothing purely for the purpose of identification are, thereby, emphasized.

The detection of disease or impaired efficiency in the flight crew

The autopsy and subsequent examinations may reveal disease as the unequivocal cause of death of one of the pilots and, therefore, as already suggested, provide a strong clue to the likely circumstances or cause of the accident. It cannot be too strongly emphasized, however, that evidence that a medical abnormality was present in a pilot is usually a long way from proof that the abnormality was either the cause of his death or connected with the accident. A list of diseases known to cause sudden complete incapacitation and death in apparently normal healthy persons can readily be prepared. It would include coronary artery disease with or without thrombosis, myocarditis and ruptured cerebral arterial aneurysm, for example. However, severe coronary artery disease and myocarditis can be present and consistent with normal function and both are known to have an appreciable incidence in the normal population. The presence of either could be coincidental in a pilot whose aircraft had crashed because of some technical failure. Similarly, in the presence of extensive cranial injury it would be only a careful examination that would reveal a cerebral arterial aneurysm. Even if found, it might be difficult to be sure whether it had ruptured in life or had been traumatically ruptured as part of the cranial injury.

Pilot function may be adversely affected, especially in managing some in-flight emergency, by almost any form of illness, however minor, even though clinically unsuspected. The detailed autopsy and subsequent laboratory investigations advocated imply that every effort will be made to discover whether the flight crew were suffering from any disease or illness or whether they were suffering from any form of intoxication or any possible effect of having taken drugs. When all investigations have been completed and no evidence of any disease or cause for impaired function has been found, it is possible to state that this has been excluded, for practical purposes, as an event or cause of the accident. When some evidence has been

found of disease or potential cause of impaired function, very careful consideration must be given to the nature of the condition, its potential for affecting function, and any discovery of an alternative hypothetical cause for the accident derived from the engineering and general investigation of the accident. When correlation of all this evidence has been effected by the Investigator-in-Charge, through the reports of the Human Factors Group and other groups, it will be possible to put forward any theory formed concerning human factors on the flight deck in relation to the circumstances and the cause of the accident with a balanced judgement as to its probability.

Evidence to be derived from the examination of passengers and cabin crew

The volume of work involved in an accident with many fatalities dictates that the autopsy examinations and organ and tissue sampling of bodies known to be those of the passengers should be less extensive than for the operating crew on the flight deck or in the cockpit. Nevertheless, there are certain points that should not be overlooked in the examination of any body.

Sufficiently detailed examination and sampling of these bodies are required to provide the precise cause of death:

a) an estimate of deceleration forces, derived from the state of the heart, aorta, diaphragm, liver and spleen together with the presence of fractures in sternum, spine and pelvis;
b) an assessment of any evidence of seat belt injury and associated cranio-facial damage;
c) evidence of survival in fire as shown by the presence of raised carboxyhaemoglobin levels in blood or tissues;
d) the presence of microscopic changes in the lungs relevant to ante-mortem injury, to life during fire and possibly to such medico-legal questions as survivorship which may subsequently arise;
e) for medico-legal reasons note must also be taken of the presence of any pre-existing disease if subsequent compensation claims are to be settled with equity.

Examination of the bodies of passengers can establish a pattern of injuries. Such a pattern may be uniform or discordant. A uniform pattern suggests that all the passengers were subjected to much the same type and degree of force. A typical example is the combination of cranio-facial damage, seat belt injury and crushing of the lower legs associated with passenger tie-down failure in the classic crash situation. Much additional information may be derived by comparing the pattern of injuries in the passengers with the pattern in the cabin crew e.g. were the cabin crew braced for an emergency or were they in their normal operating positions.

In the discordant pattern, one group of passengers may show injuries distinctive from the remainder. This could suggest some unusual incident and the interpretation of the findings depends to a large extent on accurate identification and location in the aircraft according to the passenger seating plan. The possibility of a single body showing a deviation from the norm must always be remembered. It may be the only means by which a case of sabotage or unlawful interference with the operation of the aircraft is revealed.

RELEASE OF HUMAN REMAINS AND PERSONAL PROPERTY

Although it is preferable to retain all bodies either until all have been identified or until no further identifications are possible, bodies should be released to the local or national authorities when possible provided:

a) all the information relevant to the investigation has been derived from the cadaver;
b) there is no possible doubt as to the identity of the body.

After identification of all bodies has been established and there is no further need to retain bodies from the point of view of the accident investigation, it is normally the responsibility of the local or national authorities to return them to their families with a suitable identification notice and death certificate. (Where repatriation is required, additional permits and certificates might have to be obtained permitting the transport of the bodies or remains to other localities, districts or States.)

Regulations vary, but it will often be found that a certificate in the language of the victim's State, signed by the pathologist who carried out the autopsy, stating the body's identity and recording the precise cause of death, will facilitate repatriation and ultimate disposal.

CORRELATION WITH THE AIRCRAFT WRECKAGE EXAMINATION

The cockpit

Correlation between the degree of cockpit damage and the degree of injury to the pilot is essential. Anomalous findings may give a clue to such accident causes as failure of the automatic pilot or attempted interference with the normal operation of the aircraft. Injuries discovered should be, whenever possible, related to specific items of equipment in the cockpit. To this end a search should be made for the presence of blood and other tissues on the seats, instruments and control columns. In certain circumstances it may be necessary to identify such evidence as being related to specific flight crew members or, conceivably, to show that the tissues are not human - for example, evidence of bird strike.

The damage to and the general status of the flight crew seats and safety harness should be recorded as being pertinent to the reconstruction of events in the cockpit at the time of the accident, immediately afterwards, and to the possibilities of survival and escape.

The passenger compartment

A detailed examination and description of all seats, their attachments, seat belts, and other safety equipment and surrounding structures should be made. It is a prerequisite to a survivability study. Displacement of fasteners and evidence on the belts themselves may give an indication of the forces involved. The size of fastened but torn belts should always be measured. It might be possible to deduce the size of the seat occupant from such measurement although it should be borne in mind that seat belt adjustments may vary considerably. Of greater importance, the overall tightness of belts should enable the investigator to distinguish between a cabin that has been prepared for an emergency landing and one in which the passengers have been sitting with their belts lightly fastened as a routine. Findings of this nature must certainly be correlated with passenger seating plans when available and with the results of the autopsy examinations. When seating plans are not available and when local or national authorities removed bodies but did not record their location, clues may often be discovered as to the seating of passengers; for example, a book or handbag found in the compartment on a seat back will suggest a probable location of its owner. Fragments of fabric, fused to aircraft structure, compared with clothing removed from bodies may permit deductions about the location of bodies - at least where the bodies came to rest, if not their seat locations.

OTHER MEDICAL ASPECTS OF THE HUMAN FACTORS INVESTIGATIONS

Flight crew medical and personal records - Basic mental and physical health

The medical records of the flight crew must be studied to find out whether any condition was known to exist which might have precluded the successful completion of the demanded task in the prevailing circumstances. Particular attention should be given to any condition likely to have led to incapacitation in flight or to a deterioration in fitness and performance. The possible cause of incapacitation or lowered efficiency of performance is, theoretically, the range of the diseases of man but, with adequate medical supervision of crews, gross abnormalities are unlikely to be present.

Any information obtained from the medical records must be correlated with the pathological findings. Many functional abnormalities, however, are not demonstrable at autopsy - epilepsy being the prime example. Visual and auditory acuity of the crew should also be noted but, again, it will be the essentially negative pathological findings in an accident suspected of having a human factor cause that will focus attention on these systems.

In certain circumstances, the flight crew background should be investigated and this will include consideration of such matters as motivation for flying, general intelligence, emotional stability, character and behaviour. However, well-documented abnormalities of this sort are scarcely compatible with modern flight crew selection methods or effective working as part of an airline operation. It may be that information obtained from friends, relatives, acquaintances, supervisors, instructors, personal physicians and other observers as to both the recent activities and attitudes of the flight crew and to their long-term personal and flying habits, general health and ordinary behaviour may provide information which is of far greater value. This has been called a psychological autopsy (see further reading list).

The recognition and investigation of the psycho-physiological elements underlying many accident causes have not always been given the proper degree of attention. Human elements of perception, judgement, decision, morale, motivation, ageing, fatigue, and incapacitation are often relatively intangible, yet highly pertinent variables. Even when detected, they are difficult to measure and document. It should be emphasized that a positive association between any such abnormality discovered and the cause of the accident can seldom, if ever, be better than conjecture. Despite these difficulties, every effort must be made to investigate and report upon such human factors as fully as possible. It may be necessary to include a psychologist familiar with aviation in the Human Factors Group.

The problems of a particular flight

Many matters that are not of a medical nature may be pertinent to the Human Factors Group and it is here that a close liaison with the Operations Group is essential.

Some of the general problems of this type include:

a) the flight plan - with particular reference to instructions given and deviations made from those instructions;
b) the flight equipment - ranging from items such as the aircraft type, to cockpit layout, mechanisms for cabin pressurization, ventilation and temperature control;
c) the navigation aids - particularly whether they were used to their full extent;

d) the flight environment and flight phase - which should include a consideration of the possible presence of fumes from the engine fluids and fuel and also of toxic substances from the cargo;
e) assessment of the workload of the crew at the time of the accident.

The importance of this information to the Human Factors Group is essentially to guide them into significant areas of investigation on their own account. For example, a deviation from the flight path might suggest a need for an examination for carbon monoxide intoxication; a suspect pressurization system might indicate a need to confirm or exclude hypoxia as a cause of the accident. The itemization of likely toxic causes will simplify and direct the work of the toxicologist. These are the sort of matters that emphasize the need for frequent meetings of the heads of the investigation groups and the need for adequate exchange of information at such meetings.

Special problems of the particular flight especially concern those aspects of possible impairment of flight crew fitness and performance that are not demonstrable by autopsy. Errors and deficiency of performance may occur whether operations are as planned, whether unexpected conditions develop, or whether emergencies arise. The cause of these errors and performance decrements may be found in:

a) errors of perception. These may be related to auditory, visual, tactile or postural stimuli;
b) errors of judgement and interpretation. Misjudgement of distances, misinterpretation of instruments, confusion of instructions, sensory illusions, disorientation, lapse of memory, etc., fall into this category;
c) errors of reaction. These particularly relate to timing and co-ordination of neuromuscular performance and technique as related to the movement of controls;

Contributing causes of errors and performance deficiency may lie in such areas as:

d) attitude and motivation;
e) emotional affect;
f) perseverance.

All these factors are likely to be exaggerated by fatigue which is an ubiquitous but elusive factor in aviation operations. It is in the evaluation of these potential factors that the Human Factors Group may be of invaluable assistance to the Investigator-in-Charge.

The Human Factors Group must distinguish carefully between hypothesis and genuine evidence; whenever possible, factual evidence must be adduced before an accident can be ascribed to a psycho-physiological factor. For example, it may be suggested that the pilot was particularly irritable at the time of the flight. However, a replay of the recordings of his in-flight transmissions may give far better evidence as to whether this effect was operative at the time of the accident.

The medical contribution in the survived accident

Generally, this is a more straightforward matter than the accident in which all the aircraft occupants were killed for it largely involves the examination of living and probably co-operative subjects. Essentially the Human Factors Group will be looking for the same type of evidence as that derived from the pathological examination of those killed.

A medical examination, preferably by an aviation medical specialist or qualified aviation medical examiner, should be made on surviving flight crew members to find out whether any physical, physiological or psychological factors in the operating crew had a bearing on the circumstances of the accident. Such interrogations are likely to be harrowing to those being questioned. Interviews should be

properly planned and co-ordinated through the Investigator-in-Charge. A medical assessment might differ depending upon whether it was carried out soon after the accident before debriefing by other investigators, or at a later time after interview by others.

It might be desirable for blood and/or urine samples to be taken for analysis both for the presence of therapeutic substances and to help to determine whether any abnormal state such as hypoglycaemia may have been present. Before taking such specimens, however, the investigator should ensure that there are no local legal contraindications. The consent of the subject should be obtained and the purpose of the tests explained before they are undertaken.

The crew should be interviewed but this should be co-ordinated through the Investigator-in-Charge to ensure that there is no undue duplication because of the needs of the various Groups.

A detailed record should be made of injuries to all occupants with an assessment of their cause. The findings must be collated with their seat position, or location in the aircraft, and adjacent environment so that preventive action such as redesign may be considered.

If the aircraft has been evacuated in the presence of fire or similar hazard (e.g. sinking with a ditching), a full account of each person's escape is a valuable contribution to an assessment of factors influencing success or failure.

As the aim of accident investigation is prevention, attention should also be given to the psychological effects of the accident upon the flight crew before they are allowed to return to flying duties. The psychological effects of any accident upon the rescuers should not be forgotten. Adequate, regular debriefing sessions may help prevent the occurrence of Post Traumatic Stress Disorder.

SUMMARY

The composition of the Human Factors Group must be chosen on the basis of the type of accident and the evidence likely to be available from human sources. Specialists in aviation medicine will be of greatest value when there are many survivors but pathological assistance will be required whenever there are fatalities.

Particularly in the event of a totally fatal accident, the pathological evidence is an essential part of the medical investigation. The Investigator-in-Charge must ensure that important investigative information is not sacrificed to meet social and legal desires for rapid identification and disposal of bodies. To this end, he should, if possible, obtain the services of a pathologist familiar with aircraft accident investigation who is capable of co-ordinating the two interdependent functions of investigation and identification.

The prime object of the pathologist should be to obtain evidence as to the cause, sequence and effect of the accident through an examination of the operating crew, the cabin crew and the passengers. Coincidentally with this investigation, evidence of medico-legal significance as to identification will automatically emerge, particularly if each examination is enhanced by the co-ordinated efforts of the pathologists, police, odontologists, radiologists, etc.

The pathological examination will be greatly helped by adequate preplanning - particularly in relation to the recovery of bodies and the provision of whole body refrigeration. In the event that plans do not exist, the Investigator-in-Charge should ensure facilities for the pathologist to carry out the following minimal requirements based on investigative, medico-legal and sociological needs:

a) identification and complete examination of the operating crew on the flight deck or in the cockpit;
b) a full external examination of all fatal casualties;
c) identification of the cabin crew and comparison with the passengers;
d) minimal internal autopsy on all casualties to include:
    1) establishment of the cause of death;
    2) discovery of major disease likely to influence life expectancy; and
    3) assessment of deceleration injury to:
        - cardiovascular system, liver and diaphragm
        - head, sternum, spine and pelvis;
e) selection of blood specimens from all casualties for carboxyhaemoglobin studies;
f) collection of lung specimens from all casualties for estimation of the mode of death.

An experienced pathologist will interpret his findings with caution. For their part, the head of the Human Factors Group and the Investigator-in-Charge must ensure that the pathological findings are taken as but part of the investigation as a whole and are fully correlated with evidence adduced within the Group and by other Groups. Experience has shown that this is facilitated and maximum advantage gained if the pathologist attends the periodic briefings by the Investigator-in-Charge.

FURTHER READING

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5. SJH Véronneau: 2002: Aircraft accidents: Investigation and Prevention. In *Fundamentals of aerospace medicine.* 3rd Ed. R DeHart (Ed). Lippincott, Williams and Wilkins.

6. R E Yanowitch, S R Mohler and E A Nichols: 1972: *The psychosocial reconstruction inventory: a postdictal tool in aircraft accident investigation.* Aerospace Medicine 43 (5): 551-4.

7. INTERPOL: http://www.interpol.int/default.asp

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ATTACHMENT A. AIR ACCIDENT LABORATORY SUPPORT

Some of the reasons for a national reference laboratory include the following:

a) to ensure standard results across the country, with a high level of expertise;
b) to provide rapid response to investigators;
c) to offer special tests not performed by other forensic laboratories, but which are required by air accident investigators;
d) to work at levels of sensitivity which would pick up sub-therapeutic and trace concentrations of analysed compounds;
e) to provide forensic analyses on tissue samples in cases where fluids are unavailable;
f) to assist in the interpretation of results with respect to a causal, contributory or incidental role in accident occurrence or impact on survivability;
g) to undertake special studies as may be required to determine human factor input to the accident;
h) to keep a computerized data archive of relevant toxicological, biochemical and pathological findings to detect disease prevalence, drug use or toxin exposure from a national perspective.

State-of-the-art methods and instruments should be used by the laboratory to ensure competent screens and specific analyses. Appropriate standards should be tested with every sample to verify results.

The laboratory should participate in national level proficiency testing for quality and quantity control tests of alcohol and common drugs in biological fluids.

The verbal reporting time for ethanol, carbon monoxide and hydrogen cyanide should be within five to seven working days after receipt of samples. More demanding tests require more time, but a complete report should be issued after two to five weeks.

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Part IV

Chapter 2. ODONTOLOGICAL IDENTIFICATION

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INTRODUCTION

Forensic odontology is the area of dental practice encompassing the interaction of the dental team with the legal system. The major contribution of forensic odontology is assisting the police or other authorities in charge with identification of unknown human remains. Forensic odontology may include further activities as determination of age; tooth mark and bite pattern analysis; physical assault (child abuse); and malpractice. Forensic odontologists synthesize principles, knowledge and competence from many aspects of dentistry with those of other disciplines, as for example forensic pathology/medicine, genetics, anthropology, and criminology.

Identification by dermal-ridge fingerprints, dental means and/or DNA profiles is widely acknowledged as scientific and therefore used as so-called primary evidence, which means that it can stand alone as identification tools. This chapter is aimed at presenting an overview of forensic odontology with special emphasis on person identification as it is practiced today in mass disasters. The presentation will focus on the approach recommended by the International Criminal Investigation Organization - Interpol - and described in the Interpol Guidelines for Disaster Victim Identification (DVI) which are available from the website (see list of further reading). The guidelines include a form set of which two pages (F1 and F2) are reserved for recording dental ante mortem (AM) and post mortem (PM) information.

ORGANIZATION AND TASKS OF THE DENTAL TEAMS

Planning is crucial for successful DVI in situations with multiple casualties, such as natural disasters and aircraft accidents. A forensic odontologist with extensive experience in identification work involving foreign nationals should be appointed to the identification commission (the aviation pathology team) responsible for the organization and legal aspects of the identification process. During the investigation, the appointed forensic odontologist should confer with the chairman of the identification commission or the investigator-in-charge as appropriate. The forensic odontologist is able to contribute both to the accident investigation and to the identification of victims. The odontologist will further ensure availability of instruments and equipment needed and call upon additional staff as required.

Recovery group

Dental knowledge is essential for recovery and preservation of odontological evidence. On the site, the main task of the forensic odontologist is to give a preliminary description of the face and dentition of recovered bodies and otherwise help in the search for bodies or body fragments and assist whenever required. In case of badly burnt or maimed bodies, a preliminary description of the teeth has to be made and dental radiographs taken with portable X-ray equipment before handling and transporting the body. The forensic odontologist may even choose to complete the post-mortem registration at the scene of the accident.

Ante-mortem recording group

An ante-mortem (AM) dental data collection centre chaired by an experienced forensic odontologist should be set up as early as possible after the accident. In the aftermath of a disaster with significant numbers of victims, the local police or other approved authorities will contact dentists known to have treated specific missing persons. Access to AM dental data may differ widely from country to country, usually as a consequence of different regulations for dental record keeping. Forensic odontologists, with or without assistance from other professionals (police, forensic pathologists, etc) may facilitate the collection of dental AM data by making use of their national or world-wide contacts. The collection of AM dental information is routine in many countries, but less well established in other countries. In the latter case, guidelines from

the AM data centre should be provided detailing material to collect: dental records that are on file, conventional or digital radiographs of teeth, jaws and/or scull, dental casts or models, etc. It is equally important to give instruction on how to forward and ensure proper labeling of the AM information. Original records including x-rays are irreplaceable and may get lost if sent by ordinary mail or released to relatives or other individuals acting on behalf of the victim. To cope with this obstacle, dental AM data (records, x-rays, photographs) should be duplicated and originals kept and stored safely by the AM dental data collection centre based in the country of residence of the victims. The forensic odontologists attached to this centre may be referred to as the 'home dental AM team' or just the 'home team'. Duplicated radiographs and photographs should be clearly labeled. Alternatively the home team could enter the AM information on the DVI dental forms (yellow pages F1, F2) and forward the data to the on-site personnel via electronic transmission through a secured website and after encrypting the data. The latter method would take advance of home AM teams being able to better understand text written in their own language and translate abbreviations and characteristics which may be difficult to interpret for international teams. In case of foreign nationals, it may be advisable to obtain assistance of forensic odontologists who are compatriots of the victims involved, and who may contribute by working together with the on-site personnel by translating and checking information forwarded to the AM data collection centre. As a rule, teams of two forensic odontologists are preferable in the handling of the incoming AM material to check for discrepancies and to minimize errors while transferring the data to the appropriate forms. It is equally important that the AM data from dental records are quality checked; whether the entry is done by the home team or at the site of accident.

Post-mortem dental examination group

There will always be pressure from distressed relatives, media and political authorities to start the PM examination immediately. Priority ought to be given to photographing faces of the victims before decomposition starts and to planning a system of numbering that follows the victims, their forms and samples throughout the identification process. At present, bar coding would be a proper system to consider. As the teeth and dental structures are fairly stable under variable conditions, the forensic odontological examination may wait until adequate working conditions are established. Provided working conditions are adequate, several re-xaminations may be avoided and in the long run time may be saved. Essential dental autopsy equipment includes cameras, preferably digital cameras, and portable x-ray machines. The examination kit may further include UV-light to trace tooth-coloured restorations that may otherwise easily be overlooked. The PM examination should be carried out in the mortuary, whether permanent or temporary. Beforehand the identification commission should decide on the management of the DVI operation, preferably based on the Interpol DVI guide, and subsequently provide standardized protocols and procedures for pathology, odontology, photography, fingerprinting, re-examination, transportation of bodies, chain of custody and DNA profiling. Furthermore a decision should be made on the sequence of examinations to follow, for example fingerprinting, pathology and odontology.

A post-mortem (PM) dental data collection centre chaired by an experienced forensic odontologist should be set up as early as possible after the accident. Instruction to all PM teams should be given by the on-site PM team leader in charge before work is begun; the initial instruction should be followed by regular updating. The standards for the dental operating procedures should clearly define details included in the examination, such as type and number of photographs, type and indications for radiographs, level of details for tooth and dentition registration, and sampling of teeth for potential DNA profiling. The standards could further state that, as a rule, the recording of the dental status of the body, including the production of a radiographic and photographic record, should be performed by teams of two forensic odontologists - one is the examiner and the other is the recorder, who fills in the DVI forms (pink pages F1 and F2) and monitors the registration. Working in pairs of two forensic odontologists would allow for cross checking (quality control) and for discussion of problems and exchange of opinions. Finally the standards decided upon should state whether it is acceptable to deglove the face, to resect the mandible, and to remove jaws or jaw fragments from the body.

Comparison and identification group

The comparison and identification centre should, just like the AM and PM data collection centres, be chaired and staffed with forensic odontologists experienced within the field. Individuals with numerous complex dental treatments are usually easier to identify than those with no or fewer restorative treatments. Difficult cases (e.g., cases with insufficient AM information or where comparison of AM and PM data sets does not result in immediate identification) accumulate over time, and therefore it is of paramount importance that the reconciliation and identification team continues to be staffed for the duration of the operation with odontologists of adequate forensic experience. By carefully exploring the written dental records, the dental charting and the dental x-rays, clues for comparison can be found. Photographs of a dentition may be helpful in the comparison situation and provide clues on whether to pursue further investigations. Facial photographs, in particular smile photographs, may disclose specific features of the anterior teeth to be compared for a match against other available photographs. An evaluation of concordant features and of their relative importance should be performed. Similarities and discrepancies, both those that can be explained and those that cannot, should be recorded in the comparison report. Explainable discrepancies usually relate to the time elapse between AM and PM records but if a discrepancy is unexplainable, then exclusion must be made. The dental comparison report is then transferred to the identification team/board-in-charge for evaluation and discussion at reconciliation sessions ending up with the statement on the dental identification, including a description of the essential evidence, and written in a way understandable to non-experts. Finally the identification form is signed, preferably by two forensic odontologists to ensure strict control and accountability. In case of foreign citizens, the form may as appropriate be countersigned by forensic odontologists delegated from the countries involved.

ODONTOLOGICAL IDENTIFICATION

Proper collection, handling, storage, and processing of data are prerequisites to arrive at correct person identification by dental means. In single person accidents as well as in mass disasters, the underlying principles of dental identification remain the same: recording and comparing of the AM and PM data, and from there drawing an identification statement, which the forensic odontologist must be prepared to defend in court, if necessary. In mass disasters, however, challenges are magnified due to multinational victims, body fragmentation, mutilations, comingling, incineration, etc.

Changes brought about by age, pathological conditions, anomalies or by intervention of a dental surgeon result in the mouth being unique to the individual. Most often dental identification is based on a detailed consideration of the restorative work replacing areas damaged by dental caries. A full description of the individual dental restoration, including type of material used and surfaces restored, serves as a baseline for the comparison of the dental status AM and PM. Moreover, a comparison between AM and PM radiographs is essential and may often lead to identification or convincing proof of exclusion of an individual. The comparison between AM and PM data may yield one out of three outcomes: positive identification (identity established), corroborative identification (identity possible, identity probable), or identity excluded. The number of concordant characteristics that satisfy established dental identity has been and is still a subject for discussion. Many years ago twelve concordant characteristics, as required for dermal-ridge fingerprint identification, were proposed as the threshold for dental identification. However, distinction between common dental characteristics and those that are individual is a key factor to be considered before establishing that a combination of individual characteristics is unique to a person. In some cases a single tooth can be used for identification if it contains sufficient unique features. Radiographs and clinical photos will often provide the key for the uniqueness.

The success rate of dental identification is thus dependent not only on the character of the case (physical destruction by mutilation, fire, putrefaction, etc.) but also on community based parameters as for example

prevalence of dental disease, predominant modality of treatment, availability of dental service, and the existence and accessibility of good AM records. The contribution of dental evidence in person identification has been and continues to be substantial in single as well as mass disasters. Identification by dental means is less powerful in children and young adults with no or few restorations. In these situations dental structures, as mirrored on intraoral radiographs, can provide indicators of the individual's chronological age; in children by analysis of tooth development and subsequent comparison with developmental charts, in sub-adult ages by use of eruption dates of the teeth, and in young adults by use of third molar development.

There is no universally accepted form on which to transcribe the dental AM and PM information. While forensic odontologists continue to use a variety of dental forms, the dental data sheets of the Interpol DVI form set are now being adopted by more and more forensic odontologists in a number of countries. This trend may ultimately minimize the international diversity of information from which to draw the identification statement. The Interpol form set is reviewed every five years; the forms can be downloaded from the Interpol website (see list of further reading).

The key to successful mass disaster identification is preparedness, and many countries have appointed national or regional multi-disciplinary DVI teams or identification commissions to handle situations with multiple casualties. Others countries have no official mode of proceeding in case of mass disasters but employ "ad hoc" committees in DVI or contract private companies. Overall, DVI teams should, as a minimum, include experienced police officers/fingerprint experts, forensic pathologists, and forensic odontologists.

A number of software programmes have been designed to speed up the paper handling in mass disaster situations. Direct entering of data into the computer programme, as part of both the PM data recording in the mortuary and the AM recording at home, is expected to become routine and will undoubtedly save time and manpower. Furthermore, the ease of electronic import and export of data keeps writing errors etc. at a minimum. It can be foreseen that data miners/software experts will be attached to the DVI teams. Among the available programmes is a software programme designed to handle information from all sections of the Interpol DVI form that was developed by Plass Data Software A/S (see list of further reading) in the mid-1990s on initiative from the Norwegian and Danish Identification Commissions. Since then the software has been revised, updated, and further improved as a result of close co-operation between the developers and users representing DVI teams and experts across the world. The system, known as DVI System International, is at present the only internationally approved DVI software programme. It provides exact replica of the Interpol DVI form set and works in the four Interpol languages: English, French, Spanish, and Arabic. The forms have further been translated into a number of other languages on request from the customers. The system provides a number of functionalities, including search options to assist in dental data matching, necessary for final assessment.

COMMUNITY BASED PARAMETERS AFFECTING THE SUCCESS RATE OF ODONTOLOGICAL IDENTIFICATION

National dental health data

A working knowledge of the oral health status among citizens is essential to forensic odontologists. Further demographic factors to be aware of are differences in achievement of dental health gain between groups of the society, in dental health status between indigenous population and ethnic minority groups, and between men and women.

Variability in standard and quality of dental records

The identification statement is based on the assumption that the ante-mortem records relied on were correct and adequate as to name, dates, written and charted notations, etc. The information available so far suggests large variations in the standard of dental record keeping around the world. Experience from mass disasters indicates that dental records of good quality, including charts and x-rays, are available from Northern, Western and Central Europe, North America and Oceania, whereas dental records are limited and hard to obtain from other parts of the world, in particular Eastern Europe and Asia. In the early 1970s, a two-digit notation was proposed as an international standard, but so far this so-called FDI notation or its variant ISO 3950 is not universally used. Abbreviations for recording dental treatment in notes and charts are commonplace world-wide, but no internationally approved standard codes for the recording of various forms of dental treatment, anomalies, etc exist. The variations in dental recording with regard to notation, charting systems and abbreviations, make it important that forensic odontologists and not police officers or forensic pathologists interpret, record, and translate AM dental information.

IDENTIFICATION BY DNA "FINGERPRINTING" OF DENTAL TISSUE

In case of an inadequate number of teeth in the bodily remains or unavailability of dental records, identification and gender determination based on DNA analysis can be performed, provided tissue samples from parents or siblings (buccal swabs) or a known AM sample can be obtained and used for comparison. Teeth are a useful source of DNA material and various regions of the teeth, such as the crown body, root tip and, in particular, root body, provide sufficient quantity of DNA to support DNA extraction thus justifying extraction from a found tooth fragment. The latter may occur after explosions or airplane crashes, because human remains are then often fragmented and comingled. Genomic DNA found in the nucleus of each cell of a tooth's calcified tissues (dentine and cement) and pulp is the primary source for forensic application but the cells also contain mitochondrial DNA, which with time may become the basis of a powerful technique in dental identification. The major protein found in human enamel has a slightly different size and pattern of the nucleotide sequence in male and female enamel. These differences are sufficient to be used as a sensitive gender determinant for very small samples of DNA from unknown human skeletal or dental remains.

INTERNATIONAL CO-OPERATION AND COMMUNICATION IN FORENSIC ODONTOLOGY

Interpol is the official channel for exchange of information on dental as well as other evidence related to missing persons and unidentified bodies. To ensure minimum standards, the Interpol DVI Standing Committee is continuously working on guidelines for identification of foreign disaster victims. The Interpol DVI guidelines further provide specific recommendations to member states on international co-operation for identification of victims of mass disasters, according to which member states are encouraged to establish a national DVI team as well as a liaison team to be activated in case of mass disasters abroad. Whenever foreign nationals are involved in mass disasters, the country in charge of the identification should rapidly establish and maintain, directly or through Interpol, close co-operation with corresponding authorities in the victims home countries. Member states are advised to explore the possibility of one or more of their experts travelling to the site to attend or assist in identification of their own as well as other nationals. Despite effective collaboration between forensic experts, the differences existing between legislation and medico-legal systems may still hamper the rational and optimal coordination of the medico-legal investigation of a mass disaster. These obstacles were faced initially but mostly overcome with time during the hitherto largest, multinational DVI operation ever conducted after the Indian Ocean tsunami disaster in Thailand in December 2004. Complex challenges arose, related to identifying about 3000 victims from approximately 30 countries while working in temporary morgues. The DVI teams consisted of about 600

persons from Thailand and approx. 30 other countries and included forensic odontologists from over 20 countries. Identification of most tsunami victims in Thailand relied on dental means and fingerprints rather than DNA results; the significant contribution of dental evidence in this large-scale multinational operation is consistent with experience in other disasters. The operation resulted in relationships being built between DVI teams and experts from many nations, and skills, experiences and knowledge have been exchanged. To further increase and consolidate the forensic odontology response capabilities, the DVI Forensic Odontology Working Group, working under the auspices of the Interpol Standing Committee on DVI and comprising specialists in DVI responses and methods, has established a number of subgroups to work on important issues identified during recent disaster operations; among the action points to work on are updating and improvement of the DVI Guide and Forms and the software DVI System International including suggestions on an international standard for dental codes. Accreditation of DVI forensic odontologist, based on qualifications and experience, is a further issue of concern, because forensic odontology is a specialty that cannot be carried out by dentists without training and experience within the field.

The International Organization for Forensic Odonto-Stomatology (I.O.F.O.S.; see list of further reading) works as a unity among its constituent national societies (June 2008: 20 societies). A major objective for the organization is to provide a liaison between societies for forensic odontology on a global basis. The Worldwide Forensic Odontology Contacts archive, also called “The Burgman List”, is a list of forensic odontologists to be used by dental DVI teams or other authorities requiring assistance on ante-mortem dental information, etc. (Country index as of November 2005 encompassing 120 countries). The list is periodically updated and hosted by the I.O.F.O.S.

SUMMARY

Planning is crucial for successful DVI in situations with multiple casualties, whether a man-made accident or a natural disaster. The key to successful mass disaster identification is preparedness, and many countries have appointed multi-disciplinary DVI teams or identification commissions to handle such situations. Standardized protocols and procedures for odontology including radiography and photography should be provided from the team leaders in charge before the recordings are initiated. There is no universally accepted form on which to transcribe the dental AM and PM information but the dental data sheets of the Interpol DVI form set are now being adopted by more and more forensic odontologists in several countries. As a rule, teams of two forensic odontologists are preferable for recording and handling AM and PM data. The data should be quality assessed during recording and before being entered into databases. The concluding comparative dental identification makes use of and evaluates the two sets of recordings systematically, tooth by tooth. The system, known as DVI System International, is at present the only internationally approved software programme that supports data processing and dental data matching, required for the final identity assessment.

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