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Autopsy Biosafety

"The danger to the operator can be eliminated in the most simple and complete manner without in the least degree impairing the efficacy of the examination."

J. Jackson Clarke[1]

During the course of work, the autopsy pathologist and staff members encounter a number of potential biohazards. By adhering to strict safety precautions, practicing proper autopsy technique, and using proper instruments and equipment, the pathologist can limit the risk of injury to individuals working at the autopsy table. This chapter provides an overview of important autopsy biosafety recommendations for usual hospital-based practice. Many points cannot be discussed in sufficient detail, however. Pathologists must work with their local infection control and occupational health and safety departments to implement a complete biosafety plan that includes ongoing review of all safety concerns and a continuing program of safety education.

In the current age of global travel and bioterrorism threats, there is heightened awareness of the possibility of epidemics of severe disease caused by highly transmissible agents. The experience with severe acute respiratory syndrome (SARS) due to coronavirus in which a high percentage of health care workers were infected offered many lessons in biosafety.[2] The precautions required for such specialized lethal diseases are beyond the scope of this chapter. Suspected cases of these conditions should be referred to the Centers for Disease Control and Prevention (CDC) as soon as possible and hopefully before postmortem examination. Local medical examiners or offices and public health laboratories may provide guidance.[3] The CDC, in association with other federal, state, and local agencies, has designated regional laboratories (Laboratory Response Network) to aid in the diagnosis and containment of lethal transmissible conditions.[4,5]

AUTOPSY INFECTION CONTROL PRECAUTIONS

General Autopsy Biosafety Practices

Historically, most physicians and other healthcare workers have accepted the moral responsibility of caring for patients with contagious disease.[5] The occupational exposure, however, places them at risk for developing communicable diseases. Infective agents such as viruses, bacteria, fungi, parasites, and prions are capable of causing disease in healthcare workers exposed to sufficient inocula, especially when usual body defensive barriers are either disrupted or bypassed. In general, infective material is introduced through accidental puncture wounds from needles or other sharps, splashes into mucous membranes, inhalation, or the passage of the infective agent through preexistent wounds. To minimize the risk of infection, adequate barriers should be in place.

It is the policy of our department to perform as complete a postmortem examination, including brain and spinal cord, as the signed autopsy permit allows. Because it is difficult to ascertain which cases harbor infective agents, it is prudent to consider *all* autopsies as a potential infective source. The cornerstone of any autopsy biosafety program, therefore, is the practice of standard (universal) infection control precautions as established by the U.S. Centers for Disease Control and Prevention, the National Institutes of Health,[6] or the World Health Organization.[7] This approach includes proper attire, barrier protection, care while using sharp instruments, tissue fixation, decontamination of equipment and work surfaces, and hand washing (Box 3-1). It also demands containment and treatment, proper cleaning of spills, immediate treatment of any injuries, and notification of the proper authorities (e.g., Infection Control, Environmental Health and Safety).

General Rules

All autopsies or fresh autopsy tissues must be handled as if they contain an infective agent (standard precautions). The entire autopsy area and its contents are designated a biohazard area and posted with appropriate warning signs. The ideal autopsy suite is well ventilated with a negative airflow exhaust system and contains a separate low-traffic isolation room. Whenever possible, postmortem examinations are carried out during normal working hours by adequate, well-trained staff. It is helpful to have a second autopsy assistant who remains "clean" to record weights, measurements, and other observations, as well as to circulate for any needed supplies. If multiple autopsies are to be performed sequentially, those with the greatest infective risk should be done first, before the staff becomes fatigued. All procedures are carried out in

Box 3-1 Basic biosafety principles for standard (universal) precautions

Prevention of puncture wounds, cuts, abrasions by safe handling of needles and sharp instruments
Protection of existing wounds, skin lesions, conjunctiva, and mucous membranes with appropriate barriers
Prevention of contamination of workers' skin and clothing with appropriate barriers and hand washing
Control of work surface contamination by containment and decontamination
Safe disposal of contaminated waste

a way that reduces the risk of splashes, spills, droplets, or aerosols. All contaminated equipment, instruments, containers, and so forth should be confined to designated areas (autopsy table, instrument table, dissection area, sink). Paperwork leaving the autopsy suite must not be contaminated.

Attire

For all autopsies, personal protective equipment (PPE) includes scrub suits, gowns, waterproof sleeves, plastic disposable aprons, caps, N95 particulate masks, eye protection (goggles or face shields), shoe covers or footwear restricted to contaminated areas, and double sets of gloves. Cut-resistant and puncture-resistant hand protection (plastic or steel gloves) is also available and certainly recommended for high-risk procedures. A retrospective study has demonstrated their effectiveness in reducing injuries.[8]

Use of Sharp Instruments

One should exercise extraordinary care to minimize the risk of injury from sharp instruments and needles. Whenever possible, the use of needles should be avoided. Needlestick injuries occurring during routine autopsy procedures are entirely preventable; blunt needles and bulb syringes should be used to aspirate fluids in most situations. Because many needlestick accidents occur during disposal of needles, needles should *never* be recapped after use. Needles and other sharps should be disposed of directly into the approved receptacle; they should not be left lying around the work area.

Accidental self-inflicted cuts, particularly to the distal thumb and index and middle fingers, are the most frequent injuries sustained by pathologists.[9] This type of injury usually occurs during dissection or trimming of tissues for microscopy. The frequency of hand injuries sustained while performing autopsy procedures can be reduced by several simple practices (Box 3-2). A pair of scissors can adequately substitute for a scalpel during most autopsy procedures, including evisceration. The use of blunt-tipped, rather than pointed, scissors for almost all autopsy tissue dissection is advisable. When dissecting with a sharp implement in one hand, one should apply countertraction on tissues by using a long-handled tissue forceps held in the opposite hand; do *not* hold tissues with the fingers of the noncutting hand. For high-risk cases or dissections, steel-link gloves or some other scalpel-resistant material can be used. Plastic or Kevlar cut-resistant gloves provide protection while still allowing relative dexterity, and we encourage their use whenever possible.

Box 3-2 Rules that reduce injury from scalpels and other sharp autopsy instruments

Minimize the use of scalpels for tissue dissection.
Never use a scalpel to make blind cuts.
Prepare a sufficient number of scalpels before beginning the autopsy to obviate the need for changing scalpel blades during the procedure.
Remove blades only with a special safety scalpel blade remover.
Allow only a single individual to use a scalpel at any given time, especially in a limited dissection area.
Be mindful of where you rest scalpels and other sharp instruments; do not put them haphazardly on the dissection table, but rather place them back in clear sight on an instrument table.
Never hand off scalpels directly; place the instrument on a flat surface for transfer.
Announce in advance any movements that involve repositioning of a sharp instrument.

Rib cutters or shears are used to cut the costal cartilage near the costochondral junction during removal of the sternum. Surgical towels should be placed over the cut edges of the ribs to protect against a scrape injury. When making slices of large organs with a long knife, the prosector should use a thick (3-inch) sponge to stabilize the organ with the noncutting hand. When suturing the body wall at the end of the autopsy, hold skin flaps with a large toothed forceps or toothed clamp rather than with a hand.

Limiting Aerosols

Aerosolization of bone dust during the removal of the calvaria or vertebral bodies can be reduced with a plastic cover or a vacuum bone dust collector, or both, on the saw. A number of systems utilizing high-efficiency particulate air (HEPA) filtering systems are commercially available. Bone surfaces should be moistened before sawing to cut down the dispersal of bone dust. To limit aerosols, screw cap containers are preferable to snap-top, rubber-stoppered, or cork-stoppered containers. When opening capped containers, cover the opening with a plastic bag to contain aerosols and splashes. Do not overfill a blood specimen vacuum tube by applying pressure through a syringe. To avoid spattering, do *not* sear tissue to sterilize it before obtaining a culture. Rather, the organ surface should be swabbed centrifugally with an iodine solution and incised centrally before a sample is removed.

Photography

Photography of fresh specimens requires the same precautions employed for doing the autopsy, and the camera must be kept clean. In situ photographs obviate the additional risk of moving fresh tissue around the room. Photography of fixed specimens is cleaner and, in this respect, preferable, especially when an infective agent is known to be present. Whether the specimen is fresh or fixed, a pan is used for cleanliness during transport of the organ to the photographic stand. The camera should be handled with clean gloves or by a second person

who stays clean. After photographs have been taken, the photostand should be cleaned with disinfectant. Cameras, lenses, and other photographic equipment may be disinfected with a variety of germicidal substances without compromising their functionality.[10] A hands-free camera system would also reduce contamination risk.

Tissue Fixation

Adequate fixation in 10% formalin (containing 3.7% formaldehyde) requires an amount that is at least 10 times the tissue volume; this kills or inactivates all important infective agents except prions and mycobacteria. Embalming fluid containing glutaraldehyde is similarly effective. Mycobacteria remain viable in tissues for days, and these organisms are even difficult to kill with standard formalin fixatives or embalming fluids.[11-13] Mycobacterium are killed in a fixative of 10% formalin in 50% ethyl alcohol.[14] Adequate time must be allowed for fixatives to penetrate tissues before trimming blocks for histology. Fixation of tissue suspected of containing prions is discussed later in this chapter.

Decontamination of Equipment, Work Surfaces, and Laundry

For decontamination, one should use a germicidal solution appropriate for any known or suspected agents. For routine decontamination, all instruments and autopsy devices should be immersed in an enzymatic cleaner or detergent solution for at least 10 minutes, then rinsed with water and decontaminated with disinfectant such as 5.25% sodium hypochlorite (1:10 solution of household bleach in water) for another 10 minutes. Instruments used for infective cases are immersed in an enzymatic cleaner or detergent, then rinsed and soaked in 2% aqueous glutaraldehyde or 1:10 solution of bleach for at least 10 minutes. Glutaraldehye is advantageous because, unlike bleach, it doesn't damage aluminum and steel. One should rinse work surfaces with hot water followed by a 1:10 solution of bleach. Several commercial products containing bleach are suitable. Splashing should be avoided. Floors in the autopsy work area should be cleaned with a detergent solution, decontaminated, and rinsed with water. If available, ultraviolet light provides a secondary source for decontaminating room surfaces and air. All laundry should be treated as contaminated and disinfected in a routine fashion. Any wet clothing, towels, or other reusable laundry should be placed into leakproof biohazard bags before transport.

Remains

After autopsy, one should wash the body with a detergent solution followed by an antiseptic such as a 1:10 solution of household bleach. The body should be rinsed with water and placed in a disposable leakproof plastic body bag. By law, in many states, all bodies with known infective diseases must be labeled as such for the mortician and others who may come in contact with the remains. Usually this is indicated on the death certificate as well. Absence of this warning, however, should *not* be taken to mean there is no risk; all bodies should be handled with caution. We find it helpful to inspect bodies in storage on a daily basis to assess whether there has been any undue leakage of fluid into the body bag. Obviously, fluid accumulations should be carefully removed by aspiration or blotting. If necessary, place a warning on the outside of the body bag, alerting others to the possibility of leaking fluids.

Storage and Transportation of Tissue and Waste

Tissue to be stored should be placed in a nonbreakable, watertight plastic container. Before transporting tissue outside the autopsy suite, the container should be placed in a plastic bag and sealed adequately. Waste for disposal should be double-bagged in specially designated biohazard waste bags, secured, and stored in metal or plastic canisters until removal.

Handling of Spills

Spills should be cleaned up with absorbent, disposable paper towels. The contaminated area should be cleaned with detergent, then decontaminated using a 1:10 dilution of bleach. After the area has been decontaminated, wipe it dry.

Hand Washing

After removing gloves, the pathologist should wash his or her hands with soap and water. In fact, hands should be washed immediately and thoroughly any time they become contaminated.

Employee Health

Employees are strongly urged to be vaccinated against hepatitis B.[15] Each employee is encouraged to maintain tetanus and diphtheria immunity. Other immunizations (e.g., against rubella, measles, and polio) are also advisable. We have initiated preexposure rabies prophylaxis before performing an autopsy on a decedent infected with rabies.[16] However, if exposure as defined by the Centers for Disease Control and Prevention (i.e., potential introduction of virus through skin puncture or contact with mucous membranes) occurs, postexposure prophylaxis that includes vaccination and administration of rabies immune globulin should be undertaken. Smallpox vaccinations for healthcare workers is advisable but controversial.[15] All employees should have yearly purified protein derivative (PPD) skin tests.

Cuts and puncture wounds should be washed and irrigated *immediately* with soap and water. If conjunctival splashes occur, the eyes should be washed immediately at the nearest eye wash station in the autopsy suite. Injured employees should go to the emergency department or employee health service; the infection control nurse or appropriate employee health official can be notified from there. Most hospitals have hotlines manned by personnel trained in counseling, treatment, and follow-up for healthcare workers who suffer on-the-job injuries. The employee should always protect his or her rights by completing an incident report. Persons with uncovered wounds or dermatitis should not assist in autopsy procedures unless the injured skin can be completely covered with a waterproof dressing or other acceptable barrier.

Isolation Procedures

Although all autopsies are performed in a manner that reduces the risk of contamination, autopsies of bodies that

Box 3-3 Some infections for which postmortem examinations should be performed in a separate or "isolation" room

- Anthrax
- Hantavirus
- Hepatitis
- Human immunodeficiency virus/acquired immunodeficiency syndrome
- Influenza
- Leprosy
- Meningococcal meningitis
- Multidrug-resistant bacteria (methicillin-resistant *Staphylococcus,* vancomycin-resistant *Enterococcus*)
- Plague
- Prion diseases
- Rabies
- Rickettsial diseases (Rocky Mountain spotted fever)
- Systemic infections of unknown etiology
- Tuberculosis
- Typhoid fever

harbor a known pathogenic microorganism are best performed in a separate specially designed room to isolate and contain any infective material (Box 3-3). While performing these autopsies, personnel are limited to only those necessary—the pathologist, autopsy assistant, and possibly a circulating assistant—to accomplish the task. As usual, standard precautions are strictly enforced. Special safety and decontamination procedures are instituted as required. With proper precautions, overhead ultraviolet lights may be used for secondary decontamination. If an isolation room is nonexistent and there is more than one autopsy table in the room, the table with the least traffic should be used for the infective case. In cases in which facilities are inadequate, it is advisable to identify alternative, better-designed, safer sites for postmortem examinations. Health and safety requirements may exceed the capabilities of even the best hospital morgues in suspected cases of infection with highly contagious organisms such as arboviruses, arenaviruses, or filoviruses. In such situations, guidance should be sought from the appropriate public health agency.

Practices to Reduce Transmission by Infective Aerosols

Even in the current age, those performing and attending autopsies are at increased risk for tuberculous infection via aerosols produced during the procedure on a patient with tuberculosis.[17-22] Other infections including rabies, plague, legionellosis, meningococcemia, rickettsioses, coccidiomycosis, and anthrax may also be acquired by aerosols such as those generated during an autopsy.[23] Thus, it is clear that the utmost care must be taken to provide adequate protection against infective aerosols. For protection against diseases transmissible by aerosols, such as tuberculosis, N95 particulate masks (masks able to filter 1-μm particles in the unloaded state with a filter efficiency of 95%, given flow rates up to 50 liters/minute) or containment hoods or suits equipped with powered, air-purifying respirators with high-efficiency particulate air (HEPA) filters are used. Collecting body cavity fluids with a ladle or bulb syringe generates less aerosol than a hose aspirator connected to a sink faucet. Placing plastic bags over the head of the decedent during removal of the calvarium with a Stryker saw or saws equipped with HEPA filters within the vacuum system can also reduce the amount of aerosolization. Towfighi and colleagues designed a relatively simple tentlike device for reducing aerosal dispersion during brain removal.[24]

Practices Specific to Autopsies if a Prion Disorder Is Suspected

The infective agent that transmits Creutzfeldt-Jakob disease (CJD) and related prion disorders has been termed a *prion* because it does not have the morphologic and chemical composition of a virus or other conventional infective agent. Rather, all the evidence indicates that the sole functional component of the prion is an abnormal protease-resistant isoform of a normal brain protein. The normal isoform is designated PrP^{C} and the pathogenic isoform PrP^{CJD} in humans and PrP^{Sc} in animals. Some investigators refer to the pathogenic form as PrP^{res} because of resistance to protease digestion.

Consistent with these characteristics, prions are resistant to inactivation by procedures that denature nucleic acids, such as ultraviolet radiation, but are inactivated by procedures that denature or hydrolyze proteins, such as exposure to some detergents or to NaOH. Because it is a protein, PrP^{CJD} is not easily aerosolized by routine procedures used in the morgue or in the histology laboratory. The procedures outlined here are more than adequate to prevent aerosolization of prions. Although CJD can be transmitted to laboratory animals by intracerebral inoculation of formalin-fixed tissues, it should be noted that aldehyde fixatives cross-link proteins in a tissue block, and therefore prions are not readily transmissible from the tissue block.

The incidence of CJD among medical personnel, histotechnologists, and morgue attendants is the same as that in the general population (1 per million), and the disease in these medical personnel resembles sporadic CJD and not CJD caused by infection, such as occurred with contaminated lots of human growth hormone.[25] In contrast, many medical personnel have contracted serious illness due to tuberculosis or hepatitis acquired directly or indirectly from patients. Thus, although CJD and related disorders are transmissible, they are not contagious.

When working with prion-infected or contaminated material, caution must be taken to avoid breach of the skin. The prosector should wear cut-resistant gloves. If accidental contamination of skin occurs, swab the area with 1 N sodium hydroxide for 5 minutes and then irrigate with copious amounts of water. Boxes 3-4 through 3-6 list specific modifications to routine safety procedures for cases of suspected spongiform encephalopathies.

EXPOSURE TO OTHER BIOHAZARDS AT AUTOPSY

Formaldehyde

Formaldehyde is a highly toxic chemical, and exposure to formaldehyde or its vapors may cause a variety of symptoms or diseases. These include contact dermatitis; headache; eye,

Box 3-4 Autopsies of patients with suspected prion disease (human transmissible spongiform encephalopathies)—modifications of standard precautions

1. Attendance is limited to three staff members, including at least one experienced pathologist. One of the staff avoids direct contact with the deceased but assists with handling of instruments and specimen containers.
2. Standard autopsy attire is mandatory. However, a disposable, waterproof gown is worn in place of a cloth gown. Cut-resistant gloves are worn underneath two pairs of surgical gloves, or chain mail gloves are worn between two pairs of surgical gloves.
3. Containment hoods or suits equipped with powered, air-purifying respirator with high-efficiency particulate air (HEPA) filters are worn by all staff.
4. Reduce contamination of the autopsy suite.
   a. Cover the autopsy table with an absorbent sheet that has a waterproof backing. Drape instrument trays, working surfaces, and weighing pans with plastic or disposable plastic underpads. Use clear 2-inch plastic tape to connect seams and to secure edges against the table.
   b. Because prion infectivity is retained after drying and the dried material is harder to clean from surfaces, reusable instruments should be kept wet between time of use and disinfection.
   c. Use disposable equipment (headrest, cutting board, scalpels, forceps, scissors, brain knife, plastic formalin containers) to the greatest extent possible.
   d. Dedicate a set of instruments for autopsies involving possible transmissible spongiform encephalopathies, to include Stryker saw, blade and wrench, skull breaker and hammer, 5-inch forceps, 5-inch scissors, and rib cutter.
   e. Reduce bone dust aerosol during brain removal. Place a plastic bag over the head, and tie it securely around the neck. Open the sealed end of the bag. Remove the brain within a plastic bag to reduce potential aerosol exposure.
   f. Immediately place brain into a preweighed container of 10% neutral buffered formalin. Reweighing the container provides the weight of the brain.
5. Mix liquid waste 1:1 with 2N NaOH in a waste collection bottle.

Box 3-5 Autopsies of patients with suspected prion disease (human transmissible spongiform encephalopathies)—modifications of autopsy suite decontamination procedures

1. Place instruments (open box locks and jaws) and saw blades into a large stainless steel dish.
2. Soak instruments for 1 hour in Kleenzyme; immerse for 1 hour in 1N sodium hydroxide, and rinse for 2 to 3 minutes in water. (Collect all waste.)
3. Transfer instruments into red autoclavable biohazard waste bags, and autoclave at 134 °C (gravity displacement steam autoclaving for 1 hour; porous load steam autoclaving for one 18-minute cycle at 30 lb psi or six 3-minute cycles at 30 lb psi).
4. Clean the Stryker saw by repeated wiping with 1N sodium hydroxide solution.
5. Double bag the absorbent table cover and instrument pads, disposable clothing, and so forth in appropriate infective waste bags for incineration.
6. Decontaminate any suspected areas of contamination of the autopsy table or room by repeated wetting with 1N sodium hydroxide over 1 hour, followed by thorough rinsing and washing.

Box 3-6 Autopsies of patients with suspected prion disease (human transmissible spongiform encephalopathies)—modifications of brain cutting procedures

1. After adequate formaldehyde fixation (at least 10 to 14 days), the brain is examined and cut on a table covered with an absorbent pad with an nonpermeable (i.e., plastic) backing.
2. Samples for histology are placed in cassettes labeled with "CJD precautions." These are placed in 95% to 100% formic acid for 1 hour, followed by fresh 10% neutral buffered formalin solution for at least 48 hours. This procedure eliminates all prion infectivity in the embedded specimen.
3. All instruments and surfaces that come in contact with the tissue are decontaminated as described in Box 3-5.
4. Tissue remnants, cutting debris, and contaminated formaldehyde solution should be discarded in a water-tight plastic container as infective hospital waste for incineration.

nose, and throat irritation; shortness of breath; wheezing; chronic cough; mucus hypersecretion; asthma; chronic airway obstruction; bronchitis; rhinitis; pharyngitis; menstrual and reproductive disorders; and sexual dysfunction.[26] Although many individuals have experienced the milder irritative disorders following acute limited formaldehyde exposure, the incidence of most of the more severe reactions is extremely low. Nonetheless, the sensitivity of individuals is highly variable. Exposure studies performed in rats have shown that formaldehyde appears to induce nasal squamous cell carcinomas[27,28]; however, implications for humans are equivocal. Studies relating the rat and human data indicate that the carcinogenic risk for humans at relevant levels of formaldehyde exposure is minimal; further, it is likely that precautions effective against noncancer toxic effects of the chemical are sufficient to protect against its carcinogenic effects.[29]

The autopsy suite should have sufficient ventilation and effective chemical fume hoods to reduce employee exposure to formaldehyde vapor. As mandated by the Occupational Health and Safety Administration (OHSA), employers must monitor formaldehyde levels in the workplace and maintain employee exposures below the legal safe limits. Institutions should provide a mandatory training program for all employees exposed to formaldehyde at or above 0.1 ppm on an 8-hour time-weighted average. Box 3-7 lists some important components of a safety training program for employees exposed to formaldehyde.

Radioactivity

On rare occasions, the autopsy pathologist may be required to examine the body of a patient who died shortly after receiving diagnostic or therapeutic radioactive substances or after

Box 3-7 Components of mandatory training for employees exposed to formaldehyde above 0.1 ppm on an 8-hour time-weighted average basis

1. Explanation of the OSHA standard and contents of the formaldehyde material safety data sheet (MSDA).
2. A description of the medical surveillance program including potential health hazards, signs and symptoms, and instructions to report the development of signs and symptoms the employee suspects are related to formaldehyde exposure.
3. A description of operations in which formaldehyde is present and explanation of safe work practices for jobs requiring the use of formaldehyde.
4. A discussion of the purpose, proper use, and limitations of personal protective equipment.
5. Instruction on the handling of spills, emergencies, and cleanups.
6. An explanation of the importance of engineering and work practice controls and instruction and, if applicable, training in how to use the controls.
7. A review of emergency procedures and the role of each employee in the event of an emergency.

OSHA, Occupational Safety and Health Administration.
Modified from Lott AL, Greenblatt M: Formaldehyde regulations: What you need to know, *CAP Today* 4:32-35, 1993.

accidental radioactive contamination.[30] In such circumstances, the body may contain a level of radiation that would result in a radiation exposure risk to autopsy staff. Handling of the radioactive cadaver requires special care and is best done with the assistance of personnel trained in radiation safety.[30-32]

In most cases, radioisotopes used for diagnostic studies are given in small doses (less than a millicurie) or have short half-lives, and patients who die after recent nuclear medicine examinations are usually not a radiation hazard. Patients who die after receiving therapeutic doses of radioisotopes or implanted radioactive sources may require special handling, depending on the level of radioactivity remaining (Table 3-1). Hospitals where such patients are treated will have patient treatment records available, as well as radiation safety specialists who can advise the pathologist.

The United States Atomic Energy Commission recommends that patients who have received radioisotopes remain in the hospital until the level of radioactivity falls to 30 mCi or less. Thus, most patients who die after hospital discharge present minimal hazard. However, because radioisotopes may be concentrated in tissue or body fluids, the attending physician signing the death certificate should alert the pathologist and the radiation safety officer if the body contains more than 5 mCi. The assigned mortuary should also be advised. A form identifying the isotope, the amount given, and the time of administration should be attached to the death certificate, the autopsy consent, and the medical record.

If an implanted radioactive source cannot be removed from the patient before an autopsy, if radioactive fluid is present after administration of an isotope, or if high levels of radioactivity are likely to be present in a specific organ, a radiation safety specialist should be consulted for assistance in the safe collection and proper disposal of the radioactive source, fluid, or tissue. In consultation with the specialist, the amount of activity remaining in the body should be estimated by reference to the half-life of the isotope. If the remaining amount is less than 5 mCi, no special precautions are necessary, other than the usual wearing of gloves. An exception is cases of ^{131}I therapy or therapy with insoluble radioisotopes, in which specific tissues (e.g., thyroid) or body cavities contain most of the activity.

When the residual activity exceeds 5 mCi, a survey of residual radioactivity before the body is opened helps establish the maximum working time allowed. A team of pathologists, each prosector performing a limited portion of the autopsy, may be required to limit individual exposures. Film badges may be required to monitor exposure. The pathologist should drain potentially contaminated body fluids carefully first and immediately shield them for assay later. For example, in cases of ^{131}I therapy, the blood, urine, and thyroid are radioactive. Highly radioactive fluids should be stored behind appropriate shields until they can be safely removed from the autopsy suite.

After the body is opened, a second survey should be made to estimate the level of beta dose for ^{32}P or other beta-emitting radionuclide. In cases of ^{131}I administration, the thyroid gland may emit a sufficient gamma dose that it should not be touched by hand directly but rather removed with the aid of a long instrument.

After the autopsy, all instruments, towels, and clothing involved in the procedure should be checked for radioactivity and either stored shielded until safe or decontaminated before being returned to general use or sent to the laundry. The autopsy room should be monitored for radioactive contamination and decontaminated if necessary.

Similar to gamma rays, X-rays pass easily through fairly thick materials. X-ray machines, including the cabinet type used commonly by pathologists, have built-in shielding. The radiation safety specialist should assist the pathology department in monitoring and complying with any safety measures required for the operation of these machines.

Implantable Cardioverter-Defibrillator

An implantable cardioverter-defibrillator (ICD), also known as an automatic implantable cardioverter-defibrillator (AICD), consists of a pulse generator, one or two sensing electrodes, and a set of anode and cathode electrodes for countershock. As in pacemakers, which they resemble, the generator is usually placed subcutaneously within the left anterior chest wall. Depending on the make and model, the electrodes reach their attachment points on the heart by a transthoracic or transvenous route.

Prahlow and colleagues[33] have reviewed the safety issues surrounding ICDs encountered at autopsy. A small but definite risk of electric shock exists when the detection lead of an ICD is broken or cut, resulting in a discharge of 25 to 40 J. Although shocks of this magnitude are unlikely to cause death, manufacturers recommend that the ICDs be deactivated before manipulation and that high-quality latex surgical gloves be used when handling the devices. In many cases, the autopsy prosector is aware of the presence of an ICD after

Table 3-1 Diagnostic and therapeutic procedures involving administration of radioactive substances

Indication	Radionuclide	Physical half-life	Form of administration
Nuclear medicine diagnostic tests			
Bone, renal parathyroid, cerebral blood flow imaging	Tc-99	6.6 hours	Intravenous
Somatostatin receptor imaging	In-111	2.8 days	Intravenous
Neurectodermal tumor imaging	I-123	13.2 hours	Intravenous
PET tumor imaging	F-18	1.8 hours	Intravenous
Therapeutic procedures involving administration of unsealed radioactive substances			
Thyrotoxicosis and nontoxic goiter	I-131	8.04 days	Usually oral
Carcinoma of thyroid	I-131	8.04 days	Usually oral
Malignant disease	I-131	8.04 days	Intravenous
Arthritic conditions	Y-90	2.7 days	Intraarticular
Polycythemia vera	P-32	14.2 days	Intravenous or oral
Bone metastases	Sm-153 Sr-89	46.2 hours 51 days	Intravenous
Non-Hodgkin's lymphoma	Y-90	2.7 days	Intravenous
Liver cancer	Y-90	2.7 days	Hepatic arterial injection
Carcinoid	Y-90	2.7 days	Intravenous
Therapeutic procedures involving administration of temporarily implanted sealed radioactive substances (brachytherapy)			
Malignant disease	Y-90	2.7 days	Rods
Malignant disease	Cs-137		Tubes, wire, small diameter cylinders or pellets
Malignant disease	Ir-192	74 days	Wire, pins, or small diameter cylinders
Eye diseases	Sr-90 and daughter Y-90	28.7 years	Metal eye plaques
Eye diseases	Ru-106		Metal eye plaques
Therapeutic procedures involving administration of permanently implanted sealed radioactive substances			
Prostate cancer	I-125	60 days	Metal seeds
Prostate cancer	Pd-103	17 days	Seeds
Various sites, e.g., tongue, rectal margin	Au-198	2.7 days	Grains

Modified from Singleton M, Start RD, Richardson C, Conway M: The radioactive autopsy: Safe working practices, *Histopathology* 51:289-304, 2007. Reprinted with permission from *Archives of Pathology & Laboratory Medicine,* copyright College of American Pathologists.

review of the medical history of the deceased. However, in cases in which history is incomplete or totally lacking, the pathologist encountering an implanted device during autopsy dissection should ascertain whether it is a pacemaker or an ICD before continuing with the autopsy. If an ICD is present, the pathologist should discontinue the postmortem examination until the device is properly deactivated (Box 3-8 and Table 3-2). Because ICDs may explode if incinerated, they should never be discarded without special attention. Because most ICD manufacturers request the return of the device after its removal, the manufacturer's representative usually assists in the removal and collection of an ICD.

Foreign Bodies and Occult Medical Devices

Bullet Recovery

Bullets may fragment on impact or may by design raise pointed edges on entering their target. In either case, the resulting deformation can produce sharp edges in shrapnel that present a risk for injury to those who remove or handle them. For autopsies of gunshot victims, Russell and coworkers[34] recommended that anteroposterior and lateral radiographs be taken to locate bullets, bullet fragments, and any sharp or irregular edges. Bullets should be handled only by personnel wearing double heavy-duty gloves. To prevent marring of the projectile surface, a rubber-tipped bullet extractor

Box 3-8 Safety precautions for autopsies on patients with an implantable cardioverter-defibrillator (ICD)

1. Obtain medical history.
2. Use universal precautions (gloves) and other insulating devices.
3. Locate and identify all implanted electrical devices; avoid cutting leads.
4. If ICD is present, do NOT proceed until deactivated.
5. Call dedicated local cardiologist or manufacturer's representative (see Table 3-2).
6. Wait for cardiologist or representative to deactivate ICD, or follow representative's instructions for deactivation.
7. Request manufacturer's representative to obtain information from internal memory of ICD.
8. Do NOT discard ICD.
9. Do NOT incinerate ICD.
10. Contact manufacturer representative for removal or collection of ICD.

From Prahlow JA, Guileyardo JM, Barnard JJ: The implantable cardioverter-defibrillator: A potential hazard for autopsy pathologists, *Arch Pathol Lab Med* 121:1076-1080, 1997. Reprinted with permission from Archives of Pathology & Laboratory Medicine, copyright College of American Pathologists.

fashioned from a Kelly forceps fitted with 2 cm of rubber catheter over its ends or a plastic forceps should be used to recover bullets and bullet fragments. After collection of any trace evidence on the projectile itself, the bullet should be gently rinsed to remove contaminating blood or body fluids to decrease its subsequent infective risk. Finally, the bullet or bullet fragments should be double packed in leakproof packaging with at least one of the containers composed of hard plastic to prevent injury during subsequent handling. In addition to the appropriate identifying information, the container should be labeled with a biohazard sticker.

Needle Fragments and Other Sharp Objects

Medical devices such as surgical staples, vena-caval (Greenfield) filters, and other devices may have sharp edges or points that can be encountered unexpectedly at autopsy.[35] Needle fragments are a potential hazard to pathologists performing autopsies on drug-addicted patients. Embolized needle foreign bodies have been discovered in soft tissues of the neck and even within internal organs.[36-38] Hutchins and colleagues[38] recommended preautopsy radiographic screening, reduced tissue manipulation during prosection, and delay of autopsy in

Table 3-2 Selected manufacturers of implantable cardioverter-defibrillators

Manufacturer	Toll-free telephone number	Brand name
Biotronik (Lake Oswego, Ore)	1-800-547-0394	Phylax 06 Phylax 03 Phylax XM Phylax AV Mycrophylax Mycrophylax Plus TACHos
ELA Medical (Plymouth, Minn)	1-800-352-6466	Defender I, II, III, and IV Sentinel*
Guidant (Redmond, Wash) Division of Boston Scientific Intermedics, Inc Division of Boston Scientific	1-800-227-3422	Metrix† Res-Q
Medtronic Inc (Minneapolis, Minn)	1-800-328-2518	PCD Jewel Gemini
St. Jude's Medical Cardiac Rhythm Management Division, formerly Telectronics Pacing Systems (Sylmar, Calif)	1-800-722-3422	GUARDIAN SENTRY
St. Jude's Medical Cardiac Rhythm Management Division, formerly Ventritex Incorporated (Sunnyvale, Calif)		Cadence Cadet Contour Ventritex Angstrom Profile Photon
St. Jude's Medical Cardiac Rhythm Management Division, formerly Cardiac Pacemakers, Inc.		AIDB VENTAK

*Device is an atrial defibrillator.
†Device manufactured by Angeion, Plymouth, Minn.
Data from Prahlow JA, Guileyardo JM, Barnard JJ: The implantable cardioverter-defibrillator: A potential hazard for autopsy pathologists, *Arch Pathol Lab Med* 121:1076-1080, 1997.

human immunodeficiency virus–positive cases, along with the standard recommendations for protection against injury from sharp instruments.

Cyanide Exposure

Exposure to cyanide vapors during autopsy has been associated with clinical symptoms and toxic concentrations of cyanide in autopsy personnel.[39,40] Autopsies on victims of cyanide poisoning should be performed in a negative-pressure isolation room. Although cyanide may vaporize from other tissues, stomach contents containing ingested cyanide salts present the highest risk, because the gastric acid converts cyanide salts to volatile hydrocyanic gas. Therefore, the prosector should open the stomach only in a chemical fume hood or externally vented biologic safety cabinet to reduce the risk of exposure to the toxic gas. Similarly, toxicology laboratory workers handling samples possibly containing cyanide should wear gloves and face and eye protection and manipulate the specimen only in a chemical fume hood.

CONCLUSION

This chapter has reviewed the main components of autopsy biosafety. The objective of any autopsy biosafety program must be to provide autopsy staff and any visiting personnel with an environment as free from hazardous exposure risk as possible. Achieving this goal requires a continuous program of safety education and constant diligence in enforcing safe methods of autopsy practice.

REFERENCES

1. Clarke JJ: *Post-mortem examinations in medico-legal and ordinary cases*, London, 1896, Longmans, Green.
2. Li L, Gu J, Shi X, et al: Biosafety level 3 laboratory to autopsies of patients with severe acute respiratory syndrome: Principles, practice and prospects, *Clin Infect Dis* 41:815-821, 2005.
3. Nolte KB, Hanzlic RL, Payne DC, et al: Medical examiners, coroners, and biologic terrorism. A guidebook for surveillance and case management, *MMWR Recomm Rep* 53(RR-8):1-27, 2004.
4. Marty AM: Anatomic laboratory and forensic aspects of biological threat agents, *Clin Lab Med* 26:515-540, 2006.
5. Sharp SC: The physician's obligation to treat AIDS patients, *South Med J* 81:1282-1285, 1988.
6. Richmond JY, McKinney RW: *Biosafety in microbiological and biomedical laboratories*, ed 4, Washington, DC, 1999, U.S. Department of Health and Human Services.
7. World Health Organization: *Laboratory biosafety manual*, ed 2, Geneva, 1993, WHO.
8. Fritzsche FR, Dietel M, Weichert W, Buckendahl AC: Cut-resistant protective gloves in pathology—effective and cost-effective, *Virshows Arch* 452:313-318, 2008.
9. O'Briain DS: Patterns of occupational hand injury in pathology. The interaction of blades, needles and the dissector's digits, *Arch Pathol Lab Med* 115:610-613, 1991.
10. LeBeau LJ: Health hazards in biomedical photography. In Vetter JP, editor: *Biomedical photography*, Boston, 1992, Butterworth-Heinemann, pp 499-507.
11. Nolte KB: Survival of *Mycobacterium tuberculosis* organisms for 8 days in fresh lung tissue from an exhumed body, *Hum Pathol* 36:915-916, 2005.
12. Gerston KF, Blumberg L, Tshabalala VA, Murray J: Viability of mycobacteria in formalin-fixed lungs, *Hum Pathol* 35:571-575, 2004.
13. Meade GM, Steenken WM, Jr: Viability of tubercle bacilli in embalmed human lung tissue, *Am Rev Tuberc* 59:429-437, 1949.
14. Bauer S, Daniel A, Alpert LI, et al: *Protection of laboratory workers from instrument biohazards and infectious disease transmitted by blood, body fluids, and tissue; approved guideline*, NCCLS M29-A, December 1997, Clinical and Laboratory Standards Institute.
15. Ruef C: Immunization for hospital staff, *Curr Opin Infect Dis* 17:335-339, 2004.
16. Centers for Disease Control and Prevention (CDC): Human rabies prevention—United States, 1999. Recommendations of the Advisory Committee on Immunization Practices (ACIP), *MMWR Recomm Rep* 48:1-21, 1999.
17. Hedvall E: The incidence of tuberculosis among students at Lund University, *Am Rev Tuberc* 41:770-780, 1940.
18. Morris SI: Tuberculosis as an occupational hazard during medical training, *Am Rev Tuberc* 54:140-157, 1946.
19. Meade GM: The prevention of primary tuberculosis infections in medical students, *Am Rev Tuberc* 58:675-683, 1948.
20. Reid DD: Incidence of tuberculosis among workers in medical laboratories, *Br Med J* 2:10-14, 1957.
21. Wilkins D, Woolcock AJ, Cossart YE: Tuberculosis: Medical students at risk, *Med J Aust* 160:395-397, 1994.
22. Templeton GL, Illing LA, Young L, et al: The risk for transmission of *Mycobacterium tuberculosis* at the bedside and during autopsy, *Ann Intern Med* 122:922-925, 1995.
23. Nolte KB, Taylor DG, Richmond JY: Biosafety considerations for autopsy, *Am J Forensic Med Pathol* 23:107-122, 2002.
24. Towfighi J, Roberts AF, Foster NE, Abt AB: A protective device for performing cranial autopsies, *Hum Pathol* 20:288-289, 1989.
25. Brown P, Preece MA, Will RG: "Friendly fire" in medicine: Hormones, homografts, and Creutzfeldt-Jakob disease, *Lancet* 340:24-27, 1992.
26. Greenblatt M, Swenberg J, Kang H: Facts about formaldehyde, *Pathologist* 37:648-651, 1983.
27. Swenberg JA, Kerns WD, Mitchell RI, et al: Induction of squamous cell carcinoma of the rat nasal cavity by inhalation exposure to formaldehyde vapor, *Cancer Res* 40:3398-3402, 1980.
28. Albert RE, Sellakumar AR, Laskin S, et al: Gaseous formaldehyde and hydrogen chloride induction of nasal cancer in the rat, *J Natl Cancer Inst* 68:597-603, 1982.
29. Connolly RB, Kimbell JS, Janszen D, et al: Human respiratory tract cancer risks of inhaled formaldehyde: dose-response predictions derived from biologically-motivated computational modeling of a combined rodent and human dataset, *Toxicol Sci* 82:279-296, 2004.
30. Singleton M, Start RD, Richardson C, Conway M: The radioactive autopsy: Safe working practices, *Histopathology* 51:289-304, 2007.
31. Wallace AB, Bush V: Management and autopsy of a radioactive cadaver, *Australas Phys Eng Sci Med* 14:119-124, 1991.
32. Schraml FV, Parr LF, Ghurani S, Silverman ED: Autopsy of a cadaver containing strontium-89-chloride, *J Nucl Med* 38:380-382, 1997.
33. Prahlow JA, Guileyardo JM, Barnard JJ: The implantable cardioverter-defibrillator: A potential hazard for autopsy pathologists, *Arch Pathol Lab Med* 121:1076-1080, 1997.
34. Russell MA, Atkinson RD, Klatt EC, Noguchi TT: Safety in bullet recovery procedures: A study of the Black Talon bullet, *Am J Forensic Med Pathol* 16:120-123, 1995.
35. Burton JL: Health and safety at necropsy, *J Clin Pathol* 56:254-260, 2003.

36. Williams MF, Eisele DW, Wyatt SH: Neck needle foreign bodies in intravenous drug abuse, *Laryngoscope* 103:59-63, 1993.
37. Thorne LB, Collins KA: Speedballing with needle embolization: Case study and review of the literature, *J Forensic Sci* 43:1074-1076, 1998.
38. Hutchins KD, Williams AW, Natarajan GA. Neck needle foreign bodies: An added risk for autopsy pathologists, *Arch Pathol Lab Med* 125:790-792, 2001.
39. Andrews JM, Sweeney ES, Grey TC, Wetzel T: The biohazard potential of cyanide poisoning during postmortem examination, *J Forensic Sci* 34:1280-1284, 1989.
40. Nolte KB, Dasgupta A: Prevention of occupational cyanide exposure in autopsy prosectors, *J Forensic Sci* 41:146-147, 1996.