Biosafety Considerations for Autopsy

Kurt B. Nolte, M.D., David G. Taylor, Ph.D., and Jonathan Y. Richmond, Ph.D.

An autopsy may subject protoners and others to a wide variety of infectious agents, including bloodborne and aerosolized pathogens such as human immunodeficiency virus, hepatitis B and C viruses, and Mycobacterium tuberculosis. Other hazards include toxic chemicals (e.g., formalin, cyanide, and organophosphates) and radiation from radionuclides used for patient therapy and diagnosis. These risks can be substantially mitigated through proper assessment, personal protective equipment, appropriate autopsy procedures, and facility design.

Key Words: Autopsy—Biohazards—Chemical hazards—Toxic hazards.

...What kind of a cut is it? Where is it?"
"Right here, on my finger. I rode over to the village today—you know, the one they brought that mouzhik with typhus from. For some reason or other they were getting ready to do an autopsy on him, and it’s been a long time since I’ve had any practice of that sort.”
"...Old timer," Bazarov began in a hoarse, slow voice, “my goose is cooked; I’ve been infected and in a few days you’ll be burying me.” Ivan S. Turgenev, Fathers and Sons, 1862

Autopsies can be performed with the consent of the next-of-kin of persons who die of natural causes in hospitals, or they can be performed under legislated authority (forensic or medicolegal autopsies) on persons who die of violent, unnatural, suspicious, sudden, or unexplained causes. The frequency of consent autopsies has declined substantially over the previous several decades, from approximately 50% of all hospital deaths in 1950 to less than 10% in 1995 (1). One reason for this decline is the potential increased risk of occupational exposure of pathologists to dangerous pathogens (2). With decreased hospital autopsy rates, the proportion of medicolegal postmortem examinations has increased. Medicolegal autopsies constituted a large proportion, and in some jurisdictions the majority, of the total number performed in 1981 (3). Since then, national hospital autopsy rates have continued to decline, and medicolegal autopsies likely represent the majority of these procedures performed in almost all areas of the United States.

AUTOPSY HAZARDS

Infectious Agents

The risk of infectious disease transmission has long been recognized for protoners, observers, and other persons in close proximity to an autopsy. Retrospective surveys of British clinical laboratories between 1970 and 1989 demonstrated that the highest rates of laboratory-acquired infections were in autopsy workers (4–8). Autopsy-transmitted infections may occur after direct cuta-
Pathology residents sustained a percutaneous injury with blood exposure in 1 of 11 autopsies and experienced pathologists in 1 of 55 autopsies (9). Autopsy prosectors sustained cuts at twice the frequency that they sustained needle punctures (9). Scalpel blades created the majority of these cuts, resulting in a potentially large inoculum of infectious agent. However, many other sharp objects such as broken glass, embedded needle fragments, bone shards, and fragmented projectiles can injure autopsy personnel (9–11). In addition, approximately 8% of surgical gloves are punctured during autopsy, and approximately one third of these punctures remain undetected by the prosector (12). Glove punctures may cause preexisting hand lesions to be bathed in infectious blood for prolonged periods of time.

Many infections can be transmitted by direct inoculation. For example, pathologists have died of streptococcal sepsis after sustaining minor cutaneous injuries during autopsies on persons with the same disease (13). Other infections that can be transmitted in this manner include tuberculosis, blastomycosis, coccidioidomycosis, acquired immunodeficiency syndrome, hepatitis B and C (or non-A, non-B), rabies, tularemia, diphtheria, erysipelas, and some of the viral hemorrhagic fevers (4,8,14–33). Some of these autopsy-transmitted infections have proved to be fatal.

Among physicians, pathologists are recognized as a high-risk group for occupationally acquired hepatitis B virus (HBV) because of their exposure to blood (34,35). There are at least two records of autopsy workers who died of occupationally acquired hepatitis (8,32). The prevalence of HBV, hepatitis C virus (HCV), and human immunodeficiency virus (HIV) infection is higher in forensic autopsy populations than in the general public because of an overrepresentation of intravenous drug abusers among decedents subjected to autopsy (36,37). In some areas of the United States, up to 90% of intravenous drug abusers may be infected with HCV (38). In one study of the autopsy population in Baltimore, Maryland, the medical examiner demonstrated an infection seroprevalence of 5.6% for HIV, 23.2% for HBV, and 19.1% for HCV (37). This study did not discriminate between acute and remote HBV infections. Another study of a medicolegal cadaver population in Milan, Italy, revealed an infection seroprevalence of 16% for HIV and 29% for HCV (39). Other studies of forensic autopsy populations have identified an HIV seroprevalence of 2% in Vancouver, Canada (40), 11% in South Africa (41), 2.2% in Philadelphia, Pennsylvania (42), and 1% in Scotland (43). In 1983, 18% of young adults who died suddenly in San Francisco had antibodies to HIV (44). The transmission risk with infected blood for HIV is 0.3% per exposure (45); for HBV, at least 30% per exposure (31); and for HCV, an average of 1.8% per exposure but may be as high as 10% (38,46). Although the viability of HIV in cadaveric blood appears to decrease over time, this organism has been isolated from specimens from deceased persons with postmortem intervals of 6, 11, and 16 days (47–50). HIV-infected bodies should be considered infectious for at least 2 weeks after death. HBV in the environment is also hardy. HBV in human plasma retained infectivity 1 week after being dried and exposed to an ambient environment (51). Clearly, the transmission risks for these bloodborne pathogens, combined with their high seroprevalence in certain autopsy populations and the frequency of percutaneous injury, place autopsy personnel at high risk for sustaining an occupational infection.

Performing autopsies on persons who have died of viral hemorrhagic fever (VHF) poses even greater risks. Prosectors have died of autopsy-transmitted Marburg, Ebola, and Lassa hemorrhagic fevers (22,26,52,53). These infections have been transmitted by direct cutaneous inoculation. Although aerosol transmission of VHF has been suspected in outbreaks occurring within hospitals (54,55), whether these infections may also be transmitted via autopsy aerosols is unclear. Lymphocytic choriomeningitis and yellow fever have been fatally transmitted to human prosectors, and Rift Valley fever has been transmitted to prosectors of veterinary case material (56–58). None of these persons were reported to have sustained an injury during dissection. The prosectors in whom Rift Valley fever developed did not wear masks during the procedure. Autopsy aerosols could have transmitted these infections. The conditions where autopsies are performed are often primitive in most locations where deaths resulting from VHF occur. Therefore, the risks and benefits must be carefully considered before an autopsy is performed on a person suspected to have died of one of these conditions (19). Immunohistochemical procedures on formalin-fixed skin biopsy specimens have proved useful in the diagnosis of Ebola hemorrhagic fever (52). A skin biopsy can be performed more safely and readily than an autopsy, thereby reducing exposure to infectious materials. However, if the skin biopsy result is negative and no autopsy has been performed, definitive diagnosis may be impossible. Autopsies have been performed safely on deceased persons with VHF, using strict safety protocols (59). Similar to the diagnosis of VHF, immunofluorescence and immunohistochemical procedures can be used to detect rabies virus antigen in skin and may obviate the risks associated with an autopsy (60,61).

Autopsies on persons who died of hantavirus infections appear to pose fewer risks than other VHFs. A study of health care workers (including autopsy prosectors) involved in a 1993 hantavirus pulmonary syndrome outbreak indicated no evidence of autopsy transmission.
Spongiform encephalopathies such as Creutzfeldt-Jakob disease (CJD) also can be transmitted by percutaneous autopsy exposure. These transmissible dementias are caused by infectious isoforms of host membrane sialoglycoproteins known as prion proteins (64). No clearly documented cases of occupational CJD among general pathologists, neuropathologists, laboratory and autopsy technicians, or morticians exist (65); however, two cases of CJD have been documented in histology technicians working in separate neuropathology laboratories (66,67). Whether these cases represent an occupational exposure or another unknown exposure is unclear.

Although no evidence exists of contact or aerosol transmission, the absence of any known effective treatment of prion diseases demands caution during the handling of infected tissues. Recommendations for safely conducting autopsies, handling and processing tissues, and decontaminating instruments and work surfaces are given at the end of this article. Note that prions are not inactivated by formalin (a routine fixative used in preparing samples for pathologic examination) and retain transmissibility in paraffin blocks (68).

Infectious aerosols are composed of airborne particles approximately 1 to 5 μm in diameter, which can remain suspended in air for long periods of time. When inhaled, the particles traverse the upper respiratory passages and reach the pulmonary alveoli (69). Particles with diameters larger than 5 μm (i.e., droplets) can also pose a risk for autopsy participants. However, droplets have less potential for traveling substantial distances beyond the autopsy area. Aerosols are generated by fluid aspirator hoses vented into sinks, oscillating saws applied to bones and soft tissues, and water sprayed by hoses onto tissue surfaces (70,71). Even compressing and dissecting lungs with standard autopsy tools can create infectious aerosols and droplets (72). Oscillating saws produce large quantities of respirable dust and bacteria when they are applied to bone (71,73). Concentrations of respirable bone dust up to 5700 particles/ml have been measured in the breathing zone of autopsy workers using oscillating saws (71). Infectious HIV has been recovered from aerosols created experimentally by applying oscillating saws to infected blood (74). Given the uniform form of oscillating saws and spray and aspirator hoses by prostectors, a fair assumption is that all autopsies generate potentially infectious aerosols.

*Mycobacterium tuberculosis* is the prototypical organism transmitted by autopsy-generated aerosols. However, these aerosols can also potentially transmit other infections, including rabies, plague, legionellosis, meningococcemia, rickettsioses (e.g., Q fever), coccidioidomycosis, and anthrax (21,75–83). Historically, a large portion of medical students became tuberculin skin test–positive, and fatal tuberculosis developed in several of them, after the autopsy training period of their curriculum (84,85).

An autopsy is an exceptionally efficient method of transmitting tuberculosis from the decedent to those present in the dissection room. Eight of 35 Mantoux-negative medical students exposed to a tuberculosis autopsy for 1 hour became infected. The risk for infection did not vary with distance from the autopsy table (86). Autopsy exposures as brief as 10 minutes have resulted in transmission of tuberculosis to an observing medical student (87). Unprotected autopsy prospectors exposed to unsuspected tuberculosis often have a higher risk for contracting this infection than clinicians who cared for the patient before death (87,88).

Periodic retrospective surveillance of British clinical laboratories between 1970 and 1989 revealed six cases of occupationally acquired tuberculosis in autopsy workers (4). Between 1953 and 1955, British autopsy pathologists had the highest claim rates for disability benefits resulting from occupational tuberculosis. For this same group, between 1949 and 1953, the incidence of disabling tuberculosis ranged from three times (men) to eight times (women) the incidence in the general population. The incidence remained high when investigators controlled for socioeconomic status (89). Teppo et al. (90), in a survey of Finnish pathologists spanning a wide range of practice years, reported that active tuberculosis attributable to autopsy performance developed in 10%.

The occupational tuberculosis rate of pathologists was substantially higher than that of clinicians (1%) and specialists in tuberculosis and pulmonology (4%). Similarly, in Japan, pathologists and pathology technicians who engaged in autopsies were 6 to 11 times more likely to experience occupational tuberculosis than were non-autopsy workers in pathology departments and workers in university departments of preventive medicine and public health (91).

It is not unusual for tuberculosis to remain undetected until a patient dies. Of all tuberculosis cases reported in the United States between 1985 and 1988, 5.1% (4,541 cases) were recognized post mortem (92). In a study of hospital autopsies from New York City, 4% of cases in which tuberculosis was the cause of death were undiagnosed before autopsy (93). However, 50% of autopsied active tuberculosis cases in hospitals in Dundee, Scotland, were unrecognized before autopsy (94). Because autopsy cases in hospitals usually have more clinical diagnostic information available before the autopsy than most medicolegal autopsies, the percentage of unrecognized tuberculosis cases in a forensic autopsy population would likely be substantially higher.

In recent years, outbreaks of autopsy-transmitted tuberculosis have occurred in the Syracuse Medical Exam-
iner’s Office, the Los Angeles Coroner’s Office, the University of Arkansas School of Medicine, and the University of Health Sciences/Chicago Medical School (87,88,95,96). Multidrug-resistant *M. tuberculosis* caused the Syracuse outbreak, which was attributed to a positive pressure autopsy room, where exhausted room air circulated throughout the facility (95). Similarly, the outbreak in the Los Angeles Coroner’s Office was attributed to inadequate ventilation (96). However, tuberculosis can be efficiently transmitted to autopsy projectors in facilities that have adequate ventilation when proper personal respiratory protection is not used (88). Cultures from embalmed bodies have yielded isolates of *M. tuberculosis* as long as 60 hours after fixation (97); therefore, the dissection of formalin-fixed tissues has the potential to transmit infectious tuberculous aerosols. Indeed, even the process of embalming has been shown to transmit tuberculous aerosols (98).

Autopsy-generated droplets (>5 μm in diameter) also have the potential to transmit infections if they are inhaled or ingested. For example, glanders was fatally transmitted to a veterinary prosector who had a drop of infected horse blood enter his mouth (99). Similarly, fatal glanders developed in a prosector as a consequence of smoking while he was dissecting an infected guinea pig (100).

Autopsy personnel occupationally acquired other infections; however, the mechanism of transmission remains unspecified. These infections have included scrub typhus and toxoplasmosis (101,102). In two separate incidents, fatal smallpox developed in a prosector and an observer after they participated in autopsies on subjects who had died of smallpox (103,104). The mechanism of transmission for the smallpox cases and the precautions taken by the infected persons were not specified. However, the fact that smallpox was transmitted to an observer suggests an airborne mechanism. Fatal glanders developed in a prosector after dissection of an infected human body (99). Despite speculation about direct inoculation and aerosolization of the organism, the mechanism of transmission is unknown.

**Toxic Agents**

The most common toxic agent to which autopsy projectors are exposed is formaldehyde used to preserve tissues. Formaldehyde is highly volatile and causes an array of symptoms, including irritation of the eyes, mucous membranes, and skin (105,106). The Occupational Safety and Health Administration limits the occupational exposure to this chemical to 0.75 ppm as an 8-hour time-weighted average and to 2.0 ppm for short-term (15-minute) exposures (107). The odor threshold for formaldehyde ranges from 0.1 to 1.0 ppm and most commonly is 0.5 ppm (105). Therefore, the ability to smell this substance generally means that the person is breathing a concentration that exceeds the occupational standard. Long-term inhalation of this substance has been associated with an increased risk for all cancers and cancer of the lung as a function of cumulative exposure (108). An association between chronic formaldehyde exposure and cancer of the nasal passages remains controversial (105,109). Interestingly, mortality studies of pathologists and laboratory technicians demonstrated no carcinomas of the nasal passages and a decreased risk of lung cancer compared with the general population (32,110). However, these studies did not evaluate their smoking history.

Forensic pathologists and their technicians are sometimes exposed to cyanide when performing autopsies on persons who have died after ingesting this substance (111). Although cyanide can volatilize from autopsy tissues, the major risk to autopsy personnel occurs when the stomach is opened. In the acid gastric environment, cyanide salts are converted to highly volatile hydrocyanic gas (112,113). Prosectors risk inhaling potentially toxic concentrations of this gas unless the stomach is opened in a totally exhausted biosafety cabinet or chemical fume hood (114).

A similar inhalation danger exists with metallic phosphides used in commercial rodenticide pellets. In cases of fatal metallic phosphate ingestion, phosphine (hydrogen phosphide) is released in the acid medium of the stomach (115). This extremely poisonous gas causes symptoms at concentrations of approximately 2 ppm (115). Prosectors have become ill (headache and nausea) after dissecting persons with fatal metallic phosphate ingestion without taking proper safety precautions (D. Little, personal communication, 1999) (116). However, autopsies have also been performed safely on these cases by prosectors using fume respirators and limiting their duration of autopsy exposure (KA Margolius, personal communication, 1999). In one case of fatal metallic phosphate ingestion, the autopsy risk was deemed excessive, and the procedure was contravened (PSJ Ellis, personal communication, 1999).

Autopsy projectors may examine persons who have died of organophosphate pesticide (e.g., malathion and parathion) poisoning (116–118). These substances may cause toxicity as a consequence of inhalation, ingestion, or dermal absorption (119–122). Exposure to gastric contents and clothing containing or contaminated with organophosphate pesticides can be dangerous (116,123). The stomach should be opened in a fume hood. Prosectors should routinely wear gloves when handling potentially contaminated clothing and other personal articles.

Nerve gas agents, (e.g., tabun, sarin, VX, and soman) are also organophosphorus compounds and are potentially weapons of chemical warfare and bioterrorism (124). These agents can slowly penetrate heavy rubber gloves and aprons and be absorbed through the skin.
Consequently, bodies contaminated with these agents should be thoroughly washed with water, or preferably an alkaline solution (e.g., 5.0% hypochlorite) (125). Prosectors should wear a positive pressure, pressure-demand, full facepiece, self-contained breathing apparatus (SCBA) or pressure-demand supplied air respirator with escape SCBA and a fully encapsulating, chemical-resistant suit with butyl/neoprene or viton/neoprene gloves (126). Nerve gas vapors from casualties can overwhelm prosectors (127). Organic vapor respirators specific for nerve gases offer effective protection from toxic nerve agent or organophosphate pesticide vapors (125).

A chemical used in the manufacture of certain herbicides is 2,4-Dichlorophenol (2,4-DCP). Chemical workers exposed to 2,4-DCP in its liquid state can die rapidly after dermal absorption because this substance uncouples oxidative phosphorylation (128). Prosectors handling the bodies in such fatalities must wear impermeable barrier garments, be cautious while handling contaminated clothing, and thoroughly wash the decedent’s skin before the postmortem examination.

Prosectors also may be exposed to elemental mercury. This element is highly volatile and is well absorbed through inhalation (129). However, no reported cases of toxicity in autopsy personnel have been documented.

Phytotoxins such as abrin in the rosary pea (Abrus precatorius) and ricin in the castor bean (Ricinus communis) are toxic in minute concentrations (130–132). Most fatalities from these substances occur from ingestion of the seeds. Seed or seed fragments within stomach contents would likely pose no risk to autopsy prosectors. However, a homicide case thought to be a consequence of ricin poisoning involved a small partially hollowed metallic sphere injected into a leg with an umbrella specifically fabricated for this purpose (133,134). Such toxin-bearing devices can pose an inoculation risk for prosectors dissecting wounds, especially if the injected devices are sharp.

Individuals who die of botulism are generally not considered to pose a risk to autopsy personnel. Currently, aerosolized Clostridium botulinum toxin is considered to be a potential bioterrorism agent (135). Three prosectors experienced botulism after performing necropsies on guinea pigs and rabbits experimentally exposed to aerosolized botulinum toxin. The workers wore gloves but no other protective equipment. The toxin was thought to have been aerosolized from the animals’ fur during necropsy (136). The application of this episode to potential human bioterrorism fatalities from aerosolized botulinum toxin is unclear. However, prosectors would be wise to take aerosol precautions when handling such cases.

In 1994, a mysterious fatality in California was initially thought to be a consequence of a toxin that generated incapacitating fumes for emergency room personnel. The precise toxin was never identified, although both dimethyl sulfate (produced from dimethyl sulfoxide use) and chloramine (produced by mixing bleach and urine in a hospital sink) have been hypothesized (137–139). The autopsy in this case was safely performed in a specially constructed chamber. The prosectors used airtight suits and external air supplies (137,140,141).

One homicide case involved an attempt to destroy the body by placing it in concentrated hydrochloric acid (D Little, personal communication, 1999). Such a case poses the risk of both fume inhalation and cutaneous/ocular splash to autopsy workers. The autopsy was safely performed by the use of a downdraft autopsy table; copious washing of the body surface with water and sodium bicarbonate; and the use of face shields, water-resistant polypropylene overalls with hoods, and acid-resistant gloves and boots.

**Radiation**

Autopsy workers may be exposed to radioactive materials in a body from diagnostic or therapeutic procedures (142). A pathologist who performed an autopsy without precautions on an individual who had recently undergone a 67-gallium scan received an excessive radiation exposure (143). However, with proper precautions, bodies containing strontium-89-chloride and sodium-131-iodide have been safely examined (144–147). When bodies contain isotopes that have a long half-life, such as strontium-90 (28 years), it may be preferable to bury the body in a sealed casket without performing an autopsy (145).

The extent of radiation exposure is dependent on the dose administered to the patient, the type of radiation emitted, the radionuclide, the exposure time, and the shielding or protection used by the autopsy prosector. Although the half-lives of the diagnostic radionuclides are short (Table 1), their emissions are usually of the more penetrating type (i.e., gamma rays). The therapeutic and implant nuclides have longer half-lives and rep-

### Table 1. Isotopes commonly used in human subjects

<table>
<thead>
<tr>
<th>Use</th>
<th>Type of radiation</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I-131</td>
<td>gamma</td>
<td>8 days</td>
</tr>
<tr>
<td>Tc-99m</td>
<td>gamma</td>
<td>6 hours</td>
</tr>
<tr>
<td>Ga-67</td>
<td>gamma</td>
<td>78 hours</td>
</tr>
<tr>
<td>In-111</td>
<td>gamma</td>
<td>2.8 days</td>
</tr>
<tr>
<td>Therapeutic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I-131</td>
<td>gamma</td>
<td>8 days</td>
</tr>
<tr>
<td>Sr-90</td>
<td>beta</td>
<td>28.8 years</td>
</tr>
<tr>
<td>P-32</td>
<td>beta</td>
<td>14 days</td>
</tr>
<tr>
<td>Implants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cs-137</td>
<td>gamma</td>
<td>30 years</td>
</tr>
<tr>
<td>Ir-192</td>
<td>beta</td>
<td>74 days</td>
</tr>
<tr>
<td>Permanent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I-125</td>
<td>gamma</td>
<td>60 days</td>
</tr>
<tr>
<td>Pd-103</td>
<td>x-ray; EC</td>
<td>17 days</td>
</tr>
</tbody>
</table>

EC, electron capture.
resent a potential concern for a longer time. Exposure time and shielding are important factors to consider for minimizing radiation exposure. Rubber gloves will appreciably reduce beta radiation but not the more penetrating gamma radiation from isotopes (148).

If a body is thought to contain radioactive materials, a radiation safety expert should be consulted before the autopsy to evaluate potential exposure, to recommend protective equipment, and to determine what procedures may be necessary to allow safe release of the body to funeral home personnel. Prosecutors need to prevent contamination of the cadaver cart, the route from the patient’s room to the autopsy room, and the autopsy facility. The autopsy facility and instruments need to be appropriately decontaminated. Radiation levels and personnel exposures need to be monitored and documented. Autopsy personnel need to be evaluated for contamination before they leave the autopsy area (147).

**Electronic Devices**

Implantable cardioverter-defibrillators are used to treat tachyarrhythmias. Prosecutors who manipulate these devices or cut the leads can sustain an electrical discharge of 25 to 40 J. Their presence may not always be suspected before the autopsy. If such a device is found, the procedure should be stopped until it can be deactivated. Manufacturers have service representatives available to assist with the deactivation process (149).

**AUTOPSY PRECAUTIONS**

**Risk Assessment**

Safety guidelines for autopsy personnel indicate that any autopsy can potentially harbor a risk for prosecutors (150). Although agent-specific degrees of risk (biosafety levels) have been clearly established for biomedical and microbiologic laboratories, the same standards have not been well articulated for autopsy facilities. However, the biosafety principles that have been developed for clinical laboratories, biomedical research laboratories, and animal facilities (21) can be broadly applied to autopsy activities.

Achieving appropriate worker protection from biohazards involves personal protective equipment, engineering controls, and work practices and procedures instituted as a result of risk assessment. The barriers and procedures used to protect health care workers from blood and body fluid pathogens were formerly termed Body Substance Isolation Procedures or Universal Precautions. Recently, these precautions were combined into Standard Precautions, which were developed to reduce the transmission of all pathogens from moist body substances (151). Biosafety Level 2 (BSL-2) (Table 2) provides personnel protection against most bloodborne pathogens (i.e., Standard Precautions). The increased containment of Biosafety Level 3 (Table 3) provides protection when a risk of exposure to agents transmissible by aerosols is present (e.g., *M. tuberculosis*, rabies virus, and *Y. pestis*) (21).

Although the agents of the viral hemorrhagic fevers are classified as Biosafety Level 4, bodies potentially infected with these agents can be safely autopsied using the barrier precautions of BSL-2 combined with the negative airflow and respiratory precautions of BSL-3.

**Personal Protective Equipment**

Autopsy workers need protection from bloodborne and aerosol-transmissible pathogens. To protect the eyes, skin, and mucous membranes, all prosecutors and autopsy observers should wear a surgical scrub suit, surgical cap, impervious gown or apron with full sleeve coverage, some form of eye protection (goggles or face shield), shoe covers, and double surgical gloves (Fig. 1) (20,151–153). Metal and synthetic mesh gloves worn underneath surgical gloves may mitigate the risk of autopsy injuries from scalpels and other sharp objects, but they offer no protection from needle punctures (154,155).

Surgical masks may mitigate the risk from splashed body fluids (i.e., droplets) and will help keep prosecutors’ hands from contacting their noses or mouths. However, because of substantial marginal air leakage, standard surgical masks worn conventionally do not protect au-

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**TABLE 2.** Principles of Biosafety Level 2

<table>
<thead>
<tr>
<th>Suitable for work with agents of moderate potential hazard to personnel and the environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>■ Personnel are trained in hazard identification and work procedures</td>
</tr>
<tr>
<td>■ Access to work area is controlled and limited; hazard signs are posted</td>
</tr>
<tr>
<td>■ Extreme precautions with sharps are observed</td>
</tr>
<tr>
<td>■ Special equipment may be used to contain or control chemical fumes, splatters, or biological aerosols</td>
</tr>
</tbody>
</table>

**Emphasis is on safe practices and procedures**

| ■ Restrictions on smoking, eating, and drinking in the autopsy area are enforced to reduce ingestion potential |
| ■ Gloves, gowns, and aprons are worn |
| ■ Other personal protective equipment is worn as needed (e.g., to protect mucous membranes) |
| ■ Handwashing after removal of gloves and before leaving the work area is required |
| ■ Instruments and work surfaces are decontaminated and cleaned |
| ■ Waste is decontaminated or processed for incineration |
| ■ Samples are labeled (including hazard warnings) and contained for transport to other locations |

**Policy issues include**

| ■ A qualified person provides supervision |
| ■ Immunizations are offered (e.g., HBV); medical services are available |
| ■ Standard operating procedures (with biosafety issues addressed) are developed |

**Facility requirements include**

| ■ The location is away from public areas; doors are lockable |
| ■ Consideration is given for directional inward airflow without recirculation to other areas |

Adapted from reference (20).
topsy participants from inhaling airborne contaminants (156). When a risk of an aerosolized pathogen such as *M. tuberculosis* is present, these individuals should wear N-95 respirators (Fig. 2) at a minimum (69). The fabric of these masklike respirators is designed to filter 95% of particles that are 1 micrometer in diameter. The use of these inexpensive and comfortable respirators should be considered for all autopsies because it is frequently impossible to determine the risk for an aerosolized pathogen before an autopsy. Autopsy prospectors and observers who cannot wear N-95 respirators because of beards are advised to wear powered air-purifying respirators (PAPRs) equipped with appropriate N-95 or high-efficiency particulate air (HEPA) cartridge filters (Fig. 3). Both N-95 and HEPA respirators are currently available as disposable products. HEPA-filtered PAPRs can provide an additional measure of respiratory protection for high-risk autopsies (69). Respirators of this type should be worn during the examination of persons who have died of conditions such as the viral hemorrhagic fevers and plague (59,63,83).

When volatile chemicals are suspected, organic vapor cartridges must be used. These cartridges may be sandwiched with a HEPA-filter cartridge for use in a PAPR (125). Personnel who need to wear respirators are required to receive medical clearance and training in proper fit-testing (157,158).

**Autopsy Procedures**

When prospectors use safe procedures, the risks for autopsy-transmitted infections can be decreased. To avoid percutaneous injury, prospectors must be careful with sharp instruments such as scalpels, needles on sy-

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**TABLE 3. Principles of Biosafety Level 3**

<table>
<thead>
<tr>
<th>Suitable for work with indigenous or exotic agents that can cause serious or potentially lethal disease as a result of exposure by the inhalation route</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Personnel receive specific training in handling materials (potentially) infected with pathogenic and potentially lethal agents</td>
</tr>
<tr>
<td>▪ Supervision is provided by competent scientists who are experienced in working with such agents</td>
</tr>
<tr>
<td>▪ Localized containment or ventilation devices (e.g., downdraft tables) are used to control or contain fumes, splatters, or biologic aerosols</td>
</tr>
<tr>
<td>▪ Special engineering controls and appropriate personal protective clothing and equipment (including respirators) are required and used</td>
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</tbody>
</table>

**In addition to the principles of BSL-2**

| ▪ Additional medical surveillance procedures might be applicable (e.g., periodic TB skin testing, serum collection and testing) |
| ▪ Biohazard warning signs indicating suspect agents and necessary precautions are posted |
| ▪ All personnel demonstrate proficiency in the practices and procedures specific to the nature of the hazard |

**Facility requirements include the following**

| ▪ A separate room is recommended; otherwise, only persons involved with the specific autopsy are allowed in the room; room doors are lockable |
| ▪ Exhaust from the autopsy room is discharged to the outside |
| ▪ Ventilation to the autopsy room is balanced to provide directional airflow into the room (negatively pressured room) |
| ▪ Access to a personal shower is available close to the autopsy room |
| ▪ Interior surfaces of the walls, floors, and ceilings are constructed for easy cleaning and decontamination |
| ▪ Floors should be monolithic and slip resistant |
| ▪ Penetrations through floors, walls, and ceilings should be sealed; openings around ducts and doors are sealable to facilitate decontamination |
| ▪ Vacuum lines are protected with liquid disinfectant traps and HEPA filters, or their equivalent |
| ▪ Containment features of the BSL-3 autopsy room need to be verified by facility engineers and biosafety personnel before work is performed and annually thereafter |

Adapted from reference (15).

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rings, and suturing needles (151). Furthermore, prosec- tors must be aware of the potential for other sharp objects such as broken glass, splintered bone, and sharp projectiles that can be encountered during dissection (9,10). All sharp objects, including scalpels and needles, should be discarded into puncture-resistant “sharps” containers immediately after use and not be reused. Needles should not be recapped with two hands or by the use of any other method that involves pointing the needle toward any part of the handler’s body. Instead, a one-handed “scoop” technique or a mechanical device for holding the needle sheath should be used. Sharps containers should be available in the use area (151). Prosectors should thoroughly and immediately wash any skin surfaces that are contaminated with blood or other potentially infectious body fluids to prevent transmission of pathogens. Additionally, when an autopsy is completed, participants should wash their hands after they remove their gloves because inapparent defects may occur in gloves during use, and hands can become contaminated during glove removal (151). Using a manual saw or an oscillating saw equipped with an integrated exhauster can reduce exposure to aerosolized bone dust and pathogens (73).

Instruments used in autopsy procedures should be decontaminated before cleaning, by liquid chemical soaks (typically 1:10 or 1:100 dilutions of bleach) or by autoclaving (150). Sharp instruments should be placed in

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**FIG. 2.** N-95 respirator.

**FIG. 3.** Prosectors wearing powered air-air-purifying respirators. (A) front view of hooded gown, (B) rear view of filter device with air supply hose extending to hood.
rigid containers to minimize puncture hazards to persons “downstream” from the autopsy room (21). Paper products, sponges, waste tissue, and similar materials can be treated as standard hospital “red bag” waste and removed for terminal treatment (e.g., incineration) (150).

Autopsy surfaces should be decontaminated with an appropriate liquid chemical. If bleach is used, the concentration should be adjusted: heavy blood/body fluids should be treated with undiluted bleach, moderate splatter areas with 1:10 (0.5%) bleach, and usually clean areas with 1:100 (0.05%) bleach (150,159). Agents such as *M. tuberculosis* should be decontaminated with liquid tuberculocidal solutions such as phenolic compounds (160,161), and prions, with NaOH (see Agent Summary Statement on Prions at end of article).

**Vaccines, Employee Health Surveillance, and Antibiotic Prophylaxis**

A vaccine to prevent hepatitis B became available in 1982. Vaccination is currently recommended for all health care workers who are regularly exposed to blood and other body fluids and can significantly decrease the risk of occupational exposure to this pathogen (20,31). The U.S. Department of Labor and the U.S. Department of Health and Human Services require employers to provide this vaccine at no charge to at-risk health care workers (20). Other vaccines are available for diseases potentially transmitted at autopsy (e.g., plague and rabies). However, none of these vaccines are presently recommended for unexposed autopsy workers with a low risk of encountering these infections.

Autopsy workers should have a baseline tuberculin skin test at the time of employment. Periodic retesting of workers with negative skin test results should occur at regular intervals based on an assessment of risk. In addition, there should be retesting whenever there is exposure to a tuberculous patient without appropriate precautions. A history of a positive skin test result or of tuberculosis should exempt the worker from further testing (69).

Under certain conditions, administering prophylactic antibiotics to autopsy workers exposed to potentially lethal infectious organisms may be appropriate. For example, persons exposed to *Y. pestis* aerosols should receive a course of antimicrobial therapy, regardless of vaccine status (162).

**Facility Design**

Autopsy facility design is complicated and autopsy facility construction is expensive. However, from the biosafety standpoint, autopsy rooms should have a separate air supply and should be physically separated from the administrative areas of the facility (163). Separation prevents employees and other persons who do not participate in postmortem examinations from being exposed to bloodborne and aerosolized pathogens. Autopsy rooms should have a minimum of 12 air exchanges per hour and should be under negative pressure in relation to the surrounding spaces (69). Increasing ventilation above this standard yields little additional benefit of decreased risk, especially if the exposure level is high (164). The air in autopsy rooms should flow unidirectionally from clean areas to less clean areas. The air should then be exhausted directly to the outside of the facility (69).

Other equipment that can decrease exposure to aerosolized pathogens includes downdraft autopsy tables, ultraviolet irradiation devices to sterilize air, HEPA filtration, and biologic safety cabinets for handling infected tissues. Downdraft table ventilation has proved effective in reducing formaldehyde exposure during anatomy dissection (165). Pathologists can use similar downdraft dissection tables to examine fixed autopsy tissues or to perform autopsies on bodies that harbor potentially aerosolizable pathogens. Important safety concerns are associated with using ultraviolet irradiation (69). Biologic safety cabinets can be used to examine tissues potentially contaminated by infectious agents (21,166). When combined with appropriate techniques, Class I and Class II biologic safety cabinets can effectively contain moderate and high-risk microorganisms (Biosafety Level 2 and 3 agents). These cabinets have inward directed airflow velocities of 75 to 100 linear feet per minute to protect workers from infectious aerosols generated within the cabinet. Class III cabinets which contain hazardous materials in a totally enclosed, ventilated space protected by HEPA filters, are most appropriate for work with hazardous Biosafety Level 4 agents. If biosafety cabinets are ducted to the outside exhaust system, they may be used to examine specimens contaminated by toxic or volatile chemicals or radionuclides (21). Chemical fume hoods can also be effective primary containment devices for tissues contaminated by toxic or volatile chemicals (114). These cabinets and fume hoods need to be certified *in situ* at the time of installation, any time the device is moved, and at least annually thereafter. Personnel must also be trained in their use (21).

**PRESENT STATUS OF AUTOPSY FACILITIES IN THE UNITED STATES**

Most medical examiner, coroner, and hospital autopsy facilities in the United States are not constructed to enhance autopsy biosafety (167). Many autopsy rooms are located in aging facilities, often with shared ventilation between prosecting and administrative space. Most autopsy rooms barely meet the design criteria of Biosafety Level 2. Only a few are constructed to meet Biosafety Level 3 requirements. At present, the U.S. Army Medical Research Institute of Infectious Diseases in Fort Detrick, Maryland, has the only autopsy facility
in the United States that can function at Biosafety Level 4. Although this facility was designed for human autopsies, it is currently used for nonhuman primate examinations (NK Jaax, personal communication, 1999). Furthermore, many autopsy pathologists have been slow in complying with even basic precautions promulgated to prevent the transmission of both bloodborne and aerosolized pathogens (20,69,168,169).

RECOMMENDATIONS

We need to have a better prepared national autopsy infrastructure that is uniformly capable of investigating fatalities resulting from contagious and toxic agents. Achieving this goal will require substantial changes in autopsy facilities, in policies and procedures, and in the protective equipment provided to pathologists. Funding should be made available to effect these changes and to bring autopsy facilities into compliance with accepted public health standards (20,21,69). All autopsy facilities should be able to function at Biosafety Level 3. In facilities lacking proper ventilation, personal protective equipment such as N-95 respirators, coupled with the practices and procedures of BSL-3, can provide adequate worker protection against aerosolized pathogens. However, providing this equipment does not address the issue of how to protect nonautopsy staff working elsewhere in these buildings. When the autopsy room is not negatively pressured and the air is not properly exhausted outside (i.e., the principal secondary containment features of Biosafety Level 3), protecting nonautopsy staff from aerosolized pathogens is impossible. Consequently, Biosafety Level 3 should be considered the standard for every autopsy facility.

To achieve this goal, new autopsy facilities should be constructed with adequate ventilation to ensure protection of pathologists and other building occupants. Substandard facilities need to be remodeled to reach an effective level of protection. Because new construction and facility remodeling are expensive, and hospital autopsy rates are declining nationally, some thought should be given to regionalizing autopsy services. A mobile containment autopsy facility constructed to operate at Biosafety Levels 3 or 4 may be useful in providing autopsy support to jurisdictions with inadequate facilities when they are confronted with contagious or toxic cases. Plastic film tent isolators with sleeved glove ports and negative pressure ventilation have been used for Biosafety Level 3 autopsies (170). Perhaps such mobile facilities or devices should be a resource offered by the federal government.

In addition, all agencies that perform autopsies should provide pathologists with adequate respirators and other personal protective devices, appropriate biosafety training, immunization against hepatitis B virus, periodic screening for tuberculosis, and access to appropriate health care after exposure to bloodborne and aerosolized pathogens or toxic chemicals.

AGENT SUMMARY STATEMENT ON PRIONS

Prions are proteinaceous infectious particles that lack nucleic acids (171). Prions are composed largely, if not entirely, of an abnormal isoform of a normal cellular protein. In mammals, prions are composed of an abnormal, pathogenic isoform of the prion protein (PrP), designated PrPSc. The “Sc” superscript was initially derived from the term scrapie because scrapie is the prototypic prion disease. Because all of the known prion diseases of mammals involve aberrant metabolism of PrP similar to that observed in scrapie, use of the “Sc” superscript is suggested for all abnormal pathogenic PrP isoforms (172). In this context, the “Sc” superscript is used to designate the scrapie-like isoform of PrP.

A chromosomal gene encodes PrP, and no PrP genes are found in purified preparations of prions. PrPSc is derived from PrPC (the cellular isoform of PrP) by a posttranslational process whereby PrPSc acquires a high beta-sheet content (173). Neither prion-specific nucleic acids nor virus-like particles have been detected in purified, infectious preparations. In fungi, evidence for three different prions has been accumulated (174). The mammalian prions cause scrapie and other related neurodegenerative diseases in humans and animals. The prion diseases are also referred to as the transmissible spongiform encephalopathies (175).

Autopsies

Routine autopsies should be performed using BSL-2 precautions (176) augmented by BSL-3 facility ventilation and respiratory precautions. At autopsy, the entire brain should be collected and cut into coronal sections about 1.5 inches (~4 cm) thick; small blocks of tissue can easily be removed from each coronal section and placed in fixative for subsequent histopathologic analyses. Each coronal section is immediately heat-sealed in a heavy-duty plastic bag. The outside of this bag is assumed to be contaminated with prions and other pathogens. With fresh gloves or with the help of an assistant with uncontaminated gloves, the bag containing the specimen is placed into another plastic bag that does not have a contaminated outer surface. The samples should then be frozen on dry ice or placed directly in a ~70°C freezer for storage. At the very minimum, a coronal section of cerebral hemisphere containing the thalamus and one of the cerebellar hemisphere and brainstem should be taken and frozen.

The absence of any known effective treatment for prion disease demands caution. The highest concentrations of prions are in the central nervous system and its coverings. On the basis of animal studies, high concen-
TABLE 4. Precautions for autopsies of subjects with suspected prion disease

1. Attendance should be limited to at least one experienced pathologist and minimal staff. One of the staff avoids direct contact with the deceased but assists with the handling of instruments and specimen containers.
2. Standard autopsy attire is mandatory.
   a. A disposable, waterproof gown is worn in place of a cloth gown.
   b. Cut-resistant gloves are worn underneath two pairs of surgical gloves, or chain mail gloves are worn between two pairs of surgical gloves.
   c. Aerosols are mainly created during opening of the skull with a Stryker saw. Appropriate respiratory protection should be worn (i.e., powered air-purifying respirators).
3. To reduce contamination of the autopsy suite
   a. The autopsy table is covered with an absorbent sheet that has a waterproof backing.
   b. Contaminated instruments are placed on an absorbent pad.
   c. The brain is removed while the head is in a plastic bag to reduce aerosolization and splatter.
   d. The brain can be placed into a container with a plastic bag liner for weighing.
   e. The brain is placed onto a cutting board, and appropriate samples are dissected for snap freezing.
   f. The brain or organs to be fixed are immediately placed into a container with 10% neutral buffered formalin.
   g. In most cases of suspected prion disease, the autopsy can be limited to examination of the brain only. In cases requiring a full autopsy, consideration should be given to examining and sampling thoracic and abdominal organs in situ.

4. Any suspected areas of contamination of the autopsy table or room are decontaminated by repeated wetting over 1 hour with 2N sodium hydroxide.
5. Gases are used, forceps are decontaminated.
6. Slides for immunocytochemistry may be processed in disposable Petri dishes.
7. Reagents are prepared in 100-ml disposable specimen cups.
8. Slides are processed by hand.
9. Other suggestions:
   a. Disposable specimen cups or slide mailers may be used for reagents.
   b. Slides for immunocytochemistry may be processed in disposable Petri dishes.
   c. Equipment is decontaminated as described above.

TABLE 6. Brain cutting procedures
1. After adequate formaldehyde fixation (at least 10–14 days), the brain is examined and cut on a table covered with an absorbent pad with an impermeable backing.
2. Samples for histology are placed in cassettes labeled “CJD precautions.” For laboratories that do not have embedding and staining equipment or microtome dedicated to infectious diseases, including Creutzfeldt-Jakob disease, blocks of formalin-fixed tissue can be placed in 96% absolute formic acid for 30 minutes, followed by fresh 10% neutral buffered formalin solution for at least 48 hours. The tissue block is then embedded in paraffin as usual. Standard neurohistologic or immunohistochemical techniques are not obviously affected by formic acid treatment; however, tissue sections are brittle and crack during sectioning.
3. All instruments and surfaces that come into contact with the tissue are decontaminated as described in Table 5.
4. Tissue remnants, cutting debris, and contaminated formaldehyde solution should be discarded within a plastic container as infectious hospital waste for eventual incineration.
5. Other suggestions:
   a. Disposable specimen cups or slide mailers may be used for reagents.
   b. Slides for immunocytochemistry may be processed in disposable Petri dishes.
   c. Equipment is decontaminated as described above.

TABLE 7. Tissue preparation
1. Histology technicians wear gloves, apron, laboratory coat, and face protection.
2. Adequate fixation of small tissue samples (e.g., biopsy specimens) from a patient with suspected prion disease is followed by postfixation in 96% absolute formic acid for 30 minutes, followed by 48 hours in fresh 10% formalin.
3. Liquid waste is collected in a 4-L waste bottle containing 600 ml 6N sodium hydroxide.
4. Gloves, embedding molds, and all handling materials are disposed of as biohazardous waste.
5. Tissue cassettes are processed manually to prevent contamination of tissue processors.
6. Tissues are embedded in a disposable embedding mold. If used, forceps are decontaminated.
7. In preparing sections, gloves are worn; section waste is collected and disposed of in a biohazard waste receptacle. The knife is wiped with 1–2N NaOH, and the knife used is discarded immediately in a “biohazard sharps” receptacle. Slides are labeled “CJD precautions.” The sectioned block is sealed with paraffin.
8. Routine staining:
   a. Slides are processed by hand.
   b. Reagents are prepared in 100-ml disposable specimen cups.
   c. After placing the coverslip on, slides are decontaminated by soaking them for 1 hour in 2N NaOH.
   d. Slides are labeled “Infectious—CJD.”
9. Other suggestions:
   a. Disposable specimen cups or slide mailers may be used for reagents.
   b. Slides for immunocytochemistry may be processed in disposable Petri dishes.
   c. Equipment is decontaminated as described above.
Bovine Spongiform Encephalopathy

The risk of infection for humans by bovine spongiform encephalopathy prions is unclear. Perhaps the most prudent approach is to study these prions in a Biosafety Level 2 or 3 facility (depending on the samples to be studied), as noted above for human prions (i.e., Biosafety Level 3 for brain, spinal cord, and other organs with high prion concentrations.)

Physical Properties of Prions

The smallest infectious prion particle is probably a dimer of PrPSc; this estimate is consistent with an ionizing radiation target size of 55 ± 9 kDa (178). Therefore, prions may not be retained by most of the filters that efficiently eliminate bacteria and viruses. Additionally, prions aggregate into particles of nonuniform size and cannot be solubilized by detergents, except under denaturing conditions where infectivity is lost (179,180). Prions resist inactivation by nucleases (181), ultraviolet irradiation at 254 nm (182,183), and treatment with psoralens (184), divalent cations, metal ion chelators, acids (between pH 3 and 7), hydroxylamine, formalin, boiling, or proteases (185,186).

Inactivation of Prions

Prions are characterized by extreme resistance to conventional inactivation procedures, including irradiation, boiling, dry heat, and chemicals (formalin, betapropiolactone, and alcohols). Whereas prion infectivity in purified samples is diminished by prolonged digestion with proteases (187,188), the results from boiling in sodium dodecyl sulfate and urea are variable. Sterilization of rodent brain extracts with high titers of prions requires autoclaving at 132°C for 4.5 hours. Denaturing organic solvents such as phenol, or chaotropic reagents such as guanidine isothiocyanate, or alkali such as NaOH can also be used for sterilization (189–193). Prions are inactivated by 1 N NaOH, 4.0 mol/L guanidinium hydrochloride or isocyanate, sodium hypochlorite (2% free chlorine concentration), and steam autoclaving at 132°C for 4.5 hours (190–193). The recommendation for dry waste is autoclaving at 132°C for 4.5 hours or incinerating. Large volumes of infectious liquid waste containing high titers of prions can be completely sterilized by treating with 1 N NaOH (final concentration) or autoclaving at 132°C for 4.5 hours. Using disposable plastic ware, which can be discarded as a dry waste, is highly recommended to reduce contamination and obviate the need for disinfecting reusable materials. Because the paraformaldehyde vaporization procedure does not diminish prion titers, the biosafety cabinets must be decontaminated with 1 N NaOH, followed by 1 N HCl, and rinsed with water. HEPA filters should be autoclaved and incinerated.

Although no evidence suggests that aerosol transmission occurs in the natural disease, it is prudent to avoid the generation of aerosols or droplets during the manipulation of tissues or fluids and during the necropsy of experimental animals or infected humans. It is further strongly recommended that gloves be worn for activities that provide the opportunity for skin contact with infectious tissues and fluids. Formaldehyde-fixed and paraffin-embedded tissues, especially of the brain, remain infectious. Some investigators recommend that formalin-fixed tissues from suspected cases of prion disease be immersed for 30 minutes in 96% formic acid or phenol before histopathologic processing (186), but such treatment may severely distort the microscopic neuropathology.

Handling and Processing of Tissues from Patients with Suspected Prion Disease

The special characteristics of work with prions require particular attention to the facilities, equipment, policies, and procedures involved. Handling and processing tissues from patients with suspected prion disease must be done with precautions equal to those used with prion-infected experimental animals. The related considerations outlined in Tables 4 through 7 should be incorporated into the laboratory’s risk management protocols for this work.

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REFERENCES


123. Clifford NJ, Nies AS. Organophosphate poisoning from wearing a laundered uniform previously contaminated with parathion. JAMA 1989;262:3035–6.


150. NCCLS. Protection of laboratory workers from instrument biohazards and infectious disease transmitted by blood, body fluids, and tissue; approved guideline. 1997;M-29A-17:28–34.


