confusion among humanitarian workers, health organizations, and government authorities. Many individuals and organizations are still unclear about what the infectious risks associated with dead bodies really are, who is most at risk, what precautions should be taken, and how to safely dispose of the bodies. This paper reviews the risks for both the general public and for those who may be more intimately involved in managing the dead. The article also addresses the infectious disease risks associated with the disposal of the dead, an area that often causes particular problems.

Relevant literature was identified from the PubMed on-line database of the National Library of Medicine of the United States of America. Key words included "relief work," "disaster planning," "natural disasters," "disease outbreaks," "emergency medicine," "mortuary practice," "burial," and "cadaver." Bibliographies of all relevant papers were searched to identify further papers. Studies were selected if they addressed the handling and disposal of dead bodies.

HOW INFECTIOUS ARE DEAD BODIES?

Transmission of infection requires the presence of an infectious agent, exposure to that agent, and a susceptible host. It is therefore possible to characterize the infectious risks from dead bodies following a natural disaster by considering these elements. This section considers the presence of infectious agents in cadavers; the following sections make estimates of exposure.

The human body is host to many organisms, only some of which are pathogenic. When the body dies, the environment in which pathogens live can no longer sustain them. However, this does not happen immediately, and transmission of infectious agents from a cadaver to a living person may occur. Infectious hazards for individuals who routinely handle cadavers include tuberculosis, group A streptococcal infection, gastroenteritis, transmissible spongiform encephalopathies (such as Creutzfeldt-Jakob disease), hepatitis B, hepatitis C, HIV infection, and possibly meningitis and septicemia (especially meningococcal) (4). Microorganisms involved in the decay process (putrefaction) are not pathogenic (5).

Do victims of natural disasters have these infections when they die? Usually disaster victims die from trauma, burns, or drowning (2, 6), and they are no more likely than the local population to have acute infections (meningitis and septicemia) or rare diseases (e.g., Creutzfeldt-Jakob disease). Instead, where disease is present, it is far more likely to be due to chronic infections with bloodborne viruses (hepatitis B virus, hepatitis C virus, and HIV), enteric pathogens, and possibly *Mycobacterium tuberculosis* (Table 1).

TABLE 1. General categories and specific examples of infectious hazards associated with dead bodies after a natural disaster occurs

Category/examples
Bloodborne
Hepatitis B
Hepatitis C
HIV
Gastrointestinal
Rotavirus diarrhea
Campylobacter enteritis
Salmonellosis
Enteric fevers (typhoid and paratyphoid)
Escherichia coli
Hepatitis A
Shigellosis
Cholera
Respiratory
Tuberculosis

RISK TO THE GENERAL PUBLIC

Historically, epidemics resulting in mass casualties have only occurred from a few diseases, including plague, cholera, typhoid, tuberculosis, anthrax, and smallpox (2). As previously noted, such infections are no more likely to be present in disaster victims than in the general population. Furthermore, although some of these diseases are highly contagious, their causative agents are unable to survive long in the human body following death (4). It is therefore unlikely that such epidemics will result from contact with a cadaver. Indeed, survivors present a much more important reservoir for disease (2). Where dead bodies have contaminated water supplies, gastroenteritis has been the most notable problem (7), although communities will rarely use a water supply where they know it to be contaminated by dead bodies.

HANDLING THE DEAD

The occupational risks for pathologists and mortuary staff who routinely work with dead bodies are well known, and the risks are unlikely to be different for persons who are dealing with victims of a natural disaster. However, incidents with a large number of fatalities may require a temporary workforce for the collection, transportation, storage, and disposal of the dead. These workers may include military personnel, rescue workers, volunteers, and others who have little or no experience in handling the deceased. Although there is no published literature about the risk of infections for this group, the risk is probably similar to that of public safety workers (e.g., emergency medical personnel, firefighters, and police officers) and funeral workers who are occupationally exposed to infectious agents during the intimate management of cadavers (4, 8–11). As noted above, the most likely type of infections are those produced by bloodborne viruses, enteric pathogens, and *Mycobacterium tuberculosis*.

Bloodborne viruses

The risk of infection from bloodborne viruses depends on the infection status of the victim (similar to the general population), likelihood and mode of exposure, and, in the case of hepatitis B, the vaccination status of the exposed individual. In many developing countries, especially in sub-Saharan Africa, Southeast Asia, the Middle East, the Pacific, and some countries in Latin

America, the prevalence of chronic hepatitis B infection is around 8% to 10% (12). Hepatitis C virus is estimated to infect about 3% of the world's population, with prevalence being highest in Africa (5.3%), the Eastern Mediterranean (4.6%), the Western Pacific (3.9%), and Southeast Asia (2.2%); the prevalence is lowest in the Americas (1.7%) and Europe (1.0%) (13). The prevalence of HIV infection in those 14–45 years old is as high as 30% to 40% in some African countries; about 0.1% in Asia, Eastern Europe, and Western Europe; and between 0.1% and 6% in Latin America and the Caribbean (14).

Exposure to bloodborne viruses can occur due to direct contact with nonintact skin, percutaneous injury from bone fragments and needles, and mucous membrane exposure from splashes of blood or body fluid to the eyes, nose, or mouth (10). Following one needle-stick injury from an infected individual, the risks of infection have been estimated to be: for hepatitis B, between 6% and 30% in those who have had no prior hepatitis B vaccination (15); for hepatitis C, 1.8% (9); and for HIV infection, 0.5% (14). Infection from nonintact skin or mucous membrane exposure is likely to be much lower (9, 15). Importantly, infectious HIV can survive in cadavers for a considerable amount of time (up to 16 days after death if stored at 2 °C), and viable HIV has also been isolated from bone fragments, spleen, brain, bone marrow, and lymph nodes at autopsy 6 days postmortem (16).

Gastrointestinal infections

Because a corpse will commonly leak feces, persons handling dead bodies are more likely to be exposed to gastrointestinal organisms than to bloodborne viruses (4). Workers may be exposed through direct contact with the victim's body and soiled clothes, and transmission can occur via the fecal-oral route. Contamination of other equipment, such as stretchers and vehicles used for transportation or storage, is also possible. However, common gastrointestinal organisms do not survive long in the environment and present little risk of infection where the body has been decaying for some time, or has been in the water (4).

Tuberculosis

Around 1% of the world population is infected by tuberculosis each year. Rates are generally much higher in developing countries, especially Africa and Asia, and the increase in HIV infections has led to an increase in the prevalence of tuberculosis (17). A national study of tuberculosis in the United States of America found that funeral home directors had higher tuberculosis morbidity (standardized morbidity ratio, 3.9; 95% confidence interval (CI), 2.2 to 6.3) (18) and higher tuberculosis mortality (proportionate morality ratio, 299; 95% CI, 82 to 766) (19). This suggests that even when the chest cavity is not opened up, handling intact cadavers presents an increased risk of tuberculosis. Exposure may occur from gurgling at the nose and mouth of the cadaver due to fluid buildup in the chest cavity and putrefaction of tissues and organs (11). Also, residual air in the deceased's lungs may be exhaled when the body is moved (11). However, funeral workers have repeated occupational exposures to tuberculosis (11) and so may experience greater risk than is true with the one-time exposure experienced by those handling bodies after a disaster. On the other hand, storage of many cadavers together in temporary mortuaries may present an increased risk of infection; once aerosolized, the tubercle bacilli may remain viable for extended periods of time (20). The risk of tuberculosis may be reduced by placing a cloth over the deceased's mouth when moving the body (4) and by ensuring suitable ventilation where large numbers of bodies are stored (20).

Reducing the risk of infection

A number of simple measures can be taken to reduce the risk of infection associated with handling dead bodies. Considering that some of the persons doing this work may not have had experience in handling the dead, some basic instruction about the risks and precautions may be required. Universal precautions for blood and body fluids and enteric precautions should be followed (15). When handling dead bodies, workers should wear gloves, especially if the bodies are badly damaged. Used gloves should be removed and kept in a suitable bag and disposed of appropriately (15). Where nondisposable gloves are used, they should be cleaned and disinfected (15). To avoid cross-contamination, personal items should not be handled while wearing soiled gloves, and a new pair is recommended after each body or group of bodies is handled (15). Other personal protective equipment, such as eyewear, gowns, and masks, are only required where large quantities or splashes of blood are anticipated (15) and are probably not necessary when handling bodies following a natural disaster. Hands should be washed after handling cadavers and before eating, and all equipment, including clothes, stretchers, and vehicles used for transportation, should be washed carefully with a disinfectant (15). Body bags will further reduce the risk of infection and are useful for the transport of cadavers that have been badly damaged. However, body bags reduce the rate of cooling of the cadaver, thus increasing the rate of decomposition, especially in hot climates (4, 21). Hepatitis B vaccination will help prevent infection and will be 70% to 80% effective within one week of exposure (9). Those with prior BCG vaccination may have some protection against tuberculosis, and tuberculin testing may be an appropriate follow-up measure.

DISPOSAL OF DEAD BODIES

There is often considerable concern about the disposal of the dead following a natural disaster. Putrefaction starts soon after death (22), and suitable storage facilities may not be available for a large number of remains

(23). Concerns about the infectiousness of human remains and the unpleasantness of decaying bodies may lead to rapid unplanned disposal of the dead, sometimes before proper identification of the victim has been made. Concerns about disease may also lead to unnecessary "precautions" such as burying the deceased in common graves and adding chlorinated lime as a "disinfectant" (5).

Cremation

In normal circumstances, human remains are usually buried or cremated. Although cremation will render any remains noninfectious (24), special equipment and large quantities of fuel are required to achieve high enough temperatures (around 650 °C) for sufficient lengths of time (usually 2.5–3 hours) for complete burning (24). This makes cremation less practical following mass casualty disasters. Furthermore, cremation should be avoided where victims have not been identified, in which case burial is a more practical option, allowing future disinterment of remains.

Burial

Burial of human remains can be thought of as a particular kind of landfill (25), similar to that of unlined "dilute and disperse" municipal waste landfill sites (26). A few studies of cemeteries have detected traceable plumes of indicator bacteria, suggesting that microbiological decay products reach the groundwater (25). While the pathways and composition of decay products are complex, the principal mechanism of contamination is by rainwater percolating through the soil and coming into contact with buried remains (27).

The soil in the unsaturated zone (above the water table) is the main line of defense against rainwater leaching from the grave into the groundwater. Pathogens are retained in the unsaturated soil zone, principally due to filtration and adherence to clay particles. Pathogen retention is greater in soils with high clay content but less in soil with a high water content and pH above 7 (28). Pathogens retained in the soil will eventually die off due to lack of nutrients, and die-off increases with reduced soil moisture, increased temperature (die-off rates double with every 10 °C), and soil pH outside the range of 6 to 7 (28).

In a grave site, the disturbed nature of the soil provides an aerated environment that promotes rapid aerobic decomposition (29). However, it also attracts water, which leads to wetness at grave level, even in otherwise dry areas (25). Although this favors pathogen survival, decomposition of buried remains produces heat and alkaline soil conditions (30), possibly increasing pathogen die-off (28). However, the rate of heat production is highly dependent on burial depth, with significant temperature increases occurring within just a few days after burial at 0.3 m, but taking several weeks at greater depths (1.2 m) (25). While probably similar, it is not clear how the decay and dispersion characteristics may differ where many people are buried simultaneously or where they are buried in communal graves.

Studies of cemetery groundwaters in Australia (25), Brazil[2] (31), and the United States (32, 33) have all found evidence of contamination by organic products that are mostly associated with the decay process. No fecal coliforms were found, but pathogenic *Pseudomonas aeruginosa*, streptococci, and clostridia organisms were found in some samples (24, 30). However, only one study assessed the quality of groundwater *outside* the cemetery. That study found that microbiological indicator organisms attenuated rapidly with distance and that the decay plume was better characterized by products associated with the burial process (e.g., coffin materials and embalming substances) (25).

[2] Matos BA, Pacheco A. Ocorrência de microrganismos no aqüífero freático do Cemitério Vila Nova Cachoeirinha, São Paulo. Joint World Conference on Groundwater. 31st August 2000, Fortaleza, Brazil.

Recommendations for burial

Although there is some evidence of microbiological contamination in the immediate vicinity of cemeteries, the rapid attenuation of these microorganisms suggests that they pose little risk to the public (27). However, where it is necessary to choose a new burial site, several issues should be considered. A soil of sand-clay mix of low porosity and a small- to fine-grain texture is likely to maximize pathogen retention in the unsaturated zone (27). In such soil conditions, the water table should be at least 2.5 m deep in order to allow a "traditional" grave depth of six feet (1.8 m), with a 0.7-m unsaturated zone (34). This may have to be adjusted for more porous soil conditions, topographic lows, and low points of hydraulic gradients (25). To protect water supplies, distances of at least 30 m from springs or watercourses and 250 m from any well, borehole, or any source of drinking water have been suggested (27). However, there are no accepted standards, and distances are best chosen based on local hydrogeological conditions and with the agreement of nearby communities. It may also be likely that following a flood event, soils may be saturated and the water table may be unusually high, making location of a suitable site more difficult.

CONCLUSIONS

There is no evidence that, following a natural disaster, dead bodies pose a risk of epidemics. "Epidemic-causing" acute diseases are unlikely to be more common among disaster victims than among the general population, suggesting that the risk to the general public is negligible. The same is true with casualties of conventional war (as distinct from biological, chemical, or radiological warfare). In both cases it

is far more likely that survivors will be a source of disease outbreaks. However, those who handle victims may be exposed to chronic hazards such as bloodborne viruses, gastrointestinal infections, and tuberculosis. The risk for this group can be estimated from the disease prevalence in the local population and the likelihood of exposure and transmission.

Simple measures, such as handwashing and basic hygiene, can reduce the risk of such "occupational" exposures (Table 2). Those who are likely to be given the task of managing the dead (police, civil defense, military) would benefit from basic instruction as part of disaster preparedness activities. Access to suitable equipment (gloves, body bags, etc.) should also be considered. Following a catastrophic disaster or an event in a remote region, people with no previous instruction may be called upon to assist. Basic messages about suitable precautions (Table 2) would support local authorities and agencies who may themselves be unsure of appropriate methods. Where possible, disposal of the dead should be done according to local custom and practice. Burial is the preferred option in the case of mass casualties and where victims cannot be identified. Burial is unlikely to cause contamination of groundwater if sited correctly (Table 2).

TABLE 2. Recommendations for managing the dead following natural disasters

Suggested measures
Universal precautions for blood and body fluids
Disposal or disinfection of used gloves
Avoiding cross-contamination of personal items
Washing hands after handling bodies and before eating
Disinfection of vehicles and equipment
Use of body bags, especially for badly damaged bodies
Hepatitis B vaccination
No special arrangements, such as disinfection, with disposal of bodies
New burial areas sited at least 250 m away from drinking water sources, and with at least 0.7 m of distance above the saturated zone

After natural disasters it is important that misinformation about the infectious disease risks of dead bodies not lead to inappropriate treatment of the victims' bodies. It is hoped that this article will help those who have the difficult task of managing the dead.

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Riesgo de transmisión de enfermedades infecciosas por contacto con cadáveres después de desastres naturales

RESUMEN

Objetivo. Realizar una revisión bibliográfica encaminada a determinar los riesgos de infección que plantean los cadáveres después de un desastre natural, particularmente quiénes corren mayor peligro, qué precauciones se deben tomar y cómo se debe disponer de los cadáveres.

Métodos. Para que una enfermedad se transmita, es necesario que haya un agente infeccioso, una exposición a dicho agente y un huésped susceptible. Estos son los elementos que se tuvieron en cuenta para calcular el peligro que plantean los cadáveres como fuentes de infección. Se buscaron trabajos sobre el riesgo de infección al que se exponen los trabajadores que velan por la seguridad del público (personal médico de emergencia, bomberos, la policía) y los empleados de casas funerarias, y sobre las pautas observadas para disponer de los cadáveres y prevenir infecciones. También se revisaron unos cuantos trabajos importantes sobre la disposición de los cadáveres y la contaminación de las aguas subterráneas por los cementerios.

Resultados. Las víctimas de desastres naturales suelen morir de traumatismos y raras veces tienen infecciones agudas que puedan producir epidemias. Esto significa que los cadáveres plantean un riesgo sumamente pequeño para el público. No obstante, las personas que entran en contacto cercano con los muertos —el personal militar, el personal de rescate, los trabajadores voluntarios y demás— pueden verse expuestas a fuentes de infecciones crónicas, tales como los virus de las hepatitis B y C, VIH, organismos enteropatógenos y *Mycobacterium tuberculosis*. Algunas medidas de precaución orientadas a proteger a estas personas son el adiestramiento, el uso de bolsones para los cadáveres y de guantes, las buenas prácticas de higiene y la vacunación contra la hepatitis B y la tuberculosis. Siempre que se pueda, la disposición de los cadáveres debe hacerse de conformidad con las costumbres y prácticas locales. Cuando son muy numerosas las víctimas, el entierro es probablemente el método de disposición más adecuado. Hay muy pocas pruebas de que la contaminación microbiológica del agua subterránea debido al entierro de cadáveres constituya un peligro.

Conclusiones. Es natural que muchas personas, en su afán por protegerse contra las enfermedades, piensen que los cadáveres son fuentes de infección. No obstante, se necesita información precisa sobre los peligros que puedan existir para que las autoridades locales responsables puedan garantizar el manejo adecuado y respetuoso de los cadáveres de las víctimas de desastres naturales. Este trabajo provee información de utilidad para quienes se encuentran en la lamentable posición de tener que manejar dichos cadáveres.