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Uses of Inorganic Hypochlorite (Bleach) in Health-Care Facilities

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INTRODUCTION

Antisepsis of wounds and the hands of health-care providers and disinfection of equipment have been appropriately credited as the keystones of infection control. Hypochlorite, first used as an antiseptic agent by Oliver Wendell Holmes, remains an important chemical disinfectant that is widely used in health care. This paper will review the history, in vitro activity, clinical uses, and safety concerns of inorganic hypochlorite products (bleach) used in health-care facilities.

HISTORY

Although the scientific application of disinfectants and sterilants began approximately 150 years ago, the empirical use of disinfectants dates back to ancient time (17, 120). In approximately 800 B.C., the Greek poet Homer reported the use of sulfur in the form of dioxide as a disinfectant in his classic tale of adventure, *The Odyssey*.

The discovery of chlorine in 1774 by the Swedish chemist Scheele helped usher in the age of chemistry. In 1825, the Frenchman Labarraque reported the use of calcium hypochlorite for the general sanitation of morgues, sewers, privies, stables, hospital wards, ships, and prisons. He also reported that Parisian surgeons achieved great success in cases of carbuncle, hospital gangrene, ulcers, and burns when the wounds were covered with dressings containing a diluted aqueous solution of hypochlorite (17).

The late 19th century ushered in the acceptance of the "germ theory" of infection, leading to the institution of rational infection control practices. Oliver Wendell Holmes in Boston in 1843 and Ignaz Semmelweis in Vienna in 1861 were credited with the illumination of the cause of puerperal (childbed) fever and its prevention. Both men independently concluded that

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the disease was carried from patient to patient by doctors and nurses on their hands and clothing. Holmes observed that the patients of one physician who had reported washing his hands with calcium hypochlorite solution between visits had been unusually free of disease (17). Semmelweis insisted that physicians who left the autopsy room washed their hands with chloride of lime before examining obstetrical patients (17). This resulted in a spectacular decrease in the attack rate of puerperal sepsis. Although in retrospect these infection control guidelines appear simple and highly effective, they elicited enormous opposition. During World War I, Dakin introduced the widespread use of a sodium hypochlorite solution (approximately 0.5%) for antisepsis of open and infected wounds (44).

The treatment of sewage and provision of safe drinking water represent milestones of public health. Chlorinated lime was first used for the treatment of sewage in London in 1854. In 1894, Traube established the purifying and disinfecting properties of hypochlorites in water treatment. The first known continual use of chlorine as a water disinfectant was in the small Belgium town of Middekerke in 1902. Johnson in 1908 introduced chlorinated lime for the purification of water in North America. In 1910, an important advance was introduced by Major C. R. Darnall, U.S. Army Medical Corps, who developed the first practicable gaseous-chlorine chlorinator. Within a few years, chlorination was widely practiced in the United States (47, 48).

Despite the introduction of many classes of disinfectants, hypochlorite products continue to play an important role in improving the public health by reducing cross-transmission of infectious agents via drinking water and environmental surfaces (see below).

DEFINITIONS

The precise use of scientific terms is crucial to an informed discussion of the uses of chlorine in the hospital. For this reason, we provide a brief review of disinfection, sterilization, and antiseptic practices (115, 120). Sterilization is the complete elimination or destruction of all forms of microbial life; in the hospital, it is accomplished by physical or chemical means. Disinfection describes a process that eliminates many or all pathogenic microorganisms on inanimate objects with the exception of bacterial endospores. This is usually accomplished by the use of liquid chemicals or wet pasteurization in the health-care setting. The efficacy of disinfection is affected by a number of factors, including the prior cleaning of the object, the organic load present, the type and level of microbial contamination, the concentration of and exposure time to the germicide, the nature of the object (e.g., whether the object has a lumen), and the temperature and pH of the disinfection process. Disinfectants may be further subdivided by their efficacy. A few disinfectants will kill endospores after prolonged exposure times (i.e., 6 to 10 h) and are called chemical sterilants. Agents that kill all microorganisms with the exception of large numbers of bacterial endospores after a shorter exposure time (i.e., <45 min) are called high-level disinfectants. That is, high-level disinfectants are chemical sterilants with exposure times of less than 45 min. Intermediate-level disinfectants may be cidal for tubercle bacilli, vegetative bacteria, most viruses, and fungi but do not necessarily kill bacterial endospores. Finally, low-level disinfectants kill most vegetative bacteria, some fungi, and some viruses with short exposure times (i.e., <10 min). An antiseptic is an agent that prevents or arrests the growth or action of microorganisms and is used for preparations applied to living tissue.

Items designed for use on patients may be divided into three classes based on their intended use and the risk of infection posed by possible contamination. Critical items apply to objects that enter sterile tissue or the vascular system, such as surgical instruments and implants (e.g., heart valves). These items should be sterile when used because of the high risk of infection if they are contaminated with any microorganism including bacterial endospores. Semicritical items are objects that come into contact with mucous membranes or nonintact skin, such as anesthesia equipment, endoscopes, and diaphragm fitting rings. Since intact mucous membranes are generally resistant to infection with bacterial endospores but not necessarily vegetative bacteria or viruses, these items should be free of microorganisms with the exception of large numbers of bacterial endospores. Finally, noncritical items consist of objects that come into contact with intact skin, such as bedpans, blood pressure cuffs, linens, and bedside tables. Although there is minimal risk of transmitting infectious agents to patients via noncritical items, these items could potentially contribute to secondary transmission by contaminating the hands of healthcare workers or by contact with medical equipment that will subsequently come into contact with patients. Low-level disinfection that reduces the microbial burden is usually adequate for these items.

Hypochlorite is used in hospitals as a high-level disinfectant for some types of equipment and a low-level disinfectant for noncritical environmental surfaces. In lower concentrations, it is widely used as a disinfectant for treating potable water. Currently, it is rarely used as an antiseptic.

DISEASE TRANSMISSION IN HEALTH-CARE FACILITIES

The acquisition of nosocomial pathogens depends on a complex interplay among the host, pathogen, and environment (121). Many studies have linked nosocomial infections to organisms present in the hospital environment. However, it is still unclear how often the hospital environment serves as a source for nosocomial infections. Although the precise relative contribution of the animate (i.e., endogenous flora of the patient) and inanimate reservoirs to hospital-acquired infections is unclear, we will discuss the current state of knowledge about the role of chlorine (i.e., hypochlorite) in preventing nosocomial infections.

Nosocomial infections may result from endogenous flora (i.e., microbes that are normal commensals of the skin, respiratory tract, gastrointestinal tract, or genitourinary tract), reactivation of latent infectious agents (e.g., *Mycobacterium tuberculosis*, *Pneumocystis carinii*, herpesviruses), or exogenous flora (i.e., microbes from the environment). The source of a nosocomial pathogen is the place from which the infectious agent passes to the host by either direct or indirect contact. Environmental sources of exogenously acquired pathogens include the inanimate hospital environment and the animate environment, which consists of other patients, visitors, and staff. The hospital environment may also serve as a reservoir for nosocomial pathogens. The reservoir is the place where a microorganism maintains its presence, metabolizes, and replicates. The reservoir for gram-positive bacteria is generally human hosts, whereas gram-negative bacteria may have either a human or animal reservoir (e.g., *Salmonella* spp.) or an inanimate reservoir (e.g., *Pseudomonas* and *Acinetobacter* spp.). Thus, elimination of the environment as a link in the chain of nosocomial infections may require disinfection after human contamination (e.g., vancomycin-resistant *Enterococcus* spp. and *Clostridium difficile*), elimination of potential reservoirs (e.g., *Aspergillus* and *Legionella* spp.), or prevention of trans-

mission from the environmental reservoir to the patient (e.g., protection from airborne *Aspergillus* conidia by use of HEPA filtration).

Pathogens may spread from an animate or inanimate reservoir to the patient by one or more of several different routes: airborne, common vehicle, contact, or arthropod-borne vectors. Airborne transmission describes organisms, such as *M. tuberculosis*, that have a true airborne phase as part of their pattern of dissemination. In common-vehicle spread, a contaminated inanimate vehicle serves to transmit the infectious agent to multiple persons. Common vehicles may include ingested food or water, blood and blood products, and infused products such as medications or intravenously administered fluids. In contact-spread disease, the patient has contact with the source that may be direct, indirect, or via droplet. Direct contact occurs when there is actual physical contact between the source and the patient. Indirect contact refers to transmission from the source to the patient through an intermediate object, which is usually inanimate (e.g., an endoscope). Droplet spread refers to the brief passage of an infectious agent through the air when the source and patient are within several feet of each other. Arthropod-borne nosocomial infections have not been reported in the United States.

Most nosocomial infections are thought to result from direct contact, that is, patient-to-patient transmission of pathogens via the hands of health-care providers. An increasingly important source is the patient's own endogenous flora, especially in severely immunocompromised persons. Although many epidemics of nosocomial infections have stemmed from reservoirs of pathogens in the inanimate hospital environment (144), the contribution of the environment to the acquisition and spread of endemic nosocomial infections has been thought to be insignificant (5, 92, 100).

More recently, extensive environmental contamination has been demonstrated in rooms housing patients infected with *C. difficile* (56, 93, 108), methicillin-resistant *Staphylococcus aureus* (23, 118), or drug-resistant *Enterococcus* spp. (22, 86, 104, 111, 145, 148). For all these pathogens, environmental contamination was most commonly demonstrated on surfaces in close proximity to the patient, such as patient gowns, bedrails, or bedsheets (144). However, the epidemic strain has also been demonstrated on other environmental surfaces (144). For example, strains of drug-resistant *Enterococcus* spp. have been found on dietary trays, rectal probe handles of electronic thermometers, intravenous pumps, electrocardiogram monitors, stethoscopes, blood pressure cuffs, tourniquets, bathroom doors, utility room sinks, an open tube of diaper ointment, and the sink drain in a patient's room (144).

Few controlled studies have been performed to determine whether more stringent barrier precautions, enhanced environmental disinfection, or environmental monitoring will decrease either the epidemic or endemic rate of transmission of these drug-resistant pathogens or nosocomial infections in general.

CHARACTERISTICS OF THE IDEAL DISINFECTANT

Hypochlorite has held a predominant position as a reliable disinfectant because it has many of the properties of the ideal disinfectant, which include a broad antimicrobial spectrum; rapid bactericidal action; reasonable persistence in treated potable water; ease of use; solubility in water; relative stability both in its concentrated form and at its use dilution; relative nontoxicity to humans at use concentrations; lack of poisonous residuals (reduced predominantly to chloride as a result of its oxidizing action of inorganic and organic compounds); action as a deodorizer; colorless, nonflammable, and nonstaining; and low cost (120). Disadvantages of hypochlorite as a disinfectant include irritation to mucous membranes; potential to interact with some chemicals, resulting in the formation of toxic chlorine gas; odor when used in concentrated forms; decreased efficacy in the presence of an organic load; and deleterious effects on some metals.

Potential health concerns have been raised because organohalides are formed through the reaction of chlorine with organic compounds present in natural water and wastewater. Trihalomethanes such as chloroform have been detected in chlorine-treated waters and have raised concerns because of potential health effects. Further research is required to determine the potential hazards associated with chlorination of water supplies.

Bleach solutions have been reported to contain 0.5 to 21 mg of adsorbable organic halides, which include chloroform and carbon tetrachloride but not dioxins, per liter (133). Concern has been raised because, when used, sodium hypochlorite has a tendency to form small amounts of chlorinated organic byproducts during storage and use. Mixing undiluted household hypochlorite products with wastewater showed that 1 to 2% of the available chlorine forms chlorinated organic compounds (133). Decisions about restriction of chlorine use should take into account both the potential hazards and significant benefits of chlorine use (74).

CHLORINE COMPOUNDS WITH ANTIMICROBIAL ACTIVITY

Available Agents

A large number of antimicrobially active chlorine compounds are commercially available. These include sodium and calcium hypochlorites, liquid chlorine, chlorine dioxide, and inorganic and organic chloramines (47, 114).

Hypochlorites are salts of the hypochlorite ion (OCl^-). The sodium salt produces an aqueous solution, while the calcium salt is a solid. The active species is undissociated hypochlorous acid (HOCl), not chlorine. The dissociation of hypochlorous acid to the less microbicidal form (hypochlorite ion) is dependent on pH. As the pH increases, more hypochlorite ion is formed and the microbicidal activity decreases (64). Disinfection by chlorination is optimal at around pH 6 because the concentration of HOCl is optimal and its dissociation is minimal.

A variety of commercial products used in the home and health-care facilities contain 1 to 15% sodium hypochlorite. The most prevalent products in the United States are aqueous solutions of 4 to 6% sodium hypochlorite, which are usually called household bleach. These products often contain 0.01 to 0.75% sodium hydroxide and other alkaline salts or buffers to maximize their stability. Cleaning bleaches also include surfactants to improve hard-surface cleaning.

In the literature, HOCl and/or the OCl^- in aqueous solutions is referred to as either "free residual chlorine" or as "free available chlorine." Once these compounds are reacted with ammonia or *N*-organo compounds to form a series of lower-oxidation potential compounds such as monochloramine (NH_2Cl), dichloramine ($NHCl_2$), or a variety of organo-*N*-chloro compounds, the term applied is either combined chlorine, combined residual chlorine, or combined available chlorine (48). The free and combined available chlorine, when present in the water, are collectively described as total residual (available) chlorine.

Many commercially available chlorine products have antimicrobial activity. Elemental chlorine, which is a gas, can be

TABLE 1. Microbicidal effect of free chlorine on microorganisms[a]

Microorganism	Cl_2 residual concn (ppm)	Contact time	Temp (°C)	pH	Organic load	Test methodology	Inoculum (log_{10})	Biocidal activity (log_{10} reduction)	Reference
Viruses									
Hepatitis A virus	0.5	3.6 min	5	7.0	None	Suspension	8	4	135
Hepatitis B virus	500	10 min	20	9.2	Dried plasma	Suspension	6.0	6.0	21
HIV	5,000	1 min	23–27		50% plasma	Suspension	10.5	≥7	110
HSV-1	2,000	10 min	25	7.2	None	Suspension	6.0	>5.0	42
HSV-2	2,000	10 min	25	7.2	None	Suspension	5.75	>4.75	42
Norwalk agent	10	30 min	25	7.4	None	Suspension		0% detected	76
Poliovirus 1	0.5–1.0	3 min	Room temp		None	Suspension	2.21	2.21	91
Rotavirus	3.75	30 min	25	7.4	None	Suspension	1.2	1.2	76
Bacteria									
Bacillus subtilis spores	100	5 min	Room temp	7.0	None	Suspension	5.6	4.0	137
Bacillus subtilis spores	1,000	30 s	Room temp	7.0	None	Suspension	5.6	5.0	137
Enterococcus faecium	250	5 min			None	Suspension	8.0–8.48	>6.0	18
Legionella pneumophila	3.3	0 min	25		None	Suspension	6.1	6.1	131
Mycobacterium tuberculosis	1,000	10 min	20		None	Carrier	6.38	6.38	117
Pseudomonas aeruginosa	100	10 min	20	8.2–9.2	None	Carrier	6	6	116
Staphylococcus aureus	100	10 min	20	8.2–9.2	None	Carrier	6	6 (77/80 trials)	116
Protozoa									
Acanthamoeba castellanii	1.02	30 min	25	7.0	None	Suspension	4.28	4.28	43
Cryptosporidium parvum	80	90 min	25	7.0	None	Suspension	4.78	≥2.0	79
Giardia lamblia	1.5	10 min	25	6.0–8.0	None	Suspension	2.8	2.8	67
Naegleria fowleri	0.74	30 min	25	7.0	None	Suspension	4.28	4.28	43
Fungi									
Streptomyces spores	0.79	1.5 min	10	6.95–7.05	None	Suspension	4.0–5.0	4.0–5.0	146
Streptomyces mycelia	0.96	2.5 min	10	6.95–7.05	None	Suspension	4.0–5.0	4.0–5.0	146

[a] When multiple times or concentrations were used, the lowest time and/or concentration that demonstrated complete inactivation is reported. The reader should review individual papers for specific methodology.

supplied as a liquid by compressing and cooling the gas. When released under atmospheric pressure, it immediately reverts to a gaseous form. Due to the hazards of chlorine gas, it is rarely used as a disinfectant. Chlorine dioxide is an extremely reactive compound and consequently cannot be manufactured and shipped in bulk but is usually prepared at the point of use (47). Useful properties of chlorine dioxide include its ability to break down phenolic compounds and remove phenolic tastes and odors, its lack of reaction with ammonia, and its reduced tendency to form trihalomethanes or chlorophenols. It is widely used in the chlorination of drinking water and wastewater and for elimination of cyanides, sulfides, aldehydes, and mercaptans. Inorganic chloramines are agents produced by combining ammonia with chlorine in water solution; they consist of monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and nitrogen trichloride (NCl_3). Researchers have demonstrated inferior microbial inactivation with combined available chlorine compounds compared with products producing free available chlorine. For example, it takes approximately 25 times as much chloramine as free available chlorine to effect a rapid bactericidal action. Currently, inorganic chloramines are being used for chlorination of some water supplies to prevent trihalomethane formation. Organic chloramines may also be produced by the reaction of HOCl with an amine, amide, imine, or imide. A variety of organic chloramines are available including chlorinated cyanuric acid derivatives, chloramine-T, dichlorodimethylhydantoin, halazone, succinchlorimide, chloroazodin, and trichloromelamine (47).

Mechanism of Action

Chlorine in the form of hypochlorous acid, even in minute quantities exhibits rapid microbicidal activity (Table 1) (47). The mechanism of this activity has not been fully elucidated. Experiments by Fair (50) and Morris (105) demonstrated that at 2 to 5°C at various pHs, the OCl ion possesses about 1/80 of the germicidal activity of HOCl against *Escherichia coli*. Many theories have been advanced to explain the germicidal activity of HOCl (47). The postulated mechanism by which chlorine acts as a disinfectant is the inhibition of key enzymatic reactions within the cell and protein denaturation.

SAFETY

Toxicity via Direct Contact

Tissue injury caused by sodium hypochlorite and related compounds may range from mild irritation to frank necrosis depending on the physical form and duration of exposure. Exposure to sodium hypochlorite may irritate the conjunctiva, respiratory tract, or gastrointestinal tract. Injury may occur through direct contact (especially concentrated solutions) or ingestion of sodium hypochlorite, or direct exposure or inhalation of chlorine gas. Exposure to liquid household bleach rarely results in caustic injury. Furthermore, the incidence of injury due to sodium hypochlorite use in health-care facilities is extremely low.

If skin exposure to household bleach leads to irritation, the area should be washed with soap and water. If pain or irritation persists, the area should be evaluated by a physician. Exposed eyes should be irrigated with copious amounts of tepid sterile water for at least 15 min. If irritation, pain, swelling, lacrimation, or photophobia persist, an ophthalmologic examination should be performed. Esophageal and gastric injury is unlikely following ingestion of liquid household bleach, and esophago-

scopy is not warranted unless symptoms (i.e., drooling, dysphagia, and pain) are present or a large amount is ingested.

Exposure to Chlorine Gas

When combined with an acid or ammonia, hypochlorite may produce chlorine or chloramine gas, respectively. Exposure to gas may result in irritation to mucous membranes and the respiratory tract, with coughing, choking, and dyspnea. Chemical pneumonitis or pulmonary edema may occur following severe gas exposure. However, as both gases are extremely irritating, most people rapidly leave the area, thus minimizing the likelihood of significant toxicity.

Following exposure to chlorine gas or chloramine gas, the patient should be moved to fresh air and monitored for respiratory distress. If respiratory symptoms develop, the patient should be evaluated for pneumonitis and 100% humidified supplemental oxygen should be administered. Patients with significant pulmonary symptoms or signs should be monitored by pulse oximetry or arterial blood gas analyses. Chest radiographs and pulmonary function testing may also indicated. Assisted ventilation may be required for patients with severe pneumonitis to maintain an oxygen concentration greater than 50 mm Hg.

IN VITRO EFFICACY

Sodium hypochlorite has broad antimicrobial activity (Table 1). Generally, viruses and vegetative bacteria are more susceptible to hypochlorites than are endospore-forming bacteria, fungi, and protozoa. This selective resistance of organisms to hypochlorite may be compensated for either by increasing the concentration, by lowering the pH, or by raising the temperature. Table 1 presents representative studies of the biocidal effect of hypochlorite on various microbes. It is difficult to compare cidal activity across studies because of wide variances in chlorine residual levels, contact time, temperature, and test methodology. Against the most resistant form of microbe, *Bacillus subtilis* endospores, hypochlorite solutions containing 100 to 1,200 ppm chlorine eliminated all endospores in 1 h (6). Sykes demonstrated a ≥4-log-unit reduction in *B. subtilis* endospores in 5 min with a solution containing 100 ppm available chlorine and a similar reduction in 30 s with a solution containing 1,000 ppm chlorine (137). In contrast, available chlorine concentrations of <100 ppm at contact times of <10 min are generally very effective at killing viruses and vegetative bacteria.

Many factors affect the stability of free available chlorine in solution and the efficacy of its antimicrobial activity. These include chlorine concentration, presence and concentration of heavy metal ions, pH of the solution, temperature of the solution, presence of a biofilm, presence of organic material, and UV irradiation (47, 64, 115). In general, the most stable free available chlorine solutions have the following characteristics: low chlorine concentrations; absence of copper, nickel, cobalt, or other catalysts of decomposition; high alkalinity; low temperature; absence of organic material; and storage in dark and closed containers (i.e., shielded from UV light). The hardness of the water (i.e., the presence of Mg^{2+} and Ca^{2+} ions) does not have a significant effect on the antibacterial action of hypochlorite solutions. The following physical factors have a profound influence on enhancing the microbicidal activity of hypochlorites: pH 6.0, increased concentration, decreased organic load, increased temperature, and storage in opaque containers. The conditions of chlorine use in hospitals that favor the stability of available chlorine include use at room temperature, use of relatively diluted solutions, alkaline pH range, absence of catalysts known to promote decomposition, and storage in opaque containers.

In health-care facilities an increased concentration of HOCl may be required because the antimicrobial efficacy of hypochlorite solutions is decreased in the presence of organic material and/or biofilms, a fact known for more than 80 years (44). Several investigators have evaluated the antimicrobial efficacy of chlorine in the presence of serum, plasma, milk, or albumin. Bloomfield demonstrated that combining 0.5% (wt/vol) albumin with a solution containing 250 ppm available chlorine reduced the killing of several bacteria from >6 log units to 0.3–1.9 log units and that adding 1.0% (wt/vol) albumin reduced the killing from >6 log units to 0.5 to 1.4 log units (18). A >6-log-unit reduction could be achieved reliably despite the presence of 1% (wt/vol) albumin by increasing the available chlorine concentration to 2,500 ppm. Bloomfield and Miller demonstrated that 2,500 ppm chlorine was effective despite the addition of 1% (vol/vol) plasma, but substantial failures occurred at 5% (vol/vol) plasma, and the available chlorine was totally ineffective at 20% (vol/vol) plasma (19). Prolonging the contact time from 5 to 10 min in the presence of plasma did not appreciably change the log reduction in bacteria as measured by a quantitative suspension test. Similar findings have been reported for serum (14). As noted by other investigators, increasing the concentration of available chlorine from 10 to 60 ppm significantly improved its efficacy against *Listeria* spp. despite the presence of serum (14).

The presence of a biofilm, as might be found in pipes carrying potable water or in cooling towers, significantly reduces the efficacy of hypochlorites. For example, LeChevallier et al. reported that a biofilm of bacteria grown on a variety of surfaces were 150 to 3,000 times more resistant to hypochlorous acid than were unattached or planktonic cells (82).

CLINICAL USES

Hypochlorites are widely used in health-care facilities in a variety of settings. These include hyperchlorination as a treatment for colonization by *Legionella* spp.; chlorination of water distribution systems used in hemodialysis centers; cleaning of environmental surfaces; disinfection of laundry; local use to decontaminate environmental spills of potentially infectious material such as blood, certain body fluids, or microbiologic materials; disinfection of patient equipment (e.g., hydrotherapy tanks, dental impressions); and decontamination of medical waste prior to disposal. In addition, chlorine gas or hypochlorites are used to provide disinfected potable water.

Disinfection of Potable Water

Disinfection with chlorine has been the single most important process for ensuring the microbiologic safety of potable water supplies. Since the institution of routine chlorination of water supplies, waterborne outbreaks of infectious agents have been exceedingly rare. Most waterborne outbreaks are believed to be due to the use of untreated water, systems receiving inadequate treatment, or contamination after treatment (24). The pathogens most commonly associated with waterborne outbreaks in the United States include *Giardia*, *Cryptosporidium*, *Shigella*, *Salmonella*, *Campylobacter*, and *Yersinia* spp., hepatitis A virus, Norwalk agent, and rotavirus (41). A review of in vitro studies of inactivation of human pathogenic bacteria transmitted by potable water reported that 0.1 to 1.0 ppm free chlorine inactivated (>99% kill) all pathogenic vegetative bacteria within 60 min with the exception of some

nontuberculous mycobacteria (134). Nontuberculous mycobacteria are relatively resistant to the levels of chlorine found in potable water. In one study with *M. chelonei* and *M. fortuitum*, survival at 60 min was noted for 60% of mycobacteria exposed to 0.3 ppm chlorine and for 2% of mycobacteria exposed to 0.7 ppm (27). This finding provides an explanation of why small numbers of nontuberculous mycobacteria may be isolated from adequately chlorinated hospital water supplies. Sobsey reported that all viruses tested in saline were inactivated (>99.9%) within 10 min by 0.1 to 0.5 ppm chlorine and that protozoan cysts (*Giardia*, *Acanthamoeba*, and *Naegleria* spp.) were significantly reduced (>90%) by 1 to 4 ppm chlorine (134).

The uses of chlorinated water in the health-care setting include drinking water, water used in food preparation and for ice, personal cleanliness including bathing and laundering, heating and air-conditioning systems, hydrotherapy, fire protection, and sewage systems. Most water distribution systems provide approximately 0.5 ppm free chlorine. This level of chlorine generally ensures that the total coliform count is less <1/100 ml. Coliforms are widely used as indicators of fecal contamination.

Several noncoliform bacteria, including *Pseudomonas aeruginosa*, *Burkholderia cepacia*, *Serratia marcescens*, *Acinetobacter calcoaceticus*, *Flavobacterium meningosepticum*, *Aeromonas hydrophila*, and certain nontuberculous mycobacteria, can replicate in relatively pure water (15, 103). These organisms may be present in drinking water that has acceptable levels of coliform bacteria (i.e., <1 coliform bacterium/100 ml). Although potable water is not sterile, few outbreaks have been linked to contaminated water (144). Rare outbreaks have been related to bacteria isolated from potable water including *Pseudomonas paucimobilis* (40), *Mycobacterium xenopi* (39, 46), and *Mycobacterium chelonae* (20, 87, 88, 136).

Hyperchlorination as a Treatment for Colonization by *Legionella* spp.

Infection with *Legionella* spp. is recognized as an important cause of nosocomial pneumonia (61, 139). *Legionella* spp. also cause Pontiac fever, cellulitis, sinusitis, pericarditis, pyelonephritis, pancreatitis, endocarditis, and wound infections. Most infections appear to result from direct inhalation of aerosolized bacteria or aspiration of contaminated water.

Nosocomial acquisition of *Legionella pneumophila* (60, 72, 83, 84, 90, 94, 96, 102) and *L. bozemanii* (89) has been linked to contamination of hospital water supplies, and, more recently, the association has been strengthened by the use of molecular epidemiologic typing methods (e.g., DNA fingerprinting by pulsed-field gel electrophoresis) performed on clinical and environmental isolates (60, 72, 83, 90, 94, 102, 113). *Legionella* spp. can be isolated from 67.9% of the potable water supplies and more than 10% of the distilled water supplies in hospitals (1). Recommendations for standardization of the methods to culture *Legionella* spp. from hospital potable water systems have recently been published (138). Hospital outbreaks have been linked to patient exposure to contaminated aerosols generated by cooling towers, showers, faucets, respiratory therapy equipment, and room air humidifiers. Although potable water distribution systems have been shown to be the primary reservoir for *Legionella* spp., specific sources of patient infections have also included medication nebulizers washed in tap water (96), aspirated nasogastric feedings diluted in tap water (141), and ice obtained from an ice machine (9).

Factors that promote the colonization of *Legionella* spp. include temperature (especially temperatures lower than 50°C), scale and sediment accumulation, stagnation, hot water tank configuration, commensal microflora (including free-living protozoa), and water bacteria (107). Muraca et al. have reviewed the methods for eliminating *Legionella* spp. from water distribution systems (106). Potential methods include hyperchlorination, thermal eradication, instantaneous heaters, ozonation, UV irradiation, and metal ionization. Hyperchlorination refers to the addition of chlorine to water that has existing residual chlorine. This additional chlorine may be introduced by the use of chlorinated salts such as calcium hypochlorite (solid) or sodium hypochlorite (aqueous). Chlorination systems designed for potable water systems in large buildings (chlorinators) use solutions of chlorinated salts as opposed to chlorine gas because of the lower flow rates and water usage in building distribution systems compared with water treatment plants. The use of liquid sodium hypochlorite avoids the capital costs and hazards associated with chlorine gas storage and handling. The chlorinator works by continuously injecting metered volumes of chlorinated salts to achieve the desired free chlorine residual level, usually between 2 and 6 ppm. As with other methods of reducing *Legionella* colonization of potable water (heating, ozone, etc.), hyperchlorination controls excessive levels but frequently does not eliminate colonization.

Currently, the Centers for Disease Control and Prevention (CDC) has no recommendation for the primary prevention of nosocomial Legionnaires' disease when no cases have been documented (139). The CDC, however, recommends specific interventions in response to identification of laboratory-confirmed nosocomial legionellosis as follows (139).

When a single case of laboratory-confirmed, definite nosocomial Legionnaires' disease is identified, or if two or more cases of laboratory-confirmed possible nosocomial Legionnaires' disease occur within 6 months of each other, the following steps should be taken. (i) Contact the local or state health department or the CDC if the disease is reportable in the state or if assistance is needed. (ii) If a case is identified in a severely immunocompromised patient such as an organ transplant recipient, or if the hospital houses severely immunocompromised patients, conduct a combined epidemiologic and environmental investigation to determine the source(s) of the *Legionella* spp. (iii) If the hospital does not house severely immunocompromised patients, conduct an epidemiologic investigation via a retrospective review of microbiologic, serologic, and postmortem data to identify previous cases, and begin an intensive prospective surveillance for additional cases of nosocomial Legionnaires' disease.

If there is no evidence of continued nosocomial transmission, the intensive prospective surveillance should be continued for at least 2 months after surveillance was begun. If there is evidence of continued transmission, the following steps should be taken. (i) Conduct an environmental investigation to determine the source(s) of *Legionella* spp. by collecting water samples from potential sources of aerosolized water and saving and subtyping isolates of *Legionella* spp. obtained from patients and environment. (ii) If a source is not identified, continue surveillance for new cases for at least 2 months and, depending on the scope of the outbreak, decide on either deferring decontamination pending identification of the source(s) of the *Legionella* spp. or proceeding with decontamination of the hospital water distribution system, with special attention to the specific hospital areas involved in the outbreak. (iii) If a source of infection is identified by epidemiologic and environmental investigation, promptly decontaminate it.

If the hot-water system is implicated, the following steps should be taken. (i) Decontaminate the hot-water system either by superheating (flushing, for at least 5 min, each distal

TABLE 2. Reports of hyperchlorination for disinfection of hospital water systems contaminated with *Legionella* spp.[a]

Hospital	Water source	Concn (mg/liter)	Frequency	Reference
University of Iowa, Iowa City, Iowa	Domestic	3–5	Continuous	62
Riverside Methodist, Columbus, Ohio	Domestic	4	Continuous	7
Medical Center, Burlington, Vt.	Domestic	1.5	Continuous	147
Hyde Memorial, Malone, N.Y.	Surface water	2	Continuous	60
Wadsworth Veterans Administration, Los Angeles, Calif.	Domestic	≥2	Continuous	126
Eye and Ear, Pittsburgh, Pa.	Domestic	0.2–6.4	Continuous	71
Salt Lake City, Utah	Domestic	17 (bolus)	Bimonthly	72
Montefiore, Pittsburgh, Pa.	Domestic	>10	Monthly	97

[a] Adapted from reference 107 with permission of the publisher.

outlet of the system with water at ≥65°C) or by hyperchlorination (flushing, for at least 5 min, each outlet of the system with water containing ≥10 mg of free residual chlorine per liter). Post warning signs at each outlet being flushed to prevent scald injury to patients, staff, or visitors. (ii) Depending on local and state regulations regarding potable water temperature in public buildings, maintain potable water at the outlet at ≥50 or <20°C, or chlorinate heated water to achieve 1 to 2 mg of free residual chlorine per liter at the tap in hospitals housing patients who are at high risk of acquiring nosocomial legionellosis (e.g., immunocompromised patients). (iii) There is no recommendation for treatment with ozone, UV light, or heavy-metal ions. (iv) Clean hot-water storage tanks and water heaters to remove accumulated scale and sediment. (v) Restrict immunocompromised patients from taking showers and permit them to use only sterile water for their oral consumption until *Legionella* spp. become undetectable by culture in the hospital water.

If cooling towers or evaporative condensers are implicated, decontaminate the cooling-tower system using the CDC protocol (reference 139, Appendix D). Assess the efficacy of implemented measures in reducing or eliminating *Legionella* spp. by collecting specimens for culture at 2-week intervals for 3 months. (i) If *Legionella* spp. are not detected in cultures during 3 months of monitoring, collect cultures monthly for another 3 months. (ii) If *Legionella* spp. are detected in one or more cultures, reassess the implemented control measures, modify them accordingly, and repeat the decontamination procedures. Options for repeat decontamination include the intensive use of the same technique utilized for initial decontamination or a combination of superheating and hyperchlorination.

In the event of nosocomial legionellosis, the entire guideline (139) should be reviewed in detail.

In the early 1980s, standard laboratory tests suggested that *Legionella* spp. were rapidly killed by 3.3 ppm available chlorine (131). However, analysis of cooling towers discovered that intermittent use of chlorine was ineffective in eliminating *L. pneumophila* (49). Subsequent work has established that *Legionella* spp. in water distribution systems are relatively tolerant to chlorine. Kuchta et al. demonstrated that *Legionella* spp. were much more resistant to chlorine than were coliform bacteria at levels of residual chlorine (i.e., 0.1 ppm) typically found in potable water supplies (81). This relative tolerance to chlorine has been explained, in part, by a series of laboratory observations. First, *Legionella* spp. grown in tap water are relatively more resistant to chlorine than are legionellae grown on nutrient-rich agar media (26, 80). Second, *Legionella* spp. associated with biofilms on surfaces may be significantly less susceptible to antimicrobial agents than are planktonic cells. Finally, *Legionella* spp. may grow intracellularly within protozoa, which has been demonstrated to provide partial protection against chlorine (77).

Although *L. pneumophilia* is relatively tolerant to chlorine, hyperchlorination (i.e., 4 to 6 ppm) of a model plumbing system was demonstrated to produce a 5-log-unit decrease in *Legionella* spp. in 5 h (106). Hyperchlorination has been successfully used for controlling *Legionella* spp. in institutional water distribution systems (7, 8, 60, 62, 71, 72, 97, 126, 147) (Table 2). Advantages of chlorination include proven efficacy and the ability to provide a residual concentration throughout the entire system rather than being limited to a specific site. Chlorine has several disadvantages. First, stable residuals of chemical disinfectants are often difficult to establish initially, since the levels fluctuate with changes in incoming water quality, flow rates, and scavenging by system material or indigenous biofilms. Second, qualified maintenance personnel are required to install and maintain the system. Third, system corrosion is a long-term problem. At the University of Iowa, the average number of pipe leaks increased from 0.17 per month prechlorination to 5.2 per month in the 3 years following chlorination (106). This corrosion was reduced by chemically coating all hot-water pipes with a sodium silicate precipitate. Increasing the water pH has been suggested as a means of minimizing corrosion. Finally, a potential disadvantage is the formation of halogenated organic compounds, principally trihalomethanes. At the University of Iowa, the trihalomethane concentration increased from 45 to greater than 200 μg/liter with free chlorine concentrations of 4 ppm. Trihalomethane concentrations were reduced to less than 100 μg/liter by decreasing the chlorine residual within the hot water to below 4 ppm.

Chlorine Use in Hemodialysis

It was demonstrated in the 1970s that excessive levels of gram-negative bacteria in the dialysate of hemodialyzers were responsible for pyrogenic reactions or bacteremia in patients. This hazard is caused either by the organism gaining entrance to the blood from the dialysate or by endotoxins from gram-negative bacteria in the water and dialysate passing intact membranes and causing pyrogenic reactions. The attack rates of pyrogenic reactions are directly related to the levels of gram-negative bacteria in the dialysate (54, 55). It has also been demonstrated that certain types of bacteria (e.g., *Pseudomonas* spp.) can survive and multiply in distilled, deionized, reverse osmosis, and softened water, all of which have been used to supply water for hemodialysis (55). Based on these data, it has been suggested that the water used to prepare dialysis fluid be sampled monthly and that the supply water have <200 bacteria/ml. The dialysate should also be sampled monthly and should contain <2,000 bacteria/ml (53, 58). Fac-

tors that influence microbial contamination of hemodialyzers and infection control measures have been described elsewhere (51, 55).

Chlorine has multiple uses in hemodialysis units. First, hyperchlorination of the water distribution system that provides water for dialysis machines has been used to prevent significant growth by bacteria present in potable water. Second, sodium hypochlorite at concentrations of 500 to 750 ppm for 30 to 40 min can be used for disinfecting the dialysis fluid pathways of the hemodialysis machine (31). Although chlorine provides effective disinfection, hemodialysis machines are most commonly disinfected with peracetic acid or formaldehyde. Third, hemodialysis units are high-risk areas for the transmission of hepatitis B and C; therefore, hypochlorite is widely used to disinfect environmental surfaces (see below).

The CDC has recommended that automated peritoneal dialysis machines be disinfected after use and that hypochlorite is an appropriate agent (13).

Flowers

Concern has been expressed that cut flowers may represent a reservoir of pathogenic bacteria, even though no actual outbreaks of nosocomial infections have been linked to cut flowers as a source (65). Cultures of tap water made 72 h after the water was placed in vases yielded approximately 10^7 to 10^{10} bacteria/ml (65, 112, 140) and have isolated *Acinetobacter* spp., *Klebsiella* spp., *Enterobacter* spp., *P. aeruginosa*, *B. cepacia*, *Pseudomonas fluorescens*, *Pseudomonas putida*, *A. hydrophilia*, *S. marcescens*, *Proteus mirabilis*, and *Flavobacterium* spp. (10, 75, 140, 143). Studies have failed, however, to link pathogens isolated from flower vases or potted plants with pathogens isolated from nearby patients (10, 128).

The addition of the following antibacterial agents to the vase water has been shown to lead to a significant reduction of bacteria without injuring the flowers: 10 ml of 1% hypochlorite (65), 0.01 to 0.02% chlorhexidine (70, 132), and 30 to 60 ml of 3% hydrogen peroxide (10, 112). In spite of the lack of a direct link to nosocomial infections, it seems prudent to prohibit fresh flowers from the rooms of immunocompromised and intensive care unit patients.

Medical Equipment

Semicritical equipment. Semicritical items are objects that come into contact with mucous membranes or nonintact skin (58, 115). These items should be free of all microorganisms with the exception of small numbers of bacterial endospores. Intact mucous membranes generally are resistant to infection by common bacterial endospores but susceptible to other infectious agents such as viruses and mycobacteria. Semicritical items minimally require high-level disinfection by using wet pasteurization or chemical disinfectants. Glutaraldehyde, stabilized hydrogen peroxide, peracetic acid, chlorine, and chlorine compounds are dependable high-level disinfectants, provided that the factors that influence germicidal procedures are considered.

When selecting a disinfectant for use with certain patient care items, the chemical compatibility after extended use with the items must also be considered. Although chlorine and chlorine-releasing compounds are considered high-level disinfectants, they are used only on selected items whose structural materials are not altered by chlorine. Sodium hypochlorite has been successfully used to disinfectant certain medical devices including dental prostheses, tonometers, and hydrotherapy tanks used for patients who have damaged skin (115).

Dental equipment. Dental prostheses brought into a dental office for repair or adjustment are contaminated with viruses, bacteria, and fungi. For this reason, the CDC (37) and the American Dental Association (2) have issued guidelines for the cleaning and disinfection of dentures and dental prostheses.

Investigators have immersed three different types of dental acrylic resins contaminated with 10^5 to 10^7 organisms (*S. aureus*, *E. coli*, *P. aeruginosa*, and *Streptococcus pneumoniae*) in 0.525% sodium hypochlorite and demonstrated complete killing of the tested bacteria on both the exterior and interior surfaces of the resins within 4 min (12, 33). Schwartz et al. (125) evaluated the effectiveness of four disinfectants (sodium hypochlorite, a phenolic, chlorine dioxide, and an iodophor) for irreversible hydrocolloid impressions. Immersion in 0.525% sodium hypochlorite for 10 min resulted in a greater than 5-log-unit reduction of *S. aureus*, *P. aeruginosa*, and *Salmonella cholerae-suis*, a 1.8-log-unit reduction in *B. subtilis endo*spores, and a 3.5-log-unit reduction in *Mycobacterium bovis*. Sodium hypochlorite was a much more effective disinfectant than either the phenolic or the iodophor. Immersion in sodium hypochlorite removed 5.6 log units of bacteria found on impressions contaminated by in vivo use and was the most effective disinfectant tested.

Immersion in sodium hypochlorite for disinfection has been shown not to adversely affect the roughness, surface detail, and stability of gypsum casts (63). Although sodium hypochlorite has been reported to adversely affect the metal frame of partial dentures, a more recent study, which used light and scanning electron microscopy, failed to demonstrate any adverse effects on a nickel-chromium alloy mounted in an acrylic resin immersed for 1 h in 0.525% sodium hypochlorite (28).

Tonometers. Tonometers routinely become contaminated during use. Concern about the transmission of viruses (e.g., herpes simplex virus, adenovirus, and human immunodeficiency virus [HIV]) by tonometers has prompted CDC to issue disinfection recommendations (30). The CDC recommends that the instrument be wiped clean and disinfected for 5 to 10 min with 5,000 ppm chlorine (correctly should be 500 ppm [115]), 3% hydrogen peroxide, or 70% isopropyl alcohol. After disinfection, the device should be thoroughly rinsed in tap water and dried before use. It is recommended that the tonometer be immersed in one of the above germicides for at least 5 min (115). This recommendation is based on two studies which found that disinfection of pneumotonometer tips between use with a 70% isopropyl alcohol wipe contributed to outbreaks of epidemic keratoconjunctivitis caused by adenovirus type 8 (68, 78).

Chronister and Russo determined that the structural integrity of Goldmann applanation tonometers (manufactured by Haag-Streit) was not damaged by 30 days (similar to 1 year of routine use) of immersion in 0.05% sodium hypochlorite or 3% hydrogen peroxide (36). However, immersion in 70% alcohol resulted in "extensive breakdown of the glue where the tip's surface is bonded to the rest of the biprism." Lingel and Coffey demonstrated that immersion of Goldmann tonometers in 3% hydrogen peroxide or 5,000 ppm chlorine resulted in similar intraocular pressure and clarity scale measurements but that a less distorted, brighter ring pattern image was found with hydrogen peroxide (85). The dilution of bleach used in this study was a 10-fold-higher concentration than required for effective disinfection and was probably responsible for the damage noted with immersion in 1:10 diluted bleach. Tonometers soaked in alcohol were unusable after 4 days due to front surface roughness, a finding similar to that reported by Chronister and Russo (36).

Manikins. Concern has been raised that sharing of manikins for training in mouth-to-mouth resuscitation could potentially lead to cross-transmission of herpes simplex virus and other pathogens (101). Since practicing with a manikin is an integral part of cardiopulmonary resuscitation training, the care and maintenance of the manikin is critical. Because the manikin surfaces may present a risk of disease transmission, it has been recommended that these surfaces be disinfected. This should be done at the end of each class by wetting all surfaces with a 500 ppm sodium hypochlorite solution for 10 min, rinsing the surfaces with fresh water, and immediately drying them. Between students or after the instructor demonstrates a procedure such as clearing an obstruction from the airway, the face and interior of the mouth of the manikin should be wiped with the 500 ppm hypochlorite solution or 70% alcohol.

Syringes and needles used for drug injection. All health-care workers who treat or counsel persons who are HIV infected or engaged in injecting drugs should be aware of preventive measures to reduce the risk of HIV transmission or acquisition. The National Institute of Drug Abuse, the Center for Substance Abuse Treatment of the Substance Abuse and Mental Health Services Administration, and the CDC have provided recommendations to prevent transmission of HIV through the use of bleach for disinfection of drug injection equipment (32). They recommend that (i) bleach disinfection of needles and syringes continue to play an important role in reducing the risk for HIV transmission for injecting-drug users who reuse or share a needle or syringe, and (ii) sterile, never-used needles and syringes are safer than bleach-disinfected, previously used needles and syringes. Full-strength bleach (5.25% sodium hypochlorite) should be used after thorough cleaning. Full-strength bleach has been recommended in this setting because of the difficulty of cleaning the interior of needles and syringes for parenteral injection (127). In countries where the costs of needles and syringes preclude single use, used devices should be thoroughly cleaned and disinfected with 5.25% sodium hypochlorite.

Environmental Surfaces

Evidence suggests that virus-contaminated surfaces may play a role in disease transmission (124, 142). Whenever aerosolization of infectious virus occurs, settling of particles results in contamination of surfaces. Therefore, disinfection of environmental surfaces and hand-washing are practical methods to prevent the spread of infectious diseases. This may be particularly true for viruses for which the infectious dose is low, since studies have shown that volunteers who touch a virus-contaminated surface may become infected (142).

Hypochlorite has been demonstrated to effectively reduce the level of contamination of experimentally inoculated environmental surfaces. For example, a solution containing 1,000 ppm hypochlorite applied for 1 min killed >99.9% of human coronavirus and human parainfluenza virus (124), and a 5,000 ppm hypochlorite solution applied for 1 min killed >99.9% of coxsackie B virus and adenovirus type 5 (124). In other investigations a 500 to 800 ppm hypochlorite solution applied for 10 min produced approximately 98% reduction of rotavirus (122), a solution of approximately 5,000 ppm hypochlorite applied for 1 min produced a >99.9% reduction in hepatitis A virus (98), and a solution of 800 ppm hypochlorite applied for 10 min produced a 99.7% reduction of rhinovirus type 14 (123). In general, hypochlorite was about equal or superior to other environmental disinfectants tested by the above investigators.

***C. difficile* contamination of environmental surfaces.** *C. difficile* has been associated with outbreaks of diarrhea and colitis in hospitalized adults, especially those receiving antimicrobial therapy. Although there is evidence of person-to-person transmission in the hospital as well as transmission via contaminated environmental surfaces and transiently colonized hands, control of *C. difficile* is usually achieved by careful hand-washing, barrier precautions, and meticulous cleaning of environmental surfaces (99). However, in an outbreak setting, the use of dilute solutions of sodium hypochlorite (500 ppm and 1,600 ppm) to disinfect environmental surfaces was associated with both a reduction of surface contamination (79 and 98%, respectively) and control of the outbreak (73). These findings suggest that in outbreak situations, sodium hypochlorite may be useful in reducing the levels of environmental contamination with *C. difficile.*

Decontamination of blood spills. More than 30 diseases may be transmitted by needlestick or sharps injuries. The most important pathogens are hepatitis B virus, hepatitis C virus, and HIV. The Occupational Safety and Health Administration (OSHA) (109) has provided regulations designed to minimize the risk of disease acquisition by health-care workers in the event of an environmental spill of blood, a bloody body fluid, or certain other fluids (e.g., cerebrospinal fluid and peritoneal fluid) (109).

Environmental spills of potentially infectious material such as blood should be decontaminated. The CDC has recommended that sodium hypochlorite concentrations ranging from approximately 500 ppm (1:100 dilution of household bleach) to 5,000 ppm (1:10 dilution of household bleach) are effective depending on the amount of organic material (e.g., blood and mucus) present on the surface to be cleaned and disinfected (29, 31, 52). Extraordinary care should be taken to avoid blood exposure and sharps injury while cleaning up such spills. An alternative to using aqueous hypochlorites to disinfect blood spills, which consists of powders that contain a mixture of a chlorine-releasing agent with a highly absorbent acrylic resin, has been developed (38). These powders absorb water to form a semisolid gel.

Care should be taken to avoid contaminating the outside of blood-containing tubes and containers. If the outside of the specimen container is visibly contaminated with blood, the CDC has recommended that it be cleaned with a disinfectant (such as 1:10 dilution of 5.25% sodium hypochlorite) (29).

Preparation and storage for environmental disinfection. While the CDC recommends that chlorine solutions used in environmental disinfection be prepared fresh daily, there are data demonstrating the stability of chlorine for up to 30 days (115). For example, Rutala and associates (116) demonstrated that the concentration of available chlorine at 30 days was approximately 40 to 42% of initial values when a 1:100 dilution was stored in spray or wash bottles. In contrast, solutions diluted 1:50 or 1:5 which were stored in closed, brown opaque bottles demonstrated no deterioration of the hypochlorite. Following a 30-day storage, other dilutions or storage bottles demonstrated chlorine levels between 46 and 85%. Although these experiments should be repeated with tap water from other geographic locations before universal acceptance of the data, it appears that users should prepare their initial dilution at twice the concentration of the chlorine level desired following 1 month of storage. For example, if one wished to have a solution containing 500 ppm of available chlorine on day 30, one would initially prepare a solution containing 1,000 ppm of chlorine.

TABLE 3. Uses of hypochlorite in health-care facilities

Uses of hypochlorite	Purpose
Potable water	Control of waterborne pathogens
Hyperchlorination of potable water supplies	Control of *Legionella* spp. in outbreak situations
Chlorination of hemodialysis water and machines	Reduction of bacterial growth and prevention of bacterial sepsis
Decontamination of vase water	Reduction of potential risk that fresh flowers would serve as a reservoir of gram-negative pathogens
Dental appliances	Disinfection of contaminated dental equipment to prevent potential disease transmission to health-care workers and cross-transmission to other patients
Tonometers	Prevention of cross-transmission of microorganisms, especially adenovirus and herpesviruses
Hydrotherapy tank	Reduction of risk of cross-transmission associated with shedding of pathogens into bathing water
Manikins	Prevention of potential cross-transmission of herpes simplex virus and other pathogens in trainees practicing mouth-to-mouth resuscitation
Syringes and needles used for drug administration	Reduction of risk of cross-transmission of HIV to drug users unwilling or unable to use sterile, single-use needles and syringes
Decontamination of blood spills	Prevention of acquisition of bloodborne pathogens, especially HIV and hepatitis B and C viruses, in the event of a sharps injury or contact with nonintact skin
Environmental surfaces in room	Reduction of risk of cross-transmission of *C. difficile* in outbreak situations via the hands of health-care personnel
Laundry	Reduction of potential risk of cross-transmission of pathogens and of acquisition by laundry workers
Regulated medical waste	Reduction of microbial load associated with regulated medical waste
Antisepsis	Reduction of risk of pathogen transmission via the hands of health-care personnel (historical interest only)
Dental therapy	Disinfection of the root canal

Laundry

Laundry consists of items such as bedsheets, towels, and clothing. With use, these items become heavily contaminated, predominately with gram-negative bacilli, which may reach concentrations of 10^6 to 10^8 CFU/100 cm^2 of fabric (16). Nosocomial transmission of bacterial and viral infections via contaminated laundry has rarely been reported (130). Most of these instances were due to contact with linens or aerosols associated with bed making, linen sorting, or related activities. Laundry chutes have also been associated with increased airborne concentrations of *Pseudomonas* spp. and enteric bacilli (59) and *S. aureus* (66). Because contaminated laundry represents a potential vector for transmitting nosocomial pathogens, CDC guidelines (130) and OSHA regulations (109) have been published regarding the transportation, handling, and decontamination of laundry.

In 1938, Arnold demonstrated that the exposure of laundry to water at >71.1°C for 25 min would kill nearly all bacterial forms other than spores (4). This study provided the basis for Federal and American Hospital Association guidelines until the 1980s. Although this process was effective in reducing the bacterial load on laundry, there was a high cost associated with maintaining hot-water washing. In 1981, Battles and Vesley estimated that hospital laundries accounted for approximately 10 to 15% of the energy consumed in hospitals, or approximately 1% of all energy consumed in the commercial sector of the United States (11).

In the 1980s, several carefully performed studies demonstrated that levels of microbial killing similar to those achieved with high-temperature wash cycles could be achieved at lower water temperatures of 22 to 50°C when the cycling of the washer, the wash formula, and the amount of available chlorine were carefully monitored and controlled (16, 35). The postwash microbial burden in these studies ranged from 10^1 to 10^2 CFU/100 ml, and the predominant flora changed from gram-negative bacilli to gram-positive cocci. Major factors in achieving this reduction in the bioburden were (i) agitation and dilution (3-log-unit reduction), (ii) addition of bleach (3-log-unit reduction), and (iii) passage through the drying cycle (1- to 2-log-unit reduction) (16). Low-temperature washing with bleach is therefore as effective as high-temperature washing for eliminating pathogenic bacteria from hospital laundry.

Regulated Medical Waste

Although definitions vary around the United States, regulated medical wastes generally include sharps, blood and blood products, microbiologic wastes (e.g., stocks and cultures of infectious agents), and pathologic specimens (e.g., tissues and organs) (119). State regulations usually require that regulated medical waste be rendered noninfectious before disposal. Treatment technologies include thermal (i.e., steam, microwave, plasma gas, and incineration), chemical (i.e., chlorine dioxide and inorganic chlorine), irradiation (i.e., gamma radiation and electron beam radiation), and biological (i.e., enzymatic treatment) (3).

A single treatment standard has not yet emerged. At least one treatment system involves mechanical destruction and chemical disinfection with sodium hypochlorite (69, 95). In this system, bags or containers of infectious waste are manually loaded onto an enclosed conveyer, transported to a feed hopper, and sprayed with a sodium hypochlorite solution. Waste and disinfectant first pass through a preshredder into a high-speed hammer mill. Unrecognized solid materials are captured in a rotary separator, transported up a screw auger conveyer, and deposited into a water collection cart. The entire process is maintained under negative pressure, and air is passed through a HEPA filter prior to discharge. This system has been shown to achieve ≥99.9% kill in liquid and solid waste containing *Serratia marcescens* (5 min), *Mycobacterium fortuitum* (120 min), and *B. subtilis* (120 min) (45). A later study demonstrated a ≥5-$\log_{10}$-unit reduction in all tests with *B. subtilis*, *Enterococcus faecalis*, *Candida albicans*, and *S. marcescens* and in most tests with *M. fortuitum* and bacteriophages ϕX174 and

f2 (69). Other mechanical-chemical systems that use chlorine dioxide as the disinfectant have been developed.

Antisepsis

Most nosocomial infections are believed to result from pathogens transmitted by the hands of health-care providers (120). Sources of these pathogens include other patients, the environment, and even colonized or infected remote sites of the patient. Thus, hand-washing before and after each patient contact is the single most important infection control measure. Despite its simplicity and effectiveness, several studies have documented poor compliance with hand-washing recommendations.

The primary action of plain soap is the mechanical removal of viable transient microorganisms, while the primary action of antimicrobial soap includes both mechanical removal and killing or inhibition of both transient and resident flora. Antimicrobial-containing soaps are recommended in three settings: (i) during the performance of invasive procedures such as surgery or placement and care of invasive devices; (ii) before contact with patients who have impaired host defenses (e.g., burns, alterations in humoral or cellular immunity); and (iii) following contact with patients on airborne, droplet, or contact precautions (e.g., patients colonized or infected with methicillin-resistant *S. aureus* or vancomycin-resistant *Enterococcus* spp.). Although hypochlorites were commonly used as wound antiseptics in the early part of the century, they are rarely used today because of irritation and, when used at high concentrations, toxicity. Commonly used antiseptics now include alcohol, chlorhexidine gluconate, and iodine and iodophors.

Dental Therapy

Dental root canal procedures are commonly performed to save diseased teeth. Sodium hypochlorite is commonly used as root canal irrigant to disinfect the canal prior to filling and placement of a cap (25).

Home Health Care

With the advent of managed health care, increasing numbers of patients are now being cared for by home health services. Many patients cared for in home health care settings may have communicable diseases, immunocompromising conditions, or invasive devices. Therefore, adequate disinfection in the home setting is necessary to provide a safe patient environment. Among the products recommended for home disinfection use are bleach, alcohol, and hydrogen peroxide (129). It has been recommended that reusable objects that touch mucous membranes (e.g., tracheostomy tubes and suction catheters) be disinfected by immersion in a 1:50 dilution of 5.25% sodium hypochlorite (household bleach) (129). It has also been recommended that urinary drainage and leg bags be disinfected by instilling a 1:100 dilution of 5.25% sodium hypochlorite into the bag for 30 min followed by drainage and air drying (57). Blood spills should be handled as per OSHA regulations as described in a previous section.

CONCLUSIONS

Hypochlorite continues to have many uses within the health-care setting (Table 3). Health-care facilities that use hypochlorite should develop policies that comply with recommended use dilutions (34), storage, safety, and contact times. This paper has reviewed the numerous uses of chlorine in health-care facilities and identifies where its use is likely to reduce the risk of nosocomial infections. Despite the introduction of new disinfectants, the many advantages of chlorine are likely to lead to its continued use in the health-care setting for the foreseeable future.

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