ANTIMICROBIAL AGENTS AND CHEMOTHERAPY, Dec. 2007, p. 4217–4224 Vol. 51, No. 12
0066-4804/07/$08.00+0 doi:10.1128/AAC.00138-07

MINIREVIEW

Outbreaks Associated with Contaminated Antiseptics and Disinfectants[▽]

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The Centers for Disease Control and Prevention (CDC) has estimated that health care-associated infections account for an estimated 1.7 million infections, 99,000 deaths, and $4.5 billion in excess health care costs annually (16). The key interventions used to control health care-associated infections include surveillance (27, 33), isolation of patients with communicable diseases (26) or multidrug-resistant pathogens (81), proper skin antisepsis prior to invasive procedures and hand hygiene by health care workers (12), and appropriate disinfection and sterilization of medical devices and environmental surfaces (73, 75, 79).

Multiple nosocomial outbreaks have resulted from inadequate antisepsis or disinfection. Inadequate skin antisepsis may result from a lack of intrinsic antimicrobial activity of the antiseptic, a resistant pathogen, overdilution of the antiseptic, or the use of a contaminated antiseptic. The inadequate disinfection of medical devices or environmental surfaces may result from a lack of intrinsic antimicrobial activity of the disinfectant, an incorrect choice of a disinfectant, a resistant pathogen, overdilution of the disinfectant, an inadequate duration of disinfection, a lack of contact between the disinfectant and the microbes, or the use of a contaminated disinfectant. Editorials have noted that contaminated antiseptics and disinfectants have been the occasional vehicles of hospital infections for more than 50 years (20, 72, 76). This paper concisely reviews nosocomial outbreaks associated with the use of a microbiologically contaminated germicide and focuses on the currently recommended germicides.

DEFINITIONS

A precise understanding of terminology is important to understanding the uses of germicides in modern health care. Germicides are biocidal agents that inactivate microorganisms and include antiseptics, disinfectants, and preservatives. Antiseptics are antimicrobial substances that are applied to the skin or mucous membranes to reduce the microbial flora. Disinfectants are substances that are applied to inanimate objects to destroy harmful microorganisms, although they may not kill bacterial spores. Decontamination is a procedure that removes pathogenic microorganisms from objects so they are safe to handle, use, or discard. Finally, preservatives are incorporated into medications or fluids to prevent microbial growth. Germicides may become contaminated as a result of improper manufacturing techniques or during shipping (intrinsic contamination) or during manipulation or use within the health care facility (extrinsic contamination).

Disinfectants are further categorized by their degree of effectiveness (73, 75). The choice of disinfectant agent is based on the intended use of the patient care item (Table 1).

MICROBIAL RESISTANCE TO GERMICIDES

Microbial resistance to germicides has been reviewed previously (37, 49, 62, 68, 71). As with antibiotic resistance, resistance to germicides may be an intrinsic property or may arise either by chromosomal gene mutation or by the acquisition of genetic material in the form of plasmids or transposons (49, 68, 71). Importantly, although microbes may display intrinsic resistance to specific antiseptics, antibiotic-resistant pathogens (e.g., methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant enterococci) do not demonstrate resistance to germicides at the currently used contact times and concentrations (29, 66, 67, 69, 70, 92).

ANTISEPTICS

Antiseptics are used in health care to reduce the transient microbial flora on the hands of health care providers, to reduce the person-to-person transmission of microbes (e.g., methicillin-resistant *Staphylococcus aureus*), to prepare the skin of patients prior to invasive procedures, and to achieve surgical hand antisepsis. The products commonly used in the United States include alcohols, chlorhexidine, chloroxylenol, iodine and iodophors, quaternary ammonium compounds (e.g., benzethonium chloride), and triclosan (12). The antimicrobial spectra of the currently used antiseptics are displayed in Table 2. More than 40 outbreaks and pseudo-outbreaks due to contaminated antiseptics have been reported (Table 3) (4, 5, 8, 10, 11, 13–15, 17, 19, 20, 24, 25, 28, 30, 32, 34, 36, 38, 39, 43, 45–47, 50, 52–54, 58, 59, 61, 63, 78, 83–86, 89–91, 93).

Alcohols. The majority of alcohol-based hand antiseptics contain isopropanol, ethanol, or *N*-propanol. The latter agent, *N*-propanol, is not currently approved for use for hand hygiene in the United States. Antiseptic agents are available that com-

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▽ Published ahead of print on 1 October 2007.

TABLE 1. Classification and uses of chemical disinfectants[a]

Disinfection process	Level of microbial inactivation	Agents	Health care uses
High-level (liquid immersion)	Destroys all microorganisms except high numbers of bacterial spores	>2% glutaraldehyde (20–45 min), 0.55% *ortho*-phthalaldehyde (12 min), 1.12% glutaraldehyde and 1.93% phenol (20 min), 7.35% hydrogen peroxide and 0.23% peracetic acid (15 min), 7.5% hydrogen peroxide (30 min), 1.0% hydrogen peroxide and 0.08% peracetic acid (25 min), and 650–675 ppm chlorine (10 min)	Heat-sensitive semicritical patient care items (gastrointestinal endoscopes and bronchoscopes, tonometers, vaginal specula)
Intermediate-level (liquid contact)	Destroys vegetative bacteria, mycobacteria, most viruses, and most fungi but not bacterial spores	EPA-registered hospital disinfectants with label claiming tuberculocidal activity, such as chlorine-based products and phenolics (≥60 s)	Noncritical patient care items (blood pressure cuffs) or surfaces (bed rails) with visible blood
Low-level (liquid contact)	Destroys vegetative bacteria and some fungi and viruses but not mycobacteria or spores	EPA-registered hospital disinfectants with no tuberculocidal claim, such as chlorine-based products, phenolics, and quarternary ammonium compounds (≥60 s), or 70%–90% alcohol	Noncritical patient care items (blood pressure cuffs) or surfaces (bed rails) with no visible blood

[a] Data are from reference 75.

bine two alcohols or alcohol solutions and another agent (e.g., hexachlorophene, quaternary ammonium compounds, povidone-iodine, triclosan, or chlorhexidine gluconate). Waterless alcohol foams, liquids, and gels are now widely used in health care to improve compliance with hand hygiene (35, 60, 65). Importantly, alcohols have poor activity against bacterial spores, protozoan oocysts, and certain nonlipophilic (nonenveloped) viruses.

The contamination of alcohol-based solutions has rarely been reported. One pseudoepidemic of bacteremia (34) and one outbreak of bacteremia (54) have been traced to contaminated alcohol used for skin antisepsis. These were traced to the use of intrinsically contaminated alcohol (34) and dilution of the alcohol with contaminated water (54).

Chlorhexidine. Chlorhexidine gluconate is widely used in the United States for hand hygiene. Its antimicrobial activity occurs more slowly than that of alcohols.

Multiple outbreaks have been linked to contaminated chlorhexidine. Most reports have been traced to the use of contaminated water to prepare diluted preparations and/or the practice of reusing bottles to dispense chlorhexidine without adequate disinfection. Although most outbreaks have occurred with solutions containing less than 2% chlorhexidine, an outbreak has been reported with solutions of 2% to 4% chlor-

TABLE 2. Antimicrobial spectrum and characteristics of hand hygiene antiseptic agents[a]

Group	Activity against[b]:					Speed of action	Comments
	Gram-positive bacteria	Gram-negative bacteria	Mycobacteria	Fungi	Viruses		
Alcohols	+++	+++	+++	+++	+++	Fast	Optimum concentration, 60%–95%; no persistent activity
Chlorhexidine (2% and 4% aqueous)	+++	++	+	+	+++	Intermediate	Persistent activity; rare allergic reactions
Iodine compounds	+++	+++	+++	++	+++	Intermediate	Causes skin burns; usually too irritating for hand hygiene
Iodophors	+++	+++	+	++	++	Intermediate	Less irritating than iodine; acceptance varies
Phenol derivatives	+++	+	+	+	+	Intermediate	Activity neutralized by nonionic surfactants
Triclosan	+++	++	+	−	+++	Intermediate	Acceptability on hands varies
Quaternary ammonium compounds	+	++	−	−	+	Slow	Used only in combination with alcohols; ecologic concerns

[a] Data are from reference 12. Information for hexachlorophene is not included because it is no longer an accepted ingredient of hand disinfectants.
[b] +++, excellent; ++, good but does not include entire microbial spectrum; +, fair; −, no activity or not sufficient.

TABLE 3. Outbreaks and pseudo-outbreaks due to contaminated antiseptics

Antiseptic	Contaminant(s)	Site(s) of microbes	Mechanism of contamination/source	Author(s), yr (reference)
Alcohols	*Bacillus cereus*	Blood (pseudobacteremia), pleural fluid	Intrinsic contamination	Hsueh et al., 1999 (34)
Alcohols	*Burkholderia cepacia*	Blood (catheter related)	Contaminated tap water used to dilute alcohol for skin antisepsis	Nasser et al., 2004 (54)
Chlorhexidine	*Pseudomonas* spp.	Not stated	Refilling contaminated bottles; washing used bottles using cold tap water; contaminated washing apparatus; low concentration (0.05%)	Burdon and Whitby, 1967 (13)
Chlorhexidine	*Burkholderia cepacia*	Blood, urinary, wounds	Not determined	Speller et al., 1971 (84)
Chlorhexidine	*Flavobacterium meningosepticum*	Blood, CSF,[a] wounds, skin	Not determined but possibly due to contaminated water and/or topping off of stock solution or low concentration (1:1,000–1:5,000)	Coyle-Gilchrist et al., 1976 (17)
Chlorhexidine	*Pseudomonas* sp., *Serratia marcescens*, *Flavobacterium* sp.	Not stated	Not determined, but authors speculate due to overdilution or refilling of contaminated bottles	Marrie and Costerton, 1981 (47)
Chlorhexidine	*Pseudomonas aeruginosa*	Wounds	Tap water used to dilute stock solutions; low concentration (0.05%)	Anyiwo et al., 1982 (4)
Chlorhexidine	*Bulkholderia cepacia*	Blood, wounds, urine, mouth, vagina	Metal pipe and rubber tubing in pharmacy through which deionized water passed during dilution of chlorhexidine; low concentration	Sobel et al., 1982 (83)
Chlorhexidine	*Ralstonia pickettii*	Blood	Contaminated bidistilled water used to dilute chlorhexidine; low concentration (0.05%)	Kahan et al., 1983 (38)
Chlorhexidine	*Ralstonia pickettii*	Blood	Contaminated deionized water; low concentration (0.05%)	Poty et al., 1987 (63)
Chlorhexidine	*Ralstonia pickettii*	Blood (pseudobacteremia)	Distilled water used to dilute chlorhexidine; low concentration (0.05%)	Verschraegen et al., 1985 (89)
Chlorhexidine	*Ralstonia pickettii*	Blood (pseudobacteremia)	Distilled water used to dilute chlorhexidine; low concentration (0.05%)	Maroye et al., 2000 (46)
Chlorhexidine	*Achromobacter xylosoxidans*	Blood, wounds	Atomizer (low concentration, 600 mg/liter)	Vu-Thien et al., 1998 (91)
Chlorhexidine	*Achromobacter xylosoxidans*	Blood	Atomizer	Tena et al., 2005 (85)
Chlorhexidine	*Serratia marcescens*	Bood, urine, wounds, sputum, others	Not determined, but use of nonsterile water for dilution to 2% and distribution in reusable nonsterile containers	Vigeant et al., 1998 (90)
Chlorhexidine plus cetrimide	*Pseudomonas multivorans*	Wounds	Tap water used to prepare stock solutions; low concentrations (0.05% chlorhexidine and 0.5% cetrimide)	Bassett, 1970 (8)
Chlorhexidine plus cetrimide	*Stenotrophomonas maltophilia*	Urine, umbilical swabs, catheter tips, others	Deionized water used to prepare solutions; failure to disinfect contaminated bottles between use	Wishart and Riley, 1976 (93)
Chloroxylenol	*Serratia marcescens*	Multiple sites	Contaminated (extrinsic) 1% chloroxylenol soap; sink	Archibald et al., 1997 (5)
Benzalkonium chloride	*Pseudomonas* species	Blood	Storage of benzalkonium chloride (0.1%) with cotton/gauze	Plotkin and Austrian, 1958 (61)
Benzalkonium chloride	*Pseudomonas-Achromobacteriaceae* group	Blood, urine	Storage of benzalkonium chloride (0.1%) with cotton/gauze; dilution with nonsterile water	Lee and Fialkow, 1961 (43)
Benzalkonium chloride	*Enterobacter aerogenes*	Blood, sinus tract	Storage of benzalkonium chloride (0.13%) with cotton/gauze	Malizia et al., 1960 (45)
Benzalkonium chloride	*Pseudomonas kingii*	Urine	Contamination (intrinsic) of antiseptic	CDC, 1969 (15)

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TABLE 3—*Continued*

Antiseptic	Contaminant(s)	Site(s) of microbes	Mechanism of contamination/source	Author(s), yr (reference)
Benzalkonium chloride	*Pseudomonas* EO-1	Urine	Contaminated (intrinsic) cleansing-germicide solution	Hardy et al., 1970 (32)
Benzethonium chloride	*Pseudomonas* species	Blood (pseudobacteremia)	Contaminated (intrinsic solution; 0.2%)	Dixon et al., 1976 (20)
Benzalkonium chloride	*Bulkholderia cepacia, Enterobacter* species	Blood (pseudobacteremia)	Storage of benzalkonium chloride with cotton/gauze; improper dilution; storage bottles infrequently sterilized	Kaslow et al., 1976 (39)
Benzalkonium chloride	*Bulkholderia cepacia*	Bacteremia	Storage of benzalkonium chloride with rayon balls; failure to disinfect squeeze bottles	Frank and Schaffner, 1976 (25)
Benzalkonium chloride	*Serratia marcescens*	Intravenous catheters (dogs and cats), other sites	Storage of benzalkonium chloride (0.025%) with cotton/gauze	Fox et al., 1981 (24)
Benzalkonium chloride	*Serratia marcescens*	Joint	Storage of benzalkonium chloride with cotton/gauze	Nakashima et al., 1987 (53)
Benzalkonium chloride	*Serratia marcescens*	CSF	Contamination (extrinsic) of stock bottle	Sautter et al., 1984 (78)
Benzalkonium chloride	*Mycobacterium chelonae*	Skin abscesses	Storage of benzalkonium chloride with cotton/gauze; improper dilution	Georgia Division of Public Health, 1990 (28)
Benzalkonium chloride	*Mycobacterium abscessus*	Joint	Storage of benzalkonium chloride with cotton/gauze; dilution with probable contaminated tap water	Tiwari et al., 2003 (86)
Benzalkonium chloride/ picloxydine	*Burkholderia cepacia*	Blood, urine, wound, sputum	Water used to dilute the antiseptic	Guinness and Levey, 1976 (30)
Benzalkonium chloride/ picloxydine	*Burkholderia cepacia*	Blood	Water used to dilute the antiseptic	Morris et al., 1976 (52)
Povidone-iodine	*Burkholderia cepacia*	Blood (pseudobacteremia)	Intrinsic contamination 10% povidone-iodine (probable *B. cepacia* proliferating on the deionizing resin in the water system)	Berkelman et al., 1981 (10)
Povidone-iodine	*Burkholderia cepacia*	Blood (pseudobacteremia)	Intrinsic contamination	Craven et al., 1981 (19)
Poloxamer-iodine	*Pseudomonas aeruginosa*	Peritoneal fluid, wound	Intrinsic contamination	Parrott et al., 1982 (59)
Povidone-iodine	*Burkholderia cepacia*	Blood (pseudobacteremia), peritoneal fluid	Intrinsic contamination	CDC, 1989 (14); Jarvis, 1991 (36); Panlilio et al., 1992 (58)
Povidone-iodine	*Pseudomonas putida*	Blood, catheter tips	Not determined	Bouallègue et al., 2004 (11)
Triclosan	*Serratia marcescens*	Conjunctiva	Intrinsic contamination	McNaughton et al., 1995 (50)

[a] CSF, cerebrospinal fluid.

hexidine (90). The inappropriate use of chlorhexidine as a disinfectant has also led to outbreaks. Examples include the use of contaminated chlorhexidine solutions to disinfect glass reservoirs containing urinary bladder irrigants (51), plastic clamps (48), and thermometers (17). Outbreaks due to contaminated chlorhexidine/cetrimide solutions have also been reported (8, 13, 93).

Chloroxylenol. Chloroxylenol, also known as parachlorometaxylenol, is a halogen-substituted phenolic compound that has been used both as a preservative and as an active agent in antimicrobial soaps. An outbreak of *Serratia marcescens* infection or colonization in a neonatal intensive care unit was traced to extrinsically contaminated 1% chloroxylenol soap (5).

Quaternary ammonium compounds. Quaternary ammonium compounds are composed of a nitrogen atom linked directly to four alkyl groups, which may vary in their structure and complexity. Of this large group of compounds, alkyl benzalkonium chlorides are the most widely used as antiseptics. Other agents include benzethonium chloride, cetrimide, and cetylpyridium chloride. The FDA classifies benzalkonium chloride as having insufficient data to classify it as safe and effective for use for antiseptic hygiene.

More outbreaks have been ascribed to contaminated benzalkonium chloride than any other antiseptic (Table 3). In 2003, Tiwari and colleagues reviewed the literature and referenced multiple reports of outbreaks or pseudo-outbreaks associated with the use of benzalkonium chloride (86). The most common species were aerobic, gram-negative bacilli, including *Burkholderia cepacia*, *S. marcescens*, and *Enterobacter* spp. Most but not all outbreaks were linked to the storage of benzalkonium chloride with cotton or gauze or the improper dilution of the benzalkonium chloride solution. The use of benzalkonium

TABLE 4. Reports of contaminated disinfectants

Disinfectant	Contaminating microbes (reference)
Ethanol	*Bacillus cereus* (9)[a]
Glutaraldehyde	*Mycobacterium chelonae* (41),[a] *Methylobacterium mesophilicum* (41),[a] *Mycobacterium* species (42, 87)
Formaldehyde	*Pseudomonas aeruginosa* (88),[a] *Stenotrophomonas maltophilia* (88), *Klebsiella oxytoca* (64)[a]
Quaternary ammonium compounds	*Burkholderia cepacia* (20, 21),[a] *Serratia marcescens* (22),[a] *Achromobacter xylosoxydans* (44),[a] *Pseudomonas aeruginosa* (56, 80)[a]
Phenolics	*Pseudomonas* species (18, 23, 55), *Pseudomonas aeruginosa* (6,[a] 55), *Alcaligenes faecalis* (82)

[a] Outbreak or pseudo-outbreak.

chloride to disinfect endoscopes has also led to urinary tract and pulmonary infections (20), and the use of contaminated spray bottles for environmental disinfection led to *S. marcescens* infections complicating cardiopulmonary surgery (22). The failure of benzalkonium chloride as a preservative in multidose albuterol bottles led to respiratory tract colonization and infection (31). Contaminated benzalkonium chloride used to disinfect the septa of multidose corticosteroid bottles has led to injection site abscesses with *Pseudomonas aeruginosa* (56).

Iodine and iodophors. Iodine has been used as an antiseptic for more than 100 years. Because iodine often causes irritation and discoloring of the skin, iodophors have largely replaced iodine as the active agent in antiseptics. Multiple outbreaks due to contaminated iodophors have been reported (Table 3). The prolonged survival of *B. cepacia* in commercially manufactured providone-iodine has been documented (3), and intrinsic contamination of a povidone-iodine solution led to both infections and pseudoinfections (10, 14, 36, 58–59). These reports of intrinsic microbial contamination of antiseptic formulations of povidone-iodine and poloxamer-iodine caused a reappraisal of the chemistry and use of iodophors. It was found that "free" iodine (I_2) contributes to the bactericidal activity of iodophors and that dilutions of iodophors demonstrate more rapid bactericidal action than a full-strength povidone-iodine solution. The reason for the observation that dilution increases bactericidal activity is unclear, but it has been suggested that dilution of povidone-iodine results in a weakening of the iodine linkage to the carrier polymer, with an accompanying increase of free iodine in solution. Therefore, iodophors must be diluted according to the manufacturers' directions to achieve antimicrobial activity.

Although most reports of contaminated iodophors have reported contamination with gram-negative bacilli, O'Rourke and colleagues isolated *Staphylococcus aureus* from the rims of two bottles containing an iodophor in an operating room (57). No infections were noted as a result of this contamination.

Triclosan. Triclosan at concentrations of 0.2% to 2% has antimicrobial activity and has been incorporated into soaps for use by health care workers and into a variety of commercial products. It has a broad range of antimicrobial activity, but it is often bacteriostatic.

Liquid soap bottles containing 1% triclosan used as an operating room scrub were found to be contaminated with *S. marcescens* or *Candida parapsilosis* (7). However, no infections were reported. An outbreak of newborn conjunctivitis due to *S. marcescens* was associated with the use of intrinsically contaminated 0.5% triclosan antiseptic soap (50).

DISINFECTANTS

A variety of chemical agents are used as disinfectants; the choice of an agent depends on its intended use (Table 1). Disinfectants have not been as commonly involved in outbreaks as antiseptics (Table 4) (6, 9, 18, 20–23, 41, 42, 44, 55, 56, 64, 80, 82, 87, 88). The agents currently approved for use as high-level disinfectants (e.g., chlorine, peracetic acid, and *ortho*-phthalaldehyde) have rarely, if ever, been implicated in outbreaks. However, outbreaks may occur when ineffective disinfectants, including iodophors, alcohols, and overdiluted glutaraldehyde, are used for high-level disinfection.

Alcohols. Alcohol is widely used for the environmental disinfection of small areas (i.e., "spot" disinfection). Flammability precludes its use on large surfaces. Multiple outbreaks have resulted from the use of alcohols as "high-level" disinfectants for semicritical medical devices. Rarely, contaminated alcohol used as a surface disinfectant has been linked to outbreaks. For example, Berger reported an epidemic of pseudobacteremia with *Bacillus cereus* that was traced to contaminated cotton pads maintained in 70 to 90% ethanol that were used to disinfect the top of blood culture bottles before inoculation (9). Alcohol is not effective as a surface disinfectant against adenovirus, and its use to disinfect tonometer tips has been associated with epidemic keratoconjunctivitis (40).

Glutaraldehyde. The biocidal activity of glutaraldehyde is a consequence of its alkylation of the sulfydryl, hydroxy, carboxyl, and amino groups of microorganisms, which alters RNA, DNA, and protein synthesis. There have been reports of microorganisms with resistance to glutaraldehyde, including some mycobacteria (e.g., *Mycobacterium chelonae* and *Mycobacterium xenopi*), *Methylobacterium mesephilicum*, *Trichosporon*, fungal ascospores, and *Cryptosporidium* (73). A pseudo-outbreak caused by *Mycobacterium chelonae* and *Methylobacterium mesophilicum* due to contamination of an automated endoscope washer was reported (41). *M. chelonae* grew from the endoscopes, the automated washers, and the glutaraldehyde from the washers.

Quaternary ammonium compounds. The bactericidal action of the quaternary ammonium compounds has been attributed to the inactivation of energy-producing enzymes, denaturation of essential cell proteins, and disruption of the cell membrane. A pseudo-outbreak of *B. cepacia* bacteremia was traced to the use of a contaminated quaternary ammonium compound to disinfect the rubber stoppers of blood culture bottles (21).

Formaldehyde. Formaldehyde inactivates microorganisms by alkylating the amino and sulfhydryl groups of proteins and the ring nitrogen atoms of purine bases. The aqueous solution is virucidal, bactericidal, tuberculocidal, fungicidal, and sporicidal. An outbreak *of Klebsiella oxytoca* sepsis in a neonatal and pediatric intensive care unit was traced to a contaminated solution of formaldehyde (8.0 g/dl) used for disinfection of surfaces and infusion pumps (64), while an outbreak of *Pseudomonas* sepsis due to deficient formaldehyde mixing used to disinfect dialyzers was reported (88).

Phenolics. The contamination of phenolics used for disinfection has been reported previously (Table 4).

DISCUSSION

Outbreaks and pseudo-outbreaks related to contaminated germicides have most commonly been reported with contaminated antiseptics. Outbreaks from contaminated high-level disinfectants have rarely, if ever, been reported. Outbreaks from contaminated intermediate- and low-level disinfectants have occasionally been reported. All outbreaks associated with contaminated germicides have occurred due to gram-negative bacilli or mycobacteria. This is felt to be due to the fact that the outer membrane of gram-negative bacteria or the complex cell wall of mycobacteria acts as a barrier to germicides (49).

Both outbreaks and sporadic failures of germicides may be due to user error rather than microbial contamination. Common errors include the use of overdiluted solutions, the use of outdated products, the use of tap water to dilute the germicide, the refilling of small-volume dispensers from large-volume stock containers, and the improper selection of an appropriate product (e.g., the use of a low-level disinfectant rather than a high-level disinfectant to disinfect an endoscope). Because multiple outbreaks have resulted from the refilling of small-volume dispensers from large-volume stock containers, small-volume containers should be used until they are completely empty (i.e., do not "top off" the containers), rinsed with tap water, and then air dried before they are refilled. When a potential failure of proper disinfection or sterilization occurs, we recommend the use of a standardized risk assessment for determining patient risk and the need to inform patients (74).

A critical component of disinfection is prior cleaning. Prior cleaning is necessary to remove proteinaceous material and biofilms to allow the germicide to achieve adequate microbial inactivation. Experimental studies have demonstrated that the physical thickness of the cellular and extracellular material that forms on surfaces (i.e., biofilms) can protect imbedded organisms from the microbicidal actions of disinfectants and antiseptics (1, 2). For example, the bacteria growing in a biofilm can be up to 1,500 times more resistant to germicides than the same bacteria growing in liquid culture (77). The failure to properly clean medical devices may lead to inadequate microbial inactivation for all chemical germicides.

With the use of more effective agents and newer guidelines, the number of outbreaks due to contaminated germicides had decreased over the past 50 years. However, in order to prevent future outbreaks associated with contaminated germicides, it is critical to follow the standard recommendations, which are as follows: (i) use only CDC-recommended and FDA-cleared antiseptics; (ii) use only CDC-recommended and EPA-registered or FDA-cleared disinfectants; (iii) use all germicides at their recommended use dilution, and do not overdilute products; (iv) use sterile water to dilute antiseptics; (v) use all germicides for the recommended contact times; (vi) do not use germicides labeled only as antiseptics for the disinfection of medical devices or surface disinfection; (vii) follow the recommended procedures in the preparation of products to prevent extrinsic contamination; (viii) small-volume dispensers that are refilled from large-volume stock containers should be used until they are entirely empty, and then they should be rinsed with tap water and air dried before they are refilled; and (ix) store stock solutions of germicides as indicated on the product label.

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