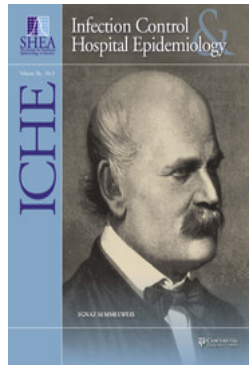

Healthcare Laundry and Textiles in the United States: Review and Commentary on Contemporary Infection Prevention Issues

Lynne M. Sehulster

Infection Control & Hospital Epidemiology / Volume 36 / Issue 09 / September 2015, pp 1073 - 1088
DOI: 10.1017/ice.2015.135, Published online: 18 June 2015

REVIEW ARTICLE

Healthcare Laundry and Textiles in the United States: Review and Commentary on Contemporary Infection Prevention Issues

Lynne M. Sehulster, PhD, M(ASCP)

Healthcare professionals have questions about the infection prevention effectiveness of contemporary laundry processes for healthcare textiles (HCTs). Current industrial laundry processes achieve microbial reductions via physical, chemical, and thermal actions, all of which result in producing hygienically clean HCTs. European researchers have demonstrated that oxidative laundry additives have sufficient potency to meet US Environmental Protection Agency benchmarks for sanitizers and disinfectants. Outbreaks of infectious diseases associated with laundered HCTs are extremely rare; only 12 such outbreaks have been reported worldwide in the past 43 years. Root cause analyses have identified inadvertent exposure of clean HCTs to environmental contamination (including but not limited to exposure to dust in storage areas) or a process failure during laundering. To date, patient-to-patient transmission of infection has not been associated with hygienically clean HCTs laundered in accordance with industry process standards. Occupationally acquired infection involved mishandling of soiled HCTs and failure to use personal protective equipment properly. Laboratory studies of antimicrobial treatments for HCTs demonstrate a wide range of activity from 1 to 7 $\log_{10}$ reduction of pathogens under various experimental conditions. Clinical studies are needed to evaluate potential use of these treatments for infection prevention. Microbiological testing of clean HCTs for certification purposes is now available in the United States. Key features (eg, microbial sampling strategy, numbers of textiles sampled) and justification of the testing are discussed.

Infect. Control Hosp. Epidemiol. 2015;36(9):1073–1088

INTRODUCTION

Recent innovations in the laundry industry have led to major advances in laundry equipment, laundry chemicals, fiber and fabric technology, and laundry facility design and engineering. Collectively, these have enabled healthcare facilities and their contract laundry operators to provide a quality product for a diverse textile inventory of bed linens, towels, washcloths, patient gowns, uniforms, scrub suits, and drapes or other surgical textiles.[1,2] Residential care facilities (eg, assisted living facilities, long-term care facilities) often will provide laundry services for residents' personal clothing in addition to typical healthcare textiles (HCTs), if laundry equipment appropriate for these garments is available.[3]

Healthcare professionals have questions about the infection prevention effectiveness of these modern healthcare laundry developments. The epidemiology of microbial contamination of HCTs and the potential for infection transmission identifies 2 distinct situations: (1) freshly laundered HCTs, and (2) HCTs in use. This review addresses evidence that current industrial laundry processes are sufficient to interrupt patient-to-patient transmission of infection, focusing on those laundered HCTs having the greatest degree of contact with patients and healthcare professionals. Although surgical textiles and drapes would normally be included among HCTs with a high degree of patient contact, the processing of reusable surgical textiles is not discussed here. This topic is thoroughly addressed in a standard published by the Association for the Advancement of Medical Instrumentation.[4] Recent industry developments (ie, antimicrobial treatments of HCTs and microbiologic testing of laundered HCTs) are reviewed in an effort to give infection preventionists some insight on these topics that may be helpful in future purchase/procurement decisions. The resources for this narrative review include peer-reviewed medical literature using PubMed (search terms including but not limited to "textiles," "laundry," "infection," "sanitization"), standards and guidelines, and textile information from industry publications and websites.

OVERVIEW OF THE LAUNDRY PROCESS

When textiles are heavily contaminated with potentially infective body substances (eg, blood, stool, urine), they can contain 1×10^4 to 1×10^6 colony-forming units of bacteria per square centimeter of fabric.[5] However, through a combination of soil removal, pathogen removal, and pathogen inactivation, contaminated laundry can be rendered hygienically clean. Hygienically clean laundry carries negligible risk to healthcare personnel and patients, provided that the clean textiles are not

Affiliations: Division of Healthcare Quality Promotion, Centers for Disease Control and Prevention, Atlanta, Georgia.

Received July 7, 2014; accepted April 9, 2015; electronically published June 18, 2015

 0899-823X/2015/3609-0012. DOI: 10.1017/ice.2015.135

inadvertently contaminated before use.[2,6] The Association for the Advancement of Medical Instrumentation defines *hygienically clean* for clean, nonsurgical, reusable textiles as being "free of pathogens in sufficient numbers to cause human illness."[4]

The laundry process starts with collection of soiled and contaminated textiles at point of use. Handling contaminated laundry with minimal agitation can help prevent the generation of potentially contaminated lint aerosols in patient-care areas.[7–9] Previously, contaminated laundry originating in hospital isolation rooms (eg, patient rooms under contact precautions) was segregated and handled with special practices. However, few, if any, cases of healthcare-associated infections (HAIs) have been linked to this source.[10] Single-blinded studies have demonstrated that laundry from isolation rooms is no more heavily contaminated with microorganisms than laundry from elsewhere in the hospital.[11] Adherence to standard precautions and minimal textile agitation when handling contaminated laundry in isolation rooms are considered sufficient to prevent the dispersal of potentially infectious aerosols.[12] The Occupational Safety and Health Administration prohibits the sorting or rinsing of contaminated laundry at the location where contamination occurred (eg, in the patient's room). These tasks should be accomplished in the facility at a hopper sink in a soiled linen room.[7] If a contract laundry service is used, sorting takes place at that off-site facility.

Laundering cycles consist of an initial flush with water, the main wash with cleaning agents and other laundry additives, followed by rinsing with clean water.[2,13] The number of rinses is determined by water quality, the size of the load, fabric type, and the laundry chemicals used, all of which are taken into account when selecting the appropriate wash/rinse cycle parameters. The last rinse for each load of laundry includes the addition of an acid (ie, a souring agent) that causes a pH shift from approximately pH 12 to pH 5. This action neutralizes residual alkalinity in the water from the soap or detergent used in the wash. Eliminating residual alkali from textiles is an important measure in reducing the risk for skin irritation.[2,13]

Dryer temperatures and cycle times are dictated by fabric and fiber characteristics. Manmade fibers (ie, polyester and nylon) require shorter dry times and lower dryer temperatures compared with those used for cotton. Sorting the textiles by fiber/fabric type before laundering can help maximize the effectiveness of the drying phase. Cleaned and dried textiles are pressed if needed, folded, and packaged for transport, distribution, and storage. Off-site laundries should package or cover clean textile bundles before transport to prevent inadvertent contamination from dust and dirt during loading, delivery, and unloading. State regulations and/or accrediting standards may dictate the procedures for this activity.[14,15]

Laundered HCTs must be stored in a manner to keep them dry and free from soil and contamination. In the healthcare facility, the clean textile storage room/area should be designed to minimize dust contamination of the textiles. The storage room should also be maintained at ambient temperature and relative humidity ranges to help prevent the proliferation of any residual microbial contamination in the textiles.[4]

MICROBIAL INACTIVATION ASSOCIATED WITH THE LAUNDRY PROCESS

Microbial Reductions Associated With Washing and Drying

The antimicrobial action of the laundering process results from a combination of mechanical, thermal, and chemical factors all in action over a period of time.[6,13,16,17] Studies demonstrate that cool water wash cycles at temperatures of 71°F–77°F (22°C–25°C) can reduce microbial contamination when the wash cycle duration, the wash detergent, and the amount of laundry additive are all carefully monitored and controlled.[5,18–23] Wash cycles with detergent and 71.6°F (22°C) water removed easily dislodged soils and achieved a 3 $\log_{10}/cm^2$ reduction in microorganisms with the help of the washer's agitation, rinsing, and drainage.[5] Surfactants and detergents function to suspend more tightly bound soils. Use of low-temperature wash cycles has demonstrated effectiveness in either inactivation or removal of healthcare-associated pathogens such as *Klebsiella pneumoniae*, total coliforms, *Staphylococcus aureus*, enterococci, poliovirus, adenovirus, and pollen allergens.[5,21–25] Use of hot water provides a sanitizing effect capable of producing microbial reduction of at least 5 $\log_{10}$ per square centimeter.[18] A temperature of at least 160°F (71°C) for a minimum of 25 minutes is recommended frequently for traditional hot-water washing.[2] Regardless of whether hot or cold water is used for washing, the temperatures reached in drying and especially during ironing provide additional microbicidal action, resulting in a reduction in the range of 0.5 to 2.0 $\log_{10}$ per square centimeter.[5,22]

Microbial Inactivation via Laundry Additives

Laundry Chemicals: Modes of Action. Contemporary laundry chemicals are divided into 5 major groups: (1) detergents and surfactants, (2) chlorine chemicals and chlorine bleach (ie, sodium hypochlorite), (3) quaternary ammonium compounds, (4) hydrogen peroxide and hydrogen peroxide/peracetic acid/acetic acid, and (5) ozone. General properties and modes of action for these chemicals are summarized in Table 1. A recent major trend to move away from an almost universal reliance on chlorine-based laundry additives in favor of using oxidative chemistries encountered some pushback from infection preventionists.[46] However, knowing the advantages, disadvantages, and function of these chemicals can be helpful when discussing laundering options with laundry contractors. Modern laundry chemistries are less destructive to modern fabrics, thereby expanding the textile options available to healthcare facilities.

Laundry Chemicals: Antimicrobial Potency. There are circumstances when adding a disinfectant or adding a detergent

TABLE 1. Major Categories of Laundry Chemicals for Soil/Microbe Removal and/or Inactivation

Chemical group	General mode of action	Important use conditions	Log_{10} reductions[a]	Applications	Comments	References
Detergents and surfactants	• Reduces water tension • Lifts soil, oils, and contamination away from fabrics and keeps them in suspension for removal during rinse	• Product selection and amounts for use determined by: ○ Product chemistry ○ Water quality ○ Water temperature ○ Type of fabric ○ Weight of the load	• 3 log_{10} in water with agitation • Use of hot water (160°F [71°C]) can boost this up to 5 log_{10}	• All wash cycles	• Detergents contain more than one surfactant • Pre-sorting by fabric is helpful when selecting a detergent product for use • Use of a souring agent reduces pH during rinsing to remove alkaline residues	5,13,18–26
Chlorine chemicals/ chlorine bleach	• Strong oxidizing agents • Stain removal • Antimicrobial action of free chlorine likely due to chemical interactions with proteins, nucleic acids, and critical structural sites	• Typical wash conditions: ○ 75-200 ppm[b] ○ 140°F-150°F (60°C-65.6°C) ○ pH 10.2-10.8 • Requires an extra rinse and use of an anti-chlor additive to remove chlorine residue	• ≥3 log_{10} when used to sanitize fabric • ≥4 log_{10} when used to disinfect fabric	• Use for fabrics that tolerate repeated bleach use • Stain removal for heavily soiled textiles • Whitening • Antimicrobial action	• Injected during specific bleach cycle • Can damage some fabrics with repeated use • Chlorine interacts with chlorhexidine gluconate residues to produce orange/ brown stains on the fabric • Do not mix with ammonia • May produce rust on steel equipment • Use concentrations may be higher in Europe	1,13,27–33
Quaternary ammonium compounds	• Positive-charged portion of the chemical covalently binds to fabrics with negative charge • Antimicrobial action due to but not limited to damaging cell structures and proteins, and inactivating key metabolic enzyme function	• Use concentration ranges 150-780 ppm[b] • Use temperature ranges ~60°F-95°F (~15.5°C-35°C)[b]	• ≥3 log_{10} when used to sanitize fabric • ≥3 log_{10} when used as a residual sanitizer • ≥4 log_{10} when used to disinfect fabric	• Use for fabrics that are not heavily stained • Antimicrobial action: ○ Deodorizer ○ Sanitizer ○ Disinfectant ○ Residual self-sanitizer ○ Mildew inhibitor	• Generally introduced into the final rinse • Use concentration varies depending on the antimicrobial action needed and the water level in the rinse cycle	32–37, N. Gaubert, personal communication, September 2014

Table 1. *Continued*

Chemical group	General mode of action	Important use conditions	Log_{10} reductions[a]	Applications	Comments	References
Hydrogen peroxide (H_2O_2), hydrogen peroxide/ peracetic acid/acetic acid	• Oxidative bleaching agents • Antimicrobial action due to oxidative action on microbial enzymes, denatures proteins • H_2O_2 produces destructive hydroxyl free radicals • Antimicrobial action of the combination product is synergistic	• H_2O_2 products used at higher wash temperatures compared with those for chlorine products • H_2O_2 use concentration: ≥250 to 300 ppm[b] • H_2O_2/peracetic acid/acetic acid use concentration: ≥100 ppm[b]	• 3 log_{10} when used to sanitize fabric • ≥4 log_{10} when used to disinfect fabric	• Use for fabrics that cannot tolerate chlorine bleach • Stain removal • Whitening • Antimicrobial action	• No interaction with chlorhexidine gluconate residues • Injected during specific bleach cycle • Often used as part of green/sustainable programs • Produces benign by-products (water, oxygen, acetic acid) • Less damage to fabrics compared with chlorine bleach	38,39, N. Gaubert, personal communication, September 2014
Ozone (O_3)	• Oxidizing agent • Antimicrobial action due to denaturation of proteins, destroys bacterial cell walls	• Use cold water temperature (~50°F-60°F [9°C-15.5°C]) • Use concentration ranges 0.5-3 ppm[b]	• ≥4 log_{10}	• Use for fabrics that cannot tolerate chlorine bleach • Antimicrobial action	• Marketed as a "system," generated on demand • Use in cold water minimizes ozone dissipation • Raise water temperature in final rinse for best wash performance • Requires higher concentrations for cleaning healthcare textiles due to heavy soil/bioburden levels • Savings on utility expenses (eg, water, natural gas)	40–45

NOTE. anti-chlor, an anti-chlorine compound or chlorine neutralizer; ppm, parts per million.

[a]Log_{10} reductions achieved via removal of microorganisms or microbial inactivation.

[b]Recommended ppm or use temperature may vary by product.

TABLE 2. Log_{10} Reductions Associated With Wash Cycles: Impact of Contemporary Laundry Additive Chemistries and Water Temperature

Process	Log_{10} reductions	
	Gram-positive	Gram-negative
Pre-wash at 95°F (35°C) (single step, 10.5 min with detergent)	0.73 to 2.47	0.70 to 1.16
Main wash at 113°F (45°C) without pre-wash (single step, 19.5 min with detergent + bleaching agent)	0.97 to 2.58	1.11 to 2.66
Main wash at 140°F (60°C) without pre-wash (single step, 19.5 min with detergent + bleaching agent)	1.34 to >5.56	3.71 to >5.6
E60 + 35: pre-wash at 95°F (35°C) (10.5 min with detergent), main wash at 140°F (60°C) (19.5 min with detergent + bleaching agent)	1.91 to >7.68	> 5.6 to >7.76
Completed main wash at 167°F (75°C) (pre-wash and main wash)	>5.56 to >7.88	>5.6 to >7.76
Disinfecting only at 167°F (75°C) (no pre-wash or main wash)	>5.56 to >7.88	>5.6 to >7.76
Complete 3-step cycle (prewash 10.5 min with detergent, main wash 19.5 min with detergent + bleaching agent, and disinfection at 176°F [80°C])	>5.56 to >7.88	>5.6 to >7.76

NOTE. Adapted and compiled from reference 49.
Detergent: anionic and nonionic surfactants (5%), phosphates (25%), silicates, sodium carbonate, optical whitener; use concentration in pre-wash: 6.2 g detergent/kg textiles; main wash: 5.0 g detergent/kg textiles.
Bleaching agent: hydrogen peroxide (35%); use concentration in main wash: 4.4 mL/kg textiles.
Disinfecting agent: hydrogen peroxide (20%), peroxyacetic acid (7.5%), acetic acid (7.5%); use concentration in main wash: 3.0 mL/kg textiles.
Equipment: laboratory washing machine: 7.5 kg capacity, 75 L volume.
Challenge organisms: *Enterococcus faecium*, *Staphylococcus aureus*, *Mycobacterium terrae*, *Candida albicans*, *Enterobacter aerogenes*, *Pseudomonas aeruginosa.* Starting inoculum for each organism (allowed to dry onto fabric): ~1×10^6 to 1×10^7 colony-forming units/cm^2.
Organic matter challenge: swine blood, swine fat, artificial sweat.
Fabric used: cotton, previously sterilized; cut into square centimeters.
Assay method: recovery of the laundered cotton squares, each immersed in 20 mL normal saline + Tween 80 and vortexed, and serial dilutions plated on appropriate selective media.
E60 + 35 is the designation in this study for the laundry process using a pre-wash and a main wash.
The disinfecting step by itself could not remove stains.

whose formula contains a disinfectant at some point into the wash/rinse cycle can enhance the overall disinfection of the laundering process. Examples of these decisions include (1) when textile properties indicate use of cooler water temperatures (eg, 104°F [40°C]), (2) if a high proportion of the textile load is very heavily soiled, or (3) if there is concern about suspended microbes in wash or rinse water settling back onto the textiles in the load.[13,27] Altenbaher et al[47] noted that when any of the 4 factors needed to produce hygienically clean textiles (ie, water temperature, agitation, chemical type and concentration, and duration of the wash cycle) is altered (eg, lowering the wash/rinse water temperature), the addition of a disinfecting laundry chemical can compensate for the anticipated loss of antimicrobial activity of the overall process. For lightly soiled textiles, however (eg, healthcare residents' clothing), the use of a disinfectant may not offer any advantage over the use of detergent.

Traditionally, the use of chlorine bleach ensured an extra margin of safety.[1,27,46,48] For example, the addition of bleach to a low-temperature wash cycle increased the microbial log reduction by an additional 3 log_{10} per square centimeter.[5,22] A total available chlorine residual of 50–150 parts per million is usually achieved during the bleach cycle.[18] Chlorine bleach in commercial laundry applications is most effective at water temperatures of 140°F–150°F (60°C–65.6°C).[31]

Potency evidence for contemporary oxidative laundry additives is now available. Fijan et al[49] conducted laboratory evaluations to determine the log reductions of bacteria achieved under varying wash cycle parameters and use of oxygenated laundry additives. Experimental design details and results of this work are summarized in Table 2. The use of a hydrogen peroxide bleaching agent and a disinfectant (containing hydrogen peroxide + peracetic acid + acetic acid) in 140°F (60°C) water produced greater than 7 log_{10} reduction for selected bacterial and yeast challenge microorganisms (ie, *Enterococcus faecium*, *S. aureus*, *Pseudomonas aeruginosa*, *Enterobacter aerogenes*, *Candida albicans*).[47,49] They also evaluated the potency of 3 disinfecting bleaches in the wash cycle under various cycle parameters.[50] The experimental details of this work are summarized in Table 3. Longer wash cycle times were necessary to achieve greater than or equal to 7 log_{10} reduction of *E. faecium* regardless of the type of laundry additive compared with the wash cycle times needed for *E. aerogenes*. Of the 3 chemicals, only the peracetic acid–containing product achieved higher reduction levels (>4.0 log_{10}) for *E. faecium* during shorter wash cycle times (10–20 minutes). These results suggest that for institutional laundries, peroxyacetic acid in hydrogen peroxide products would meet or exceed the US Environmental Protection Agency log reduction benchmark (≥4.0 log_{10}) for adequate textile disinfection for short wash cycles at warm temperatures for healthcare purposes.[32] All 3 products achieved greater than 7 log_{10} reductions for both *E. faecium* and *E. aerogenes* at 86°F (30°C) when the full wash and rinse cycles were completed in 81 minutes.[50]

TABLE 3. Log_{10} Reduction Activity of Selected Oxidative Disinfecting Bleaches in Low-Temperature Wash Cycles

	Log_{10} reductions					
	Enterococcus faecium			*Enterobacter aerogenes*		
Wash cycle parameters[a]	D1[b]	D2[c]	D3[d]	D1	D2	D3
Main wash cycle for 43 min +3 rinses with clean water; total time 81 min	>7.28	>7.28	>7.28	>7.66	>7.66	>7.66
Main wash cycle for 43 min, no rinses	3.85	>7.28	5.28	>7.66	>7.66	>7.66
Main wash cycle for 20 min, no rinses	2.13	5.36	2.63	6.09	>7.66	6.30
Main wash cycle for 10 min, no rinses	1.33	4.88	1.93	4.33	4.98	3.17
Main wash cycle for 43 min, detergent only (no disinfecting bleach), no rinses		3.80			>7.66	

NOTE. Compiled and adapted from reference 50.

[a]Water specifications: all experiments run at 86°F (30°C). Wash water volume = 8 L, bath ratio = 1:8, each rinse water volume = 9 L. Detergent used in all experiments contained 12% sodium alkylbenzene sulphonate, 2% sodium lauryl ether sulphate, 2.5% isopropanol, 3% fatty alcohol etoxylate, 1.5% sodium hydroxide. Amount used was 10 g/2.5 kg of dry textiles.
Separate cotton test swatches were inoculated with *E. faecium* and *E. aerogenes* and allowed to dry. Starting concentrations after drying were 1.9×10^7 colony-forming units (cfu)/swatch for *E. faecium* and 4.6×10^7 cfu/swatch for *E. aerogenes*. Swatches were laundered along with 2.5 kg of previously disinfected ballast cotton/polyester (50/50) fabric.
Washing machine was a small-scale laboratory industrial drum washing machine.

[b]D1 = sodium chlorate (10%). Amount used = 10 mL per 2.5 kg dry textiles.

[c]D2 = peroxyacetic acid in hydrogen peroxide (2.5% peroxyacetic acid, 10% hydrogen peroxide, 2.5% acetic acid). Amount used = 12.5 mL/2.5 kg dry textiles.

[d]D3 = hydrogen peroxide (35%). Amount used = 7.5 mL/2.5 kg dry textiles.

Questions have been asked about home laundering of hospital scrubs and uniforms. There have been concerns that home laundering of healthcare attire may expose family members to healthcare-associated pathogens.[51] However, infections in families attributed to home laundering of healthcare attire have not been demonstrated conclusively. As an example, studies have documented that the loss of antimicrobial activity by using wash water temperature of 140°F (60°C) can be compensated with longer wash cycle time, hot air drying, and ironing.[52–54] Industrial laundering offers many process advantages over home laundering, such as (1) more exact control over all aspects of the process, (2) the ability to tailor wash parameters more accurately to match the soil level of the load, and (3) more choices in detergent and laundry additives (eg, sours). The current stance is hospital-directed laundering of employee scrubs and uniforms, although home laundering continues to be debated.[55] The Occupational Safety and Health Administration regulations require employers to provide laundry processes for reusable personal protective equipment textiles and healthcare attire or uniforms with visible blood or other potentially infectious material contamination.[7]

Laundry sanitizers and disinfectants marketed in the United States must be registered by the Environmental Protection Agency. Registered laundry product labels must have the following information at a minimum: (1) the intended use of the product (eg, a presoaking additive, an additive for the wash cycle), (2) the appropriate use conditions, and (3) the product's compatibility with fabrics and other laundry chemicals. Those products intended for HCT laundering should be tested at a minimum against *S. aureus*, *K. pneumoniae*, and *P. aeruginosa* to support claims for disinfection.[32] Laboratory data for inactivation of *S. aureus* and *K. pneumonia* are required to support claims for sanitization.[32] Additional label claims for inactivation of other healthcare-associated pathogens must similarly be supported by laboratory data. The microbial log reduction benchmark for laundry disinfectants is greater than or equal to 4 log_{10}, whereas the benchmark for laundry sanitizers is greater than or equal to 3 log_{10}.

EPIDEMIOLOGY OF HAIs ATTRIBUTED TO LAUNDERED HCTs

HCTs will become populated with microorganisms while these textiles are in use. Several research teams evaluating microbial ecology in healthcare settings have demonstrated that patients and their hospital beds are at the center as a source of room contamination, with pathogen levels dropping in concentration per area as the distance from the patient increases.[56–58] This suggests that hospital bed textiles become contaminated primarily with the patient's flora and to a lesser degree with those microorganisms already present in the healthcare environment, including pathogens that are particularly adept at long-term survival.[56–61] However, the epidemiology of outbreaks associated with laundered, reusable HCTs strongly supports the notion that current industrial laundry processes are effective in interrupting patient-to-patient transmission.

Outbreaks of Infection Attributed to Laundered HCTs

The volume of HCTs processed annually in the United States is difficult to determine, but this figure provides context when

discussing the epidemiology of HAIs attributed to HCTs. A current estimate for the annual volume of US hospital laundry is approximately 4.34 billion pounds as derived from Government Accounting Office[62] and American Hospital Association data sources.[63] However, when the laundry needs for nonhospital healthcare settings are included, a conservative estimate of the total volume of HCTs processed annually in the United States today for all healthcare venues would be several billion pounds higher.

Outbreaks involving laundered HCTs from the 1970s to the present are summarized in Table 4, along with occupational exposures to pathogens on soiled HCTs. The occupational infection clusters involved exposure to infectious aerosols from mishandling of the textiles or failure to use personal protective equipment.[2] The outbreaks of clinically symptomatic infection among patients are associated mostly with textiles contaminated with environmental pathogens after laundering or contaminated owing to a deficiency in the laundering process.[2] At least 350 patients worldwide have been infected in 12 outbreaks over the past 43 years. Despite the presence of microorganisms on clothing and HCTs, there appears to be little to no evidence of patient-to-patient transmission of infection attributed to laundered textiles, even for *Clostridium difficile* infection.[81] We have not found reports of *C. difficile* spore persistence on patient-care HCTs, nor have we found reports of patient-to-patient transmission of *C. difficile* infection associated with HCTs not mixed with cleaning cloths, etc, during laundering.

Of the 12 outbreaks, 7 (58%) were due to contamination from *Bacillus cereus* (a common environmental, spore-forming microorganism) occurring in the late spring or the summer months. Towels were noted as being contaminated with *B. cereus* in 4 (57%) of these 7 events. Higher ambient temperatures (which favor spore-forming microorganisms), coupled with normally moisture-absorbent textiles, result in conditions that favor environmental pathogen proliferation. Root problems associated with the *B. cereus* outbreaks included (1) dust contamination of the clean textiles, (2) inappropriate wash/rinse water temperatures, and (3) storage conditions that promoted microbial growth. Two of these root problems were also identified in a recent *Rhizopus* outbreak in Louisiana, where storage conditions may have encouraged fungal growth on the HCTs.[73] This outbreak was limited to a very small group of severely immunocompromised patients, even though contaminated HCTs presumably were used elsewhere in the hospital. Of the 12 outbreaks, 4 (33%) reported problems with laundered textile storage in the hospital; 7 (58%) reported contaminated washing equipment, inappropriate wash cycle or water temperature settings, or recycled water issues; and 1 (8%) attributed the outbreak to inadvertent contamination occurring during transit from the laundry to the hospital. Reports of HCTs becoming contaminated during use and reports of infection attributed to HCTs used for multiple patients with no laundering are not included here.

These observations about outbreaks involving environmental pathogens strongly suggest that transport and storage of cleaned HCTs can present opportunities for postlaundering contamination of textiles. Storage or holding areas for cleaned textiles should be designed and engineered to protect textiles from dust and soil.[4,13,82] The importance of temperature, relative humidity, and moisture control in storage areas is central to preventing microbial proliferation in and on materials that have some organic components. Given that some HCTs may consist of fibers with high organic content (eg, cotton) and some textiles absorb moisture by design (eg, towels), textiles with high moisture content (eg, textiles packaged in plastic before they are completely dry) might provide a favorable environment for microbial proliferation, especially if the ambient temperature in the textile package storage area is warm.

Environmental pathogen contamination of HCTs also draws attention to the necessity of proper water and equipment management in the laundry. *Bacillus* spores can be present in water, and water recycling can potentially build up the spore concentrations in the wash and rinse cycles. Additionally, laundry additives may lack sufficient sporicidal potency to inactive large numbers of these spores during laundering. Prompt removal of wet textiles from the machines and proper washer maintenance should help to minimize equipment contamination and biofilm development.[67]

ANTIMICROBIAL TREATMENTS AND RESIDUES FOR HCTs

Early uses of antimicrobial treatments of textiles and garments prevented fabric from rotting in adverse environmental conditions.[83] Treated textiles have been evaluated in clinical studies as part of a treatment strategy for atopic dermatitis for several years.[84–86] More recent research is targeting the general infection prevention market. Antimicrobial agents for textiles represent a diverse array of chemicals and metals including but not limited to gold, silver, copper, chitosan, chitooligosaccharides, quaternary ammonium compounds, and zeolite-containing compounds. These agents can be added to textiles either as a chemical treatment of woven fabric or finished textile item, or as an impregnated fiber that is incorporated into fabric during weaving.[87] Despite the differences in experimental design, laboratory studies in general have confirmed the potency of these active agents in reducing microbial populations on fabrics during contact periods ranging from days to weeks.[88–90] The $\log_{10}$ reduction observed in these studies can range from 1 to 7 $\log_{10}$, but most microbial inactivation potencies observed cluster between 3 and 5 $\log_{10}$ (Table 5). Antimicrobial activity is affected by many factors, such as (1) properties of the challenge microorganism(s), (2) intrinsic moisture content of the fabric, (3) length of the contact time, (4) method of treatment application, (5) type of fabric, and (6) number of wash cycles after treatment. [87]

Antimicrobial treatment may be useful in inactivating microbes transferred onto fabrics touched frequently by hand,

TABLE 4. Outbreaks of Healthcare-Associated Infections Attributed to Laundered Healthcare Textiles (HCTs) and Occupational Exposures Involving Soiled HCTs: 1970 to 2015

A. Healthcare-associated infections among patients

Location & year	Organism	No. of patients affected	Textile(s) implicated	Root problem(s)	Corrective measures	References
Minneapolis, MN; late 1970s	*Aspergillus flavus*	NS	• Hospital linens	• Inadvertent environmental contamination while in transit due to malfunction of truck cargo bay door	• Repair truck cargo bay door • Improve textile packaging to better prevent dust contamination	64
UK; 1980	*Bacillus cereus*	28	• Infant diapers	• Contaminated washing machine	• Disinfect contaminated washer with boiled water ×3 days • Discontinued overnight soaking of diapers in water	65
UK; 1990	*B. cereus*	2	• Hospital linens	• Storage of soiled textiles at elevated temperatures prior to laundering	• Increase water flow during wash and rinse • Increase amount of H_2O_2 added to wash • Avoid leaving damp textiles in washers overnight	66, 67
UK; early 1990s	*Streptococcus pyogenes*	NS	• Vests for newborns	• Washing not consistent with recommended laundry cycle parameters • Hot air dryer contaminated	• Resume recommended laundering processes with main hospital laundry contractor	68
The Netherlands; 1990-1992	*Acinetobacter* spp.	107	• Feather/down pillows	• Pillows were naturally contaminated (feathers a niche for *Acinetobacter* spp.) • Pillows could not tolerate standard wash water temperature of 185°F (85°C); used 140°F (60°C) water temperature • Fluffing pillows caused release of contaminated aerosols	• Switched to synthetic fluff pillows that could tolerate laundering at 185°F (85°C)	60
Japan; 2004-2005	*B. cereus*	3	• Towels • Patient gowns	• Dust intrusion and textiles contamination from outside construction	• Minimize dust intrusion • Add chlorine bleach to wash cycle • Add 392°F (200°C) steam press	69, 70
Japan; 2004-2005	*B. cereus*	5	• Towels	• Contaminated washing machine • Recycled water • Moist towels stored for use in steam boxes	• Switched laundry service provider • Chorine bleach added to wash cycle	71
Japan; 2006	*B. cereus*	11	• Towels • Bed sheets	• Washing machine heavily contaminated • Recycled water for washing and rinsing	• Cease using recycled water • Decontaminate and clean implicated washer • Autoclave contaminated linens • Handwashing, hand hygiene	72
New Orleans, LA; 2009	*Rhizopus* sp.	5	• Bed linens • Patient gowns	• Dust intrusion • Inadvertent environmental contamination • Storage area contamination	• Replaced healthcare textiles • Switched laundry service providers • Cleaned, disinfected linen storage area • Minimize construction dust intrusion	73

UK; 2009	*B. cereus*	7	• Hospital linens • Cot blankets, sheets, pillow cases	• Lack of adequate dust control • Dust contamination of stored linens in main hospital linen storage	• Implement effective dust control • Increase amount of fresh water during wash cycle • Use a washer-extractor for selected linen items	74
Singapore; 2010	*B. cereus*	171	• Hospital textiles • Towels	• Dust intrusion from outside construction • Textile contamination in storage	• Minimize dust intrusion • Revise textile storage infection prevention strategy • Reassess laundry process parameters for infection prevention	75
Easton, PA; 2013	*Clostridium difficile*	11	• Mop pads used for cleaning	• Mop pads washed without bleach • Wash cycle erroneously set to "Microfiber" setting	• Washing machine serviced, microfiber setting inactivated • Mop pads and rags double-washed • Infection prevention inservice for staff	76

B. Occupational exposures to soiled HCTs

Location & year	Organism	No. of workers affected	Textile(s) implicated	Root problem(s)	Corrective measures	References
Kansas City, MO; 1985	Scabies	5	• Soiled textiles • Soiled bed linens	• Failure to wear PPE (gloves) while sorting soiled textiles • PPE left on soiled textiles as employees went on break • Possible nonlaundry exposures?	NS	77
Rural Ontario, Canada; late 1980s	*Microsporis canis*	13 workers 11 patients	• Soiled hospital textiles • Soiled bed linens	• Handling soiled bed linens used by infected patient	• Use PPE to cover arms, gloves for hands when collecting and sorting soiled textiles	8
Rural TN; 1992	*Salmonella hadar*	8 (3 laundry workers)	• Soiled bed linens • Soiled drawsheets	• Failure to wear PPE consistently • No use of protective outerwear	• Handle soiled linens with minimal agitation • Wear PPE garments and gloves	78
Malta; late 1990s	Hepatitis A virus	22	• Soiled hospital textiles	• Improper handling of fecally soiled textiles	• Assess soiled textile collection and sorting processes • Suggest hepatitis A vaccination	79[a]
The Netherlands; mid-2000s	Antineoplastic drugs	100–200	• Chemically soiled hospital textiles, gowns	• Gloves not worn by healthcare workers • Poor aerosol control when handling and collecting contaminated sheets	• Minimize agitation to prevent aerosols when handling contaminated linens • Comply with glove PPE recommendations	80

NOTE. NS, not specified in the report; PPE, personal protective equipment.
[a]Report is primarily a serosurvey of workers presumed at risk for hepatitis A.

TABLE 5. Antimicrobial Treatments of Textiles: Reported Log_{10} Reductions of Challenge Microorganisms for Selected Treatment Agents

	Log_{10} reductions[a]							
Antimicrobial treatment agent	Gram-positive bacteria[b]	Gram-negative bacteria[c]	Fungi and yeasts[d]	Viruses[e]	Application method	Concentration	Fabric type	References
Chitosan	3, 5	1, 3	>4 (*Candida*)		Impregnation	0.5% (w/v)	Cotton	91
	>4, >3	>4			Manufacturer treated	NS	100% cotton	92
	>3 to 5				Dipped into treatment agent solution	0.1% and 1%	Cotton	93
Chitooligosaccharide	>2, >3	>1, >3, >3	>2		Impregnation	0.5% (w/v)	Cotton	91
Citric acid + sodium hydrophosphate monohydrate (SHP)	>4 to >7	>1 to >4			Impregnation	7% citric acid +6.5% SHP	Cotton	94
Copper			>1 (*Candida*)		Copper oxide fiber woven into fabric	NS	Cotton	95
Copper zeolite[f]				>3 to >6	Manufacturer treated	NS	100% cotton	96
Quaternary ammonium compound	>1	>2			Manufacturer treated	NS	NS	92
Quaternary ammonium chloride compound (DDAC)			>4		Manufacturer treated	1.05 mg/g textile	Cotton	95
Quaternary ammonium compound + organosilane	7	5, 7			Added during wash cycle	1% in 10% nonionic detergent, 5% in 10% nonionic detergent	50%/50% C/P	97
Silver (Ag)	>4 to 5	>5			Manufacturer treated	180 ppm	20%/80% C/P	90
Ag/TiO_2 ceramic nanocomposite, hydroxyapatite binder	>2 3	2 to 3 >2 to 3			Dipped into treatment agent solution	4.5 g/m^2 to 6.0 g/m^2	100% cotton Polypropylene	98
Silver/zinc ammonium zeolite	>4	>5			Manufacturer treated	NS	40%/60% C/P	92
Silver/zinc copper zeolite	>2	>1			Manufacturer treated	NS	35%/65% C/P	92

NOTE. Ag/TiO_2, silver/titanium dioxide; C/P, cotton/polyester; DDAC, didecyldimethyl ammonium chloride; NS, not specified; ppm, parts per million; w/v, weight/volume.

[a]Results expressed as whole integers to depict the general magnitude of microbial inactivation. The range indicates maximum reductions when multiple challenge microorganisms were evaluated. Check references for complete listing of challenge microorganisms. A result preceded by the > symbol indicates the log reduction is greater than the number listed but less than the next higher integer.

[b]Strains of *Staphylococcus aureus* (eg, methicillin-susceptible *S. aureus*, methicillin-resistant *S. aureus*) used most frequently.

[c]*Escherichia coli* and *Pseudomonas aeruginosa* used most frequently.

[d]*Trichophyton* spp. and *Candida* spp.

[e]Avian influenza viruses H5N1, H5N3.

[f]Zeolite is a mineral, typically a hydrated aluminosilicate of sodium, potassium, calcium, or barium. Zeolite acts as an absorbent and/or catalyst.

such as privacy curtains,[99] or in reducing the microbial burden on hospital outerwear (eg, scrubs).[100] Patients will have the greatest degree of direct contact with their gowns, the bed linens and blankets, towels and wash cloths. Adverse effects on skin and cytotoxicity may be issues if the antimicrobial treatment chemical degrades such that bioactive compounds are released (ie, leached) from the material during wear.[101] In one study, silver-treated fabrics were found to leach silver in the presence of artificial sweat.[102] Dermal adsorption is known to occur with Triclosan and quaternary ammonium compounds.[83] Treatment chemicals could also cause skin irritation, which can lead to localized skin infections, which in turn may create portals of entry for pathogens. Sensitization and allergic reactions are also possible. Risk-benefit analyses for patient-safety purposes should be performed as part of treated textile research to evaluate potential skin reactions to continual contact with antimicrobial chemical residues.[83,103]

Once a textile treatment is deemed safe for skin contact, the antimicrobial performance of the textile should be evaluated in a clinical setting.[104] Lazary et al[105] recently studied the impact on HAI incidence when copper oxide–impregnated (biocidal) HCTs and patient garments were used in a long-term brain injury ward. Although the report's "before/after" design for an intervention study may not be the most rigorous approach from an epidemiologic perspective, the reported reduction in HAI incidence (24%) when the biocidal textiles were used suggests that the use of antimicrobial-treated HCTs may provide some benefits for infection prevention. This report may be the first to examine the public health impact of biocidal HCTs, and clearly much more research is needed employing rigorous epidemiologic methods to determine whether reductions in HAI incidence occur with biocidal HCT use. Such research could help to determine whether use of these textiles provides greater infection prevention benefits during long-term hospitalizations versus those achieved during short-term care.

Antimicrobial treatments of textiles in the United States may be subject to review by the Environmental Protection Agency to determine whether the pesticide registration provisions of the Federal Insecticide, Fungicide, and Rodenticide Act apply in full (ie, to both the treatment chemical and the treated item) or whether the "Treated Articles Exemption" in this act (40 CFR §152.25(a)) is applicable.[106,107] Note that the Treated Articles Exemption does not apply to items used in direct patient care (eg, antiseptic wound dressings, certain textiles intended for atopic dermatitis therapy). Such items would be cleared by the US Food and Drug Administration.[108]

MICROBIOLOGIC TESTING OF LAUNDERED TEXTILES

Microbiological testing of clean HCTs is conducted in Europe and Australia as part of their regulatory programs established for the healthcare sector.[109,110] Sampling methods for this test include the use of RODAC (Replicate Organism Detection And Counting) plates pressed onto a fabric's surface (followed by incubation for growth) or immersing fabric into broth and enumerating growth in the broth after incubation. Recently, microbiological testing of clean HCTs for "hygienically clean certification" purposes has been introduced to the United States.[111] The basic testing program consists of 4 phases: (1) initial qualification (2 garments tested), (2) probationary period (6 different textiles tested in 3 months), (3) quarterly quality control testing (testing 28 textiles over 3 years), and (4) onsite sampling (2 textiles tested in each of 3 years). This program adopts the pass/fail benchmark of less than or equal to 20 colony-forming units/100 cm^2 total aerobic microbial count on fabric (similar to the German test benchmark) using quarterly RODAC testing. Additional textile samples are required to be tested if a laundry's test results exceed the benchmark or if there are changes in the parameters of the laundry processes. Target microorganism testing using the US Pharmacopeia USP <62> Microbiological Examination of Nonsterile Products: Tests for Specific Microorganisms is conducted semiannually to detect *S. aureus*, *P. aeruginosa*, and *E. coli*.[112]

The Centers for Disease Control and Prevention has not recommended routine microbiological testing of nonporous environmental surfaces or of HCTs for infection control purposes.[2,113] Currently, there is no public health consensus regarding a microbial benchmark to define *hygienically clean* for textiles. Most importantly, given the historical record for patient safety and extremely infrequent episodes of infection attributed to clean HCTs, the need to establish a certification program based on microbiological testing does not appear to be supported by epidemiologic data. The testing of clean HCTs appears to be a test of a "finished" product. Currently in US health care, the only finished product testing that is recommended by the Centers for Disease Control and Prevention is the routine testing of water and dialysate in dialysis settings. The key rationale for testing performed in dialysis settings is the fact that levels of microbial contamination have been associated with adverse outcomes in dialysis patients. Based on those data, there are action level benchmarks for heterotrophic plate counts in water and dialysate that, if exceeded, require immediate action to restore water quality for patient safety.[114] The benchmark set for clean HCTs testing does not appear to be linked to patient outcomes, nor is there any indication from the certification program literature that the benchmark is statistically valid (ie, within 90%–99% confidence intervals). Microbiological testing conducted in other hospital services, such as central sterilization for instruments, is basically process monitoring of industry-established standards and equipment manufacturer specifications.

When considering adopting a microbiological testing program for textiles, there are several important factors to evaluate. The method must be scientifically rigorous and validated. If a method needs to be developed, it should undergo both intra-laboratory and inter-laboratory testing to define all aspects of the method, including aseptic technique, and ideally the validation results should be subject to scientific

scrutiny.[115,116] The method selected for use in the US HCT certification program (USP <62>) was originally developed for testing pharmaceutical and cosmetic substances. Currently there are no microbiological test methods for textiles that are part of either the AOAC International[117] or the ASTM collections of validated methods.[118] RODAC plate sampling and other sampling techniques cover very small areas, and microbial bioburden may not be spread evenly over the entire item. The method should be statistically valid, providing a meaningful representative sampling of the HCT product output during the sampling period. Given that most healthcare laundry facilities will process thousands, if not millions, of pounds of laundry in the 3-year certification period (the period established in the testing program in the United States), testing a very small number of textiles would not meet this criterion. The testing strategy should target the true end of the laundering process—when the textile goes to storage. Given the nature of the problems leading to some of the outbreaks summarized in Table 4 (poor storage conditions supporting microbial proliferation), spore-forming bacteria and fungi were identified, whereas *S. aureus*, *P. aeruginosa*, and *E. coli* were not. Microbiological testing will not detect contamination where we have seen it occur most often—in transit, in storage. Most importantly, there would need to be a plan of action for the infection preventionist at the hospital and the laundry managers when test results exceed the benchmark. Would a recall of HCTs be warranted under these circumstances, and if so, how far back from the current load? If the HCT testing benchmark is not linked to patient outcomes and no infection prevention intervention is developed to address high heterotrophic plate counts, there may be no justification for testing.

CONCLUDING REMARKS

Current infection prevention strategies and textile management during patient use appear to be adequate in preventing HAIs, provided that every step is taken to maintain the hygienic quality of HCTs before use. Patient-to-patient transmission of microorganisms involving clean textiles has not been demonstrated to date, despite the fact that pathogenic microorganisms can survive on textiles.[57,81,119] Well-designed studies are needed to determine whether and to what extent HCTs may be a factor in patient colonization.[57,58] Clinical studies are needed for risk/benefit evaluation of antimicrobial-treated or -impregnated HCTs.

Healthcare epidemiologists would benefit from gaining some familiarity with HCT laundering, facility policies, and procedures for management of hygienically clean HCTs. If an outbreak of HAIs potentially linked to HCTs occurs, it is not enough to conduct microbial sampling of laundered textiles and declare the laundry process as the source of the problem.[120] Each of the distinct operations of the laundry process needs to be evaluated in order to pinpoint the root cause of the problem. The greatest risks of diminishing the hygienically clean state of HCTs appear to be associated with inadvertent environmental contamination due to a malfunction of the laundry process or poor storage conditions of HCTs after laundering. A Hazard Analysis and Critical Control Point assessment of all post-laundering tasks should be included in any outbreak investigation of laundered HCTs.[14,121,122]

Studies to evaluate new developments in laundry processing in addition to current operations are encouraged. Survey entities such as the US Centers for Medicare & Medicaid Services are now acknowledging use of laundry additives other than chlorine bleach for HCT sanitization in healthcare facilities.[123] Following manufacturer instructions for laundry equipment, laundry chemicals, and fabrics is crucial to the provision of quality service to healthcare facility patients.[123]

The provision of hygienically clean HCTs is an important service. Healthcare facilities are responsible for ensuring that laundry contractors provide their service in a safe and effective manner.[124] At least one on-site inspection of the laundry facility by hospital staff on an annual basis is needed to make this determination. In order to help infection preventionists or environmental service directors with this inspection, the Association for Linen Management is now making a laundry facility checklist available on its website.[125]

ACKNOWLEDGMENTS

The author acknowledges prepublication review of the manuscript by Nancy Bjerke, RN, BSN, MPH, CIC, cochair, Standards Committee, Healthcare Laundry Accreditation Council; Patti Costello, executive director, Association for the Healthcare Environment; and Linda Fairbanks, executive director, Association for Linen Management. The author also acknowledges conversations with Walter W. Bond, MS, environmental microbiology consultant, RCSA, on the microbial topics addressed in this manuscript.

Financial support. None reported.

Potential conflicts of interest. The author reports that she was a member of the Healthcare Laundry Accreditation Council from 2005 to 2012. No compensation from HLAC was received during or after this tenure.

Disclaimer: The findings and conclusions in this report are those of the author and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

Address correspondence to Lynne M. Sehulster, PhD, M(ASCP), Prevention and Response Branch, Division of Healthcare Quality Promotion, Centers for Disease Control and Prevention, 1600 Clifton Rd NE, Mailstop A-35, Atlanta, GA 30329-4027 (lynne.sehulster@cdc.hhs.gov).

REFERENCES

1. Rutala WA, Weber DJ. Uses of inorganic hypochlorite (bleach) in health-care facilities. *Clin Microbiol Rev* 1997;10:597–610.
2. Centers for Disease Control and Prevention. CDC/HICPAC Guidelines for environmental infection control in health-care facilities. Centers for Disease Control and Prevention and the Healthcare Infection Control Practices Advisory Committee (HICPAC) website. http://www.cdc.gov/hicpac/pdf/guidelines/eic_in_HCF_03.pdf. Published 2003. Accessed September 29, 2013.
3. Facility Guidelines Institute. *Guidelines for Design and Construction of Health Care Facilities*. Chicago, IL: American Society for Healthcare Engineering, 2010.

4. American National Standards Institute (ANSI)/Association for the Advancement of Medical Instrumentation (AAMI). *ANSI/AAMI ST 65:2008 (R) 2013 Processing of Reusable Surgical Textiles for Use in Health Care Facilities*. Arlington, VA: Association for the Advancement of Medical Instrumentation, 2009.
5. Blaser MJ, Smith PE, Cody HJ, Wang W-LL, LaForce FM. Killing of fabric-associated bacteria in hospital laundry by low-temperature washing. *J Infect Dis* 1984;149:48–57.
6. Nicholes PS. Bacteria in laundered fabrics. *Am J Public Health* 1970;60:2175–2180.
7. US Department of Labor, Occupational Safety and Health Administration (OSHA). Occupational exposure to bloodborne pathogens: final rule (29 CFR §1910.1030). *Fed Reg* 1991; 56:64004–64182.
8. Shah PC, Krajden S, Kane J, Summerbell RC. Tinea corporis caused by *Microsporum canis*: report of a nosocomial outbreak. *Eur J Epidemiol* 1988;4:33–38.
9. Shimori T, Miyamoto H, Makishima K, et al. Evaluation of bedmaking-related airborne and surface methicillin-resistant *Staphylococcus aureus* contamination. *J Hosp Infect* 2002;50:30–35.
10. Garner JS, Simmons BP. CDC guideline for isolation precautions in hospitals. *Am J Infect Control* 1984;12:103–163.
11. Weinstein SA, Gantz NM, Pelletier C, Hibert D. Bacterial surface contamination of patients' linen: isolation precautions versus standard care. *Am J Infect Control* 1989;17:264–267.
12. Centers for Disease Control and Prevention. CDC/HICPAC Isolation precautions: preventing transmission of infectious agents in health-care settings. Centers for Disease Control and Prevention and the Healthcare Infection Control Practices Advisory Committee (HICPAC) website. http://www.cdc.gov/hicpac/pdf/isolation/Isolation2007.pdf. Published 2007. Accessed September 29, 2013.
13. Riggs CL, Klipper M. *Textile Laundering Technology*. Alexandria, VA: Textile Rental Services Association of America, 2005.
14. Healthcare Laundry Accreditation Council (HLAC). Accreditation standards for processing reusable textiles for use in healthcare facilities. HLAC website. http://www.hlacnet.org. Published 2011. Accessed September 28, 2013.
15. Fairbanks L. *Guide to Assessing Health Care Laundry Quality*. Richmond, KY: Association for Linen Management, 2011.
16. Walter WG, Schillinger JE. Bacterial survival in laundered fabrics. *Appl Microbiol* 1975;29:368–373.
17. Mouton RP, Bekkers JH. Bacteriological results of routine procedures in a hospital laundry. *Folia Med Neerl* 1967;10:71–76.
18. Jaska JM, Fredell DL. Impact of detergent systems on bacterial survival on laundered fabrics. *Appl Environ Microbiol* 1980; 39:743–748.
19. Battles DR, Vesley D. Wash water temperature and sanitation in the hospital laundry. *J Environ Health* 1981;43:244–250.
20. Christian RR, Manchester JT, Mellor MT. Bacteriological quality of fabrics washed at lower-than-standard temperatures in a hospital laundry facility. *Appl Environ Microbiol* 1983;45:591–597.
21. Smith JA, Neil KR, Davidson CG, Davidson RW. Effect of water temperature on bacterial killing in laundry. *Infect Control* 1987;8:204–209.
22. Choi SY, Lee IY, Sohn JH, et al. Optimal conditions for the removal of house dust mite, dog dander, and pollen allergens using mechanical laundry. *Ann Allergy Asthma Immunol* 2008; 100:583–588.
23. Heinzel M, Kyas A, Weide M, Breves R, Bockműhl DP. Evaluation of the virucidal performance of domestic laundry procedures. *Int J Hyg Environ Health* 2010;213:334–337.
24. Orr KE, Holliday G, Jones AL, Robson I, Perry JD. Survival of enterococci during hospital laundry processing. *J Hosp Infect* 2002;50:133–139.
25. Arnold L. A sanitary study of commercial laundry practices. *Am J Public Health* 1938;28:39–44.
26. Chemistry of soaps, how they work, soaps vs. detergents. Detergents and Soaps website. http://www.detergentsandsoaps.com. Accessed September 29, 2013.
27. Gerba CP, Kennedy D. Enteric virus survival during household laundering and impact of disinfection with sodium hypochlorite. *Appl Environ Microbiol* 2007;73:4425–4428.
28. Chlorine bleaching at institutional laundries: identifying the risks. Laundry Today website. http://www.laundrytoday.com. Accessed September 29, 2013.
29. Troubleshooting textiles: what causes pilling? Redeposition? Shrinkage? American Laundry News website. http://www.americanlaundrynews.com/articles/. Accessed September 29, 2013.
30. The stain that wouldn't fade. American Laundry News website. http://www.americanlaundrynews.com/articles/. Accessed September 29, 2013.
31. Tinker SJ. Chlorine bleach or oxygen bleach. Laundry Today website. http://www.laundrytoday.com. Accessed September 29, 2013.
32. US Environmental Protection Agency (EPA). Product performance test guidelines OCSPP 810.2400: disinfectants and sanitizers for use on fabrics and textiles–efficacy data recommendations. EPA website. http://www.epa.gov/oppfead1/cb/csb_page/updates/2012/testguidelines.html. Accessed September 29, 2013.
33. US Environmental Protection Agency (EPA). Pesticide product label system (PPLS). EPA website. http://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1. Accessed September 29, 2013.
34. Merianos JJ. Surface-active agents. In Block SS, ed. *Disinfection, Sterilization, and Preservation*, 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2001:283–320.
35. Lawrence CA. Mechanism of action and neutralizing agents for surface-active materials upon microorganisms. *Ann NY Acad Sci* 1950;53:66–75.
36. Buford LE, Pickett MS, Hartman PA. Sanitation in self-service automatic washers. *Appl Environ Microbiol* 1977;33:74–78.
37. McNeil E, Choper EA. Disinfectants in home laundering. *Soap Chem Spec* 1962;38:51–54; 94, 97–100.
38. Green laundry: an industry-changing progress (part 1 of 2). American Laundry News website. http://www.americanlaundrynews.com/articles/. Accessed September 29, 2013.
39. Tinker SJ. Peracetic acid vs. hydrogen peroxide bleaching. Technical service bulletin TB-07030. Gurtler Industries website. http://www.gurtler.com/. Accessed September 29, 2013.
40. Understanding the science behind ozone laundering. American Laundry News website. http://www.americanlaundrynews.com/articles/. Accessed September 29, 2013.
41. Tinker SJ. Ozone in laundry. Technical service bulletin TB 09110. Gurtler Industries. http://www.gurtler.com/. Accessed September 29, 2013.
42. Ozone in the laundry industry—a view from both sides. Laundry Today website. http://www.jaundrytoday.com/index.php/. Accessed September 29, 2013.

43. Ozone in the laundry industry—practical experiences in the United Kingdom. Ozone Laundry Handbook website. http://www.cwtozone.com/uploads/. Accessed September 29, 2013.
44. Guide to ozone laundry systems. OPC Solutions website. http://www.opcsolutions.co.uk/technical/. Accessed September 29, 2013.
45. Cardoso CC, Fiorini JE, Ferriera LR, Gurjão JWB, Amaral LA. Disinfection of hospital laundry using ozone: microbiological evaluation. *Infect Control Hosp Epidemiol* 2000;21:248.
46. Belkin NL. Aseptics and aesthetics of chlorine bleach: can its use in laundering be safely abandoned? *Am J Public Health* 1998; 26:149–151.
47. Altenbaher B, Šostar Turk S, Fijan S. Ecological parameters and disinfection effect of low-temperature laundering in hospitals in Sovenia. *J Cleaner Prod* 2011;19:253–258.
48. Jordan WE, Jones DV. Antiviral effectiveness of chlorine bleach in household laundry use. *Am J Dis Child* 1969;117:313–316.
49. Fijan S, Koren S, Cencič A, Šostar Turk S. Antimicrobial disinfection effect of a laundering procedure for hospital textiles against various indicator bacteria and fungi using different substrates for simulating human excrements. *Diag Microbiol Infect Dis* 2007;57:251–257.
50. Fijan S, Šostar Turk S. Antimicrobial activity of selected disinfectants used in a low temperature laundering procedure for textiles. *Fib Text E Eur* 2010;18:89–92.
51. Nordstrom JM, Reynolds KA, Gerba CP. Comparison of bacteria on new, disposable, laundered, and unlaundered hospital scrubs. *Am J Infect Control* 2012;40:539–543.
52. Honisch M, Stamminger R, Bockmühl DP. Impact of wash cycle time, temperature and detergent formulation on the hygiene effectiveness of domestic laundering. *J Appl Microbiol* 2014;117: 1787–1797.
53. Lakdawala N, Pham J, Shah M, Holton J. Effectiveness of low-temperature domestic laundry on the decontamination of healthcare workers' uniforms. *Infect Control Hosp Epidemiol* 2011;32:1103–1108.
54. Patel SM, Murray-Leonard J. Wilson APR. Laundering of hospital staff uniforms at home. *J Hosp Infect* 2006;62:89–93.
55. Association of periOperative Registered Nurses. Guideline for surgical attire. In: *2015 Guidelines for Perioperative Practice*. Denver, CO: AORN, 2015:97–119.
56. Dancer SJ, White L, Robertson C. Monitoring environmental cleanliness on two surgical wards. *Int J Environ Health Res* 2008;18:257–264.
57. Boyce JM, Potter-Bynoe G, Chenevert C, King T. Environmental contamination due to methicillin-resistant *Staphylococcus aureus*: possible infection control implications. *Infect Control Hosp Epidemiol* 1997;18:622–627.
58. Bonten MJM, Hayden MK, Nathan C, et al. Epidemiology of colonization of patients and environment with vancomycin-resistant enterococci. *Lancet* 1996;348:1615–1619.
59. Fujita K, Lilly HA, Kidson A, Ayliffe GAJ. Gentamicin-resistant *Pseudomonas aeruginosa* infection from mattresses in a burns unit. *Br Med J* 1981;283:219–220.
60. Weernink A, Severin WPJ, Thernberg T, Dijkshoorn L. Pillows, an unexpected source of *Acinetobacter*. *J Hosp Infect* 1995;29: 189–199.
61. Huang SS, Datta R, Platt R. Risk of acquiring antibiotic-resistant bacteria from prior room occupants. *Arch Intern Med* 2006;166: 1945–1951.
62. US Government Accounting Office (GAO). VA Health Care: laundry service, operations and costs. GAO website. http://www.gao.gov/new.items/he0016.pdf. Accessed September 30, 2013.
63. American Hospital Association (AHA). Fast facts on US hospitals. AHA website. http://www.aha.org/research/rc/stat-studies/fast-facts.shtml. Accessed October 1, 2013.
64. Streifel AJ. Healthcare-associated infections and the environment. In Mayhall CG, ed. *Hospital Epidemiology and Infection Control*, 4th ed. Philadelphia, PA: Wolters Kluwer/Lippincott Williams & Wilkins, 2012:1051–1058.
65. Birch BR, Perera BS, Hyde WA, et al. *Bacillus cereus* cross-infection in a maternity-unit. *J Hosp Infect* 1981;2:349–354.
66. Barrie D, Wilson JA, Hoffman PN, Kramer JM. *Bacillus cereus* meningitis in two neurosurgical patients: an investigation into the source of the organism. *J Hosp Infect* 1992;25:291–297.
67. Barrie D, Hoffman PN, Wilson JA, Kramer JM. Contamination of hospital linen by *Bacillus cereus*. *Epidemiol Infect* 1994;113:297–306.
68. Telfer Brunton WA. Infection and hospital laundry. *Lancet* 1995;345:1574–1575.
69. Ohsaki Y, Koyano S, Tachibana M, et al. Undetected *Bacillus* pseudo-outbreak after renovation work in a teaching hospital. *J Infect* 2008;54:617–622.
70. Ohsaki Y, Kuroli M, Tachibana M, Koyano S, Yoshida I, Ito Y. Use of sodium hypochlorite (NaOCl) in laundering stops cross-contamination of *Bacillus cereus*. *J Hosp Infect* 2007;55:283–284.
71. Dohmae S, Okubo T, Higuchi W, et al. *Bacillus cereus* nosocomial infection from reused towels in Japan. *J Hosp Infect* 2008;69: 361–367.
72. Sasahara T, Hayashi S, Morisawa Y, Sakihama T, Yoshimura A, Hirai Y. *Bacillus cereus* bacteremia outbreak due to contaminated hospital linens. *Eur J Clin Microbiol Infect Dis* 2011;30:219–226.
73. Duffy J, Harris J, Gade L, et al. Mucormycosis outbreak associated with hospital linens. *Pediatr Infect Dis J* 2014;33:472–476.
74. Hosein IK, Hoffman PN, Ellam S, et al. Summertime *Bacillus cereus* colonization of hospital newborns traced to contaminated, laundered linen. *J Hosp Infect* 2013;85:149–154.
75. Balm MND, Jureen R, Teo C, et al. Hot and steamy: outbreak of *Bacillus cereus* in Singapore associated with construction work and laundry practices. *J Hosp Infect* 2010;81:224–230.
76. Sooklal S, Khan A, Kannangara S. Hospital *Clostridium difficile* outbreak linked to laundry machine malfunction. *Am J Infect Control* 2014;42:674–675.
77. Thomas MC, Giedinghagen DH, Hoff GL. Brief report: an outbreak of scabies among employees in a hospital-associated commercial laundry. *Infect Control* 1987;8:427–429.
78. Standaert SM, Hutcheson RH, Schaffner W. Nosocomial transmission of *Salmonella* gastroenteritis to laundry workers in a nursing home. *Infect Control Hosp Epidemiol* 1994;15:22–26.
79. Borg MA, Portelli A. Hospital laundry workers—an at-risk group for hepatitis A? *Occup Med* 1999;49:448–450.
80. Meijster T, Fransman W, Weldhof R, Kromhout H. Exposure to antineoplastic drugs outside the hospital environment. *Ann Occup Hyg* 2006;50:657–664.
81. Bearman G, Bryant K, Leekha S, et al. Healthcare personnel attire in non-operating-room settings. *Infect Control Hosp Epidemiol* 2014;35:107–121.
82. Bureau-Chalot F, Piednoir E, Camus J, Bajolet O. Microbiologic quality of linen and linen rooms in short-term care units. *J Hosp Infect* 2004;56:329–331.

83. Elsner P. Antimicrobials and the skin physiological and pathological flora. *Curr Probl Dermatol* 2006;33:35–41.
84. Ricci G, Patrizi A, Bellini F, Medri M. Use of textiles in atopic dermatitis. *Curr Probl Dermatol* 2006;33:127–143.
85. Haug S, Roll A, Schmid-Grendelmeier P, et al. Coated textiles in the treatment of atopic dermatitis. *Curr Probl Dermatol* 2006;33: 144–151.
86. Gauger A. Silver-coated textiles in the therapy of atopic eczema. *Curr Probl Dermatol* 2006;33:152–164.
87. Szostak-Kotowa J. Biodeterioration of textiles. *Int Biodeter Biodegrad* 2004;53:165–170.
88. Gao Y, Cranston R. Recent advances in antimicrobial treatments of textiles. *Tex Res J* 2008;78:60–72.
89. Dastjerdi R, Montazer M. A review on the application of inorganic nano-structured materials in the modification of textiles: focus on anti-microbial properties. *Colloids Surf, B* 2010;79:5–18.
90. Mariscal A, Lopez-Gigosos RM, Carnero-Varo M, Fernandez-Crehuet J. Antimicrobial effect of medical textiles containing bioactive fibres. *Eur J Clin Microbiol Infect Dis* 2011;30:227–232.
91. Fernandes JC, Tavaria FK, Fonseca SC, Ramos OS, Pintado ME, Malcata FX. In vitro screening for antimicrobial activity of chitosans and chitooligosaccharides, aiming at potential uses in functional textiles. *J Microbiol Biotechnol* 2010;20:311–318.
92. Takai K, Ohtsuka T, Senda Y, et al. Antibacterial properties of antimicrobial-finished textile products. *Microbiol Immunol* 2002; 46:75–81.
93. Tavaria FK, Soares JC, Reis IL, Paulo MH, Malcata FX, Pintado ME. Chitosan: antimicrobial action upon staphylococci after impregnation onto cotton fabric. *J Appl Microbiol* 2012;112:1034–1041.
94. Vukušić SB, Grgac SF, Budimir A, Kalenić S. Cotton textiles modified with citric acid as efficient antibacterial agent for prevention of nosocomial infections. *Croat Med J* 2011;52:68–75.
95. Hammer TR, Mucha H, Hoefer D. Dermatophyte susceptibility varies towards antimicrobial textiles. *Mycoses* 2012;55:344–351.
96. Imai K, Ogawa H, Bui VN, et al. Inactivation of high and low pathogenic avian influenza virus H5 subtypes by copper ions incorporated in zeolite-textile materials. *Antiviral Res* 2012;93: 225–233.
97. Baxa D, Shetron-Rama L, Golembieski M, et al. In vitro evaluation of a novel process for reducing bacterial contamination of environmental surfaces. *Am J Infect Control* 2011;39:483–487.
98. Kasuga E, Kawakami Y, Matsumoto T, et al. Bactericidal activities of woven cotton and nonwoven polypropylene fabrics coated with hydroxyapatite-binding silver/titanium dioxide ceramic nanocomposite "Earth-plus.". *Int J Nanomed* 2011;6:1937–1943.
99. Schweizer M, Graham M, Olh M, Heilmann K, Boyken L, Diekema D. Novel hospital curtains with antimicrobial properties: a randomized, controlled trial. *Infect Control Hosp Epidemiol* 2012;33:1081–1085.
100. Bearman GML, Rosato A, Elam K, et al. A crossover trial of antimicrobial scrubs to reduce methicillin-resistant *Staphylococcus aureus* burden on healthcare worker apparel. *Infect Control Hosp Epidemiol* 2012;33:268–275.
101. Hőfer D. Antimicrobial textiles, skin-borne flora and odour. *Curr Probl Dermatol* 2006;33:67–77.
102. Kulthong K, Srisung S, Boonpavaitchakul K, Kanywansupamonkon W, Maniratanachote R. Determination of silver nanoparticle release from antibacterial fabrics into artificial sweat. *Particle Fibre Toxicol* 2010;7:8–16.
103. Kramer A, Guggenbichler P, Heldt P, et al. Hygienic relevance and risk assessment of antimicrobial-impregnated textiles. *Curr Probl Dermatol* 2006;33:78–109.
104. Borkow G, Gabbay J. Biocidal textiles can help fight nosocomial infections. *Med Hypotheses* 2008;70:990–994.
105. Lazary A, Weinberg I, Vatine J-J, et al. Reduction of healthcare-associated infections in a long-term brain injury ward by replacing regular linens with biocidal copper oxide impregnated linens. *Int J Infect Dis* 2014;24:23–29.
106. US Environmental Protection Agency. Pesticide Registration (PR) Notice 2000–1. 6 March 2000. Notice to manufacturers, formulators, producers and registrants of pesticide products. EPA website. http://www.epa.gov/pesticides/PR_Notices/pr2000-1.pdf. Accessed September 30, 2013.
107. US Environmental Protection Agency. Consumer protects treated with pesticides. EPA website. http://www.epa.gov/pesticides/factsheets/treatart.htm. Accessed September 30, 2013.
108. Ricci G, Neri I, Ricci L, Patrizi A. Silk fabrics in the management of atopic dermatitis. *Skin Therapy Lett* 2012;17:5–7.
109. German Certification Association for Professional Textile Services. RAL-GZ992/2–Hospital Linen. Bőnnigheim, Germany. http://www.waeschereien.de/en/waeschereien/guetezeichen/9922_healthcare_linen/9922_healthcare_linen.html. Accessed September 30, 2013.
110. Institute for Sustainability and Hygiene International. Certification standards for processing reusable linen. MacKenzie, Brisbane, Queensland, Australia. April 2011.
111. Textile Rental Services Association. Standards for producing hygienically clean reusable textiles. http://www.trsa.org/sites/default/files/uploads/documents/hygienic_trsa_standard.pdf. Published January 1, 2015. Accessed February 15, 2015.
112. US Pharmacopeia. USP 31 Microbiological Tests. <62> Microbiological examination of nonsterile products: tests for specific microorganisms. http://www.usp.org/sites/default/files/usp_pdf/EN/USPNF/generalChapter62.pdf. Accessed October 1, 2013.
113. Garner JS, Favero MS. Guideline for handwashing and hospital environmental control. Atlanta, GA: Centers for Disease Control, 1985, Document No. 99-1117.
114. Association for the Advancement of Medical Instrumentation (AAMI). AAMI dialysis standards. http://www.aami.org/publications/standards/dialysis.html. Accessed October 1, 2013.
115. Tomasino SF. Development and assessment of disinfectant efficacy test methods for regulatory purposes. *Am J Infect Control* 2013;41:S72–S76.
116. American National Standards Institute (ANSI). ANSI essential requirements: due process requirements for American national standards. New York, NY. http://www.ansi.org. Published January 2010. Accessed September 30, 2013.
117. AOAC International. Official methods of analysis of AOAC International, 19th ed. Gaithersburg, MD: AOAC International, 2012. http://www.aoac.org/iMIS15_Prod/AOAC/Publications/Official_Methods_of_Analysis/About/AOAC_Member/Pubs/OMA/AOAC_Official_Methods_of_Analysis.aspx?hkey=ccc1fa5c-3e0f-4f76-87ab-1604b266f9df. Accessed October 1, 2013.
118. ASTM International. *Annual Book of ASTM Standards* Vol. 07.01, *Textiles I*, and Vol. 07.02, *Textiles II*. West Conshohocken, PA: ASTM International, 2013.

119. Fijan S, Šostar Turk S. Hospital textiles, are they a possible vehicle for healthcare-associated infections? *Int J Environ Res Public Health* 2012;9:3330–3343.
120. Sifuentes LY, Gerba CP, Weart I, Engelbrecht K, Koenig DW. Microbial contamination of hospital reusable cleaning towels. *Am J Infect Control* 2013;41:912–915.
121. Fijan S, Šostar Turk S, Cencic A. Implementing hygiene monitoring systems in hospital laundries in order to reduce microbial contamination of hospital textiles. *J Hosp Infect* 2005;61:30–38.
122. Griffith C. HACCP and the management of healthcare associated infections: are there lessons to be learnt from other industries? *Int J Health Care Qual Assur* 2006;19:351–367.
123. Centers for Medicare and Medicaid Services (CMS). Center for Clinical Standards and Quality/Survey & Certification Group. Clarification of interpretive guidance at F Tag 441—laundry and infection control. Ref: S&C:13-09-NH. CMS website. http://www.cms.gov/Medicare/Providers-Enrollment-and-Certification/SurveyCertificationGenInfo/Downloads/Survey-and-Cert-Letter-13-09.pdf. Accessed October 1, 2013.
124. Centers for Medicare and Medicaid Services (CMS). Condition of participation: governing body. 42 CFR §482.12. http://www.gpo.gov/fdsys/pkg/CFR-2011-title42-vol5/pdf/CFR-2011-title42-vol5-sec482-12.pdf. Accessed October 15, 2014.
125. Association for Linen Management. Hospital oversight of contract laundry services. http://www.almnet.org.