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Review

Role of healthcare apparel and other healthcare textiles in the transmission of pathogens: a review of the literature

A. Mitchell[a,*], M. Spencer[b], C. Edmiston Jr.[c]

[a] International Safety Center, The Public's Health, Apopka, FL, USA
[b] Infection Preventionist Consultants, Boston, MA, USA
[c] Department of Surgery, Surgical Microbiology and Hospital Epidemiology Research Laboratory, Medical College of Wisconsin, Milwaukee, WI, USA

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SUMMARY

Healthcare workers (HCWs) wear uniforms, such as scrubs and lab coats, for several reasons: (1) to identify themselves as hospital personnel to their patients and employers; (2) to display professionalism; and (3) to provide barrier protection for street clothes from unexpected exposures during the work shift. A growing body of evidence suggests that HCWs' apparel is often contaminated with micro-organisms or pathogens that can cause infections or illnesses. While the majority of scrubs and lab coats are still made of the same traditional textiles used to make street clothes, new evidence suggests that current innovative textiles function as an engineering control, minimizing the acquisition, retention and transmission of infectious pathogens by reducing the levels of bioburden and microbial sustainability. This paper summarizes recent literature on the role of apparel worn in healthcare settings in the acquisition and transmission of healthcare-associated pathogens. It proposes solutions or technological interventions that can reduce the risk of transmission of micro-organisms that are associated with the healthcare environment. Healthcare apparel is the emerging frontier in epidemiologically important environmental surfaces.

Introduction

Solving the problem of healthcare-associated infections and occupationally acquired infections involves an equation with many complex variables. One of the key components is healthcare workers (HCWs), such as doctors, nurses, laboratory personnel and technical professionals, who are frequently

* Corresponding author. Address: 741 Muirfield Circle, Apopka, FL 32712, USA. Tel.: +1 713 816 0013.
E-mail address: Amber.Mitchell@internationalsafetycenter.org (A. Mitchell).

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exposed to blood and body fluids.[1,2] These fluids can transmit bacteria that cause colonization or infection, including multi-drug-resistant organisms (MDROs) such as meticillin-resistant *Staphylococcus aureus* (MRSA), *Acinetobacter* spp. and Enterobacteriaceae (e.g. *Escherichia coli, Klebsiella pneumoniae)*. There is also a risk of transmission of viruses, including noroviruses, respiratory viruses and bloodborne viruses (human immunodeficiency virus, hepatitis B and C viruses), that can survive for hours or days on surfaces.[1,3–18] In addition to the risk to HCWs acquiring micro-organisms through workplace exposures, HCWs who are already colonized with these micro-organisms represent a risk to patients; studies have reported that 2–15% of HCWs are colonized or infected with MRSA.[8,9,15–18]

Another consideration is the changes that are occurring in the way that patient care is delivered. While acute care personnel, such as those in hospital operating rooms and emergency departments, anticipate splashes and splatters of blood and body fluids, and use personal protective equipment (PPE) accordingly, new medical technologies allow for performing invasive procedures outside of the acute care environment. It may be more difficult to avoid accidental exposures to blood and body fluids in such settings, PPE may be less accessible, and as HCWs are likely to be working with little or no supervision, they may be less compliant with standard infection control precautions. Thus, HCWs who work in non-traditional settings, such as clinics, and ambulatory and community settings, may be at increased risk of occupational exposure to infectious micro-organisms. In addition, HCWs often travel to and from healthcare facilities by public transportation wearing their work clothing, creating another route by which micro-organisms can be imported into, and exported from, the healthcare environment.[19,20]

Not only are the modes of healthcare changing, but another threat comes from the impact of globalization of travel. Over the years, the emergence of novel infections has revealed gaps in public health preparedness for infectious disease in most countries. For example, in the early 2000s, gaps were identified in the preparedness for severe acute respiratory syndrome (SARS), and significant gaps were noted again last year in the responses to both Ebola virus disease (EVD) and Middle East respiratory syndrome coronavirus (MERS). In the USA, this was tragically exemplified by the two HCWs who acquired EVD from one patient who travelled from West Africa to Dallas, Texas.[21]

Viruses such as Ebola can be transmitted easily in body fluids to healthy populations. Healthcare facilities may not be prepared to prevent these types of transmissions. A survey of more than 1000 members of the Association for Professionals in Infection Control and Epidemiology (APIC) found that only 6% felt that their hospitals were fully prepared for emerging threats like Ebola, and 20% had yet to begin training their workers.[22]

Finally, while considerable effort is placed on cleaning and disinfection of non-porous or high-touch environmental surfaces, much less effort is placed on the procedures for cleaning and decontaminating porous, soft surfaces or healthcare textiles (e.g. privacy curtains, linen, upholstery, patient furniture or room furnishings). These textiles include uniforms, scrub suits and other apparel. The complex role that these textiles play in acquisition and retention of pathogens is further complicated by varied laundering conditions and requirements, including whether or not the employer allows employees to launder their work-related apparel at home. While the US Centers for Disease Control and Prevention (CDC) and other government agencies around the world provide guidance for laundering contaminated textiles, achieving optimal water temperature, drying time and dedicated process flow can be difficult to achieve in healthcare facilities, and nearly impossible in homes.

Contaminated textiles, specifically uniforms and apparel worn in healthcare settings, have been subject to recent study and debate. The role that active barrier textiles, including antimicrobial and fluid-repellent properties, could play in preventing occupationally acquired and healthcare-associated illnesses and infections among both patients and workers has been researched, and there is now some evidence to support their use as an effective strategy for preventing cross-contamination. This paper provides a summary review of current evidence of the risks around textiles in healthcare settings, and the potential benefits of novel fabrics to prevent transmission of infectious agents to and from HCWs.

Bioburden and microbial retention on soft surfaces

Experts believe that textiles (i.e. curtains, upholstery, apparel, etc.) play an important role in the acquisition and transmission of pathogens in healthcare.[23–29] HCWs' apparel is a vehicle for cross-contamination and transmission of MDROs.[30–48] Contaminated soft surfaces make an important contribution to the epidemic and endemic transmission of *Clostridium difficile*, vancomycin-resistant enterococci (VRE), MRSA, *Acinetobacter baumannii*, *Pseudomonas aeruginosa* and norovirus.[49–61]

Ohl *et al*. reported that 92% of hospital privacy curtains are contaminated rapidly (within one week) with potentially pathogenic bacteria, such as MRSA and VRE.[25] A review by Otter *et al*. stated that micro-organisms shed by patients can contaminate hospital surfaces at concentrations sufficient for transmission.[51] These pathogens survive and persist for extended periods despite attempts to disinfect or remove them, and can be transferred to HCWs' hands. According to Otter *et al*., the perspective that contaminated surfaces contribute 'negligibly to nosocomial transmission is no longer valid given the new line of scientific evidence'.[51]

Unlike curtains and other environmental textiles, apparel worn in the healthcare environment moves quickly around the healthcare facility and is likely to represent a better source of substrates for bacterial growth. Microbes tend to thrive in moisture and protein-rich soil or dirt that may be found on apparel. Thus, apparel can readily acquire, retain and transmit epidemiologically significant pathogens such as MRSA. Typically, HCWs will wear the same clothing for one day or more, during which time their apparel will have direct or indirect contact with coworkers, patients and the general public.[36,38,62]

At the end of a work shift, *C. difficile* and MRSA can be recovered from the surfaces of nurses' uniforms at counts exceeding 500 colony-forming units (cfu).[23] In one study, 23% and 18% of lab coats were contaminated with meticillin-sensitive *S. aureus* (MSSA) and MRSA, respectively.[34] Weiner-Well *et al*. reported that up to 60% of hospital staff uniforms were culture positive for MDROs, based on samples taken from the sleeves, waists and pockets of the work apparel of over 100 physicians and nurses.[30] Healthcare-associated pathogens were isolated from at least one site on 63% of the uniforms. Krueger *et al*. examined the bacterial profiles of medical residents' worn and unworn scrubs, and found that even laundered and unworn scrubs harboured normal skin flora.[61]

In an observational study across six intensive care units at a tertiary care hospital, Morgan *et al*. reported that 21% of HCW–patient interactions resulted in contamination of the HCW's gloves or gowns, most often with multi-drug-resistant *A. baumannii*.[58] They concluded that environmental contamination was the best predictor of MDRO transmission to HCWs' attire. Treakle *et al*. and others confirmed that lab coats are contaminated by their wearers (i.e. physicians, residents, nurses) in acute care settings in various departments.[31,34,39,43,45,46,62,63] Outside of hospital settings, Gaspard *et al*. established that high levels of MRSA contaminate HCWs' uniforms in long-term care facilities.[50]

Another study aimed to determine the association between the bacterial contamination of HCWs' hands and lab coats and scrub suits. Cultures were obtained from the hands, lab coats and scrubs of HCWs in five intensive care units, and 86% of 103 HCWs' hands were found to be contaminated: 13 (11%) with *S. aureus*, seven (6%) with *Acinetobacter* spp., two (2%) with enterococci and 83 (70%) with skin flora. There was a greater likelihood of bacterial pathogens on the lab coats if the hands were also positive, but not on the scrubs. The presence of *Acinetobacter* spp. on HCWs' hands was associated with a greater likelihood of contamination of lab coats but not scrubs.[35]

PPE and proper hygiene

Protecting HCWs and other workers who must respond to infectious disease outbreaks and crises requires an effective occupational health programme. In its guidance on worker safety in hospitals, the US Occupational Safety and Health Administration (OSHA) stated that an infection prevention programme must include controls for both patient and HCW, and the best programmes incorporate the two as functions of each other.[64] The appropriate use of PPE, including the proper timing and donning of gloves and isolation gowns when interacting with colonized or infected patients, is viewed as an important risk reduction strategy. In addition, isolating patients in single rooms, or room cohorting, are viewed as sentinel practices for reducing the risk of cross-contamination and transmission of healthcare-associated pathogens.[43,63,65–69]

Proper hand hygiene, including handwashing with soap and running water, the use of alcohol-based hand rubs, and appropriately timed glove use, is a key factor in controlling the transmission of MRSA to patients and staff. Workers' hands contribute greatly to the transmission of healthcare-associated pathogens.[70–83] Disrupting the points of contact in this network of transmission is a critical strategy in preventing the transmission of MRSA and VRE. Neely and Maley studied the survival of 22 Gram-positive bacteria, including VRE, MSSA and MRSA, on common hospital materials.[24] They inoculated five types of hospital materials with 10^4 to 10^5 cfu of the different bacteria. The materials included smooth 100% cotton clothing, 100% cotton terry towels, 60% cotton/40% polyester blend scrub suits, 100% polyester privacy curtains and 100% polypropylene plastic aprons. All isolates were detectable for at least one day, and some survived for more than 90 days.[35] These results demonstrate the need for meticulous contact control procedures and careful disinfection to limit the spread of these bacteria.

Of course, even after performing proper hand hygiene and donning gloves, workers can contaminate their gloved hands by touching themselves or objects in the environment (including high-touch surfaces) prior to touching their patients. For example, an observational study of office workers found that they commonly touch their eyes, lips, nostrils etc. at a rate of 15.7 times per hour.[84] HCWs may be more cognizant of the need to keep their gloved hands away from their body, but Loveday *et al*. reported that gloved HCWs touched an average of three objects, such as clinical equipment around the patient or urine bottles/bedpans, in the patient zone prior to performing a healthcare procedure.[85]

In addition, while proper hand hygiene and use of PPE are considered to be the cornerstones of any effective infection control programme, compliance with hand hygiene protocols and requirements for using PPE remain problematic.[43,63,65,66,68–73,86] Mitchell described occupational exposures to blood over a cohort of more than 60 hospitals, and noted that use of PPE can vary between 25% and 75% from incident reports from lower-risk hospital areas compared with higher-risk hospital areas.[87] Also, while there are well-established guidelines to protect both HCWs and patients from cross-contamination in the operating room and isolation precaution settings, there is little guidance specific to areas outside of these traditionally high-risk hospital departments. It is in other departments with less focus where there may be more environmental touch points and thus higher risk of transmission.[48,59,67,68] As such, relying heavily on the use of PPE and high-touch environmental disinfection is not sufficient to prevent the spread of micro-organisms that cause infection and illness.

When HCWs are caring for laboratory-confirmed patients in isolation, they are likely to be more conscientious about handwashing and the use of PPE when they anticipate exposures. However, few facilities perform routine active screening for any MDROs, which results in caring for unconfirmed patient cases and thus unanticipated (and possibly unprotected) exposures. Given the trend towards outpatient and out-of-hospital treatment and procedures, HCWs may not have the acute care workplace reliance on, and awareness of the potential for, exposure, contamination and possible transmission of pathogens.

HCWs as sources of infection

Another consideration in infection control is HCWs as a source for MDROs. Researchers estimate nasal carriage of MRSA in HCWs as between 6–8% or higher.[4] However, others have reported endemic non-outbreak carriage rates as high as 15%.[3]

A study of 135 surgeons and residents found that 1.5% were positive for MRSA and 35.7% were positive for MSSA.[88] None of the 61 residents were positive for MRSA, but 59% were positive for MSSA. Of the 74 attending surgeons, 2.7% were positive for MRSA and 23.3% were positive for MSSA. Danzmann *et al*. reviewed 152 outbreaks, mainly from surgery, neonatology and gynaecology departments.[89] The most common infections were surgical site infections, hepatitis B virus and septicaemia.

Hospital-associated outbreaks included 27 caused by hepatitis B virus, 49 by *S. aureus* and 19 by *Streptococcus pyogenes*. Physicians were involved in 59 outbreaks (41.5%) and nurses were involved in 56 outbreaks (39.4%). Causes of the outbreaks were mainly transmission via direct contact.

Laundering procedures

HCWs may have options to launder their work clothing, or some institutions may offer onsite industrial laundering for scrubs, lab coats and other apparel. Generally, industrial laundry procedures are sufficient to return garments and textiles free of microbial contamination. However, as Fijan *et al.* discovered, no procedure is foolproof, and even if the laundering process itself produces nearly sterile garments, post-laundering practices (e.g. sorting, folding and stacking) can recontaminate clean laundry unless housekeeping personnel maintain a high level of vigilance.[29,90–92]

Fijan *et al.* concluded that insufficient antimicrobial laundry procedures can result in spreading micro-organisms throughout even the clean areas of laundry facilities. They found that: (1) workers can recontaminate clean laundry unless they receive regular training and education on proper hygiene and work area cleaning and disinfecting procedures; and (2) regular cleaning and disinfecting of all laundry areas, especially the clean laundry area, is necessary to prevent the recontamination of laundered textiles during the post-laundry handling processes such as sorting, ironing, folding and packing. Fijan *et al.* specifically investigated the potential for hospital textiles to transmit rotaviruses, and noted that rotavirus RNA could be detected in hospital laundry rinse water after the washing process, even after using accepted laundering procedures, and on laundered textiles, environmental surfaces in the laundry area and the hands of laundry workers.

While industrial laundry practices and procedures may be problematic with regard to ensuring that 'clean' clothes are truly free of microbial contamination, laundering at home may not be a safe solution. Wright *et al.* recently described the investigation of a cluster of three instances of *Gordonia bronchialis* sternal infection.[60] After ruling out environmental contamination, the researchers identified a nurse anaesthetist as the source of the outbreak. Four separate strains of *G. bronchialis* were isolated from her scrubs, axilla, hands and handbag. The investigators also obtained cultures from her nurse roommate, and grew *G. bronchialis* from that nurse's axilla, hands and scrubs. In an effort to decontaminate her home, the nurse anaesthetist disposed of the washing machine that she had been using to launder her work uniforms. After disposal of the machine, the nurse anaesthetist's and her roommate's scrubs, hands, nares and scalps all tested negative for *G. bronchialis* and the infection outbreak ceased. Uncertainties about the effectiveness of home laundering are further illustrated in another study which reported that 39% of nurses' uniforms laundered at home were contaminated with MDROs at the beginning of the work shift.[30,31,36,39]

The laundry conundrum is further complicated because, even if the laundering procedures, whether at home or at work, produce clean textiles, bacterial recontamination of these surfaces will occur within hours of donning newly laundered uniforms. The previously mentioned home-laundered nurses' uniforms showed an increase in contamination from 39% at the beginning of the work shift to 54% by the end of the day. A separate analysis indicated that 100% of nurses' gowns were contaminated within the first day of use, and 33% of those were contaminated with *S. aureus*.[36] Pockets and cuffs may be the areas of highest microbial contamination.[43]

Burden *et al.* found that uniforms that were almost sterile prior to donning accumulated nearly 50% of their 8-h measured cfu count after only 3-h of wear.[31] Those researchers also found no significant differences in cfu counts from previously-worn lab coats vs newly-laundered uniforms, sleeve cuffs of either type of garment, or the pockets of lab coats vs uniforms. Results of the cultures showed that 16% of the lab coats and 20% of the short-sleeved uniforms were positive for MRSA. Burden *et al.* concluded that reducing bacterial contamination of HCWs' clothing made of conventional fabrics would require changing work clothes every few hours.[22]

The USA falls behind many other countries, especially those in Europe, because, typically, only scrub suits worn in the operating room and isolation gowns are laundered by the healthcare facility with commercial or industrial laundering capabilities. The US CDC recommends that contaminated laundry should be washed at water temperatures of at least 160°F (70°C), using 50–150 ppm of chlorine bleach to remove significant quantities of micro-organisms from grossly contaminated linen.[93] This may be possible in healthcare laundry services; however, most scrub suits, lab coats and scrub jackets are washed at home, but typical temperatures of domestic washing machines do not exceed 110°F (45°C) due to child safety laws to prevent scalding and burns. Most scrub manufacturers recommend against the use of bleach to preserve colour dye on the fabric, which is counter-intuitive to the infection prevention and infectious disease community. High drying temperatures, as well as physical agitation in both washing and drying cycles, may reduce pathogens to a sufficient threshold to reduce infectivity; however, this becomes problematic as many choose to either hand wash or hang dry items for various reasons.

Textile innovations: fluid repellency and antimicrobials

Providing every hospital worker with the equivalent of nautical storm gear is impractical. However, technical or engineered textiles, including those with fluid repellency and embedded antimicrobials, have been on the market and readily available as separate technology options for years. Unfortunately, there has been limited adoption of these types of technologies by healthcare institutions. Perhaps an underlying reason for this is the failure of healthcare professionals to recognize the benefits of this innovative technology as a significant risk-reduction strategy. Another reason may be the increased cost associated with these enhanced textiles.

Textile-based fluid or active barrier antimicrobial technology may be an effective strategy for preventing cross-contamination by reducing the burden of infectious micro-organisms on the surface of healthcare apparel. Bearman *et al.* identified a 6-log reduction in MRSA on scrub suits treated with a proprietary technology that includes a breathable, fluid barrier and non-leaching antimicrobial activity compared with scrubs that were not treated.[32] Schweizer *et al.* reported that the median time to first contamination of privacy curtains was seven times longer for curtains incorporating a complex element compound with antimicrobial properties than for standard curtains.[94] They concluded that using privacy curtains with antimicrobial properties could increase the time intervals between necessary laundering, as well as possibly decrease the transmission of pathogens.

Studies have shown that textile-based antimicrobials alone may not be enough; fluid repellency is an important consideration in minimizing infectious dose for textile-based technologies.[95–98] Not having hydrophobic repellency means that the organic material from blood and body fluids may actually interfere with the impregnated antimicrobial agent's ability to inhibit or kill bacterial contamination.

Several studies have assessed the effectiveness of textiles and apparel that use antimicrobials alone (i.e. silver, Chitosan).[94–97] These studies indicate that an antimicrobial alone may not be sufficient to reduce the growth (and thus the retention and transmission) of micro-organisms. Mitchell confirmed this and pointed out that several recent studies have found that textiles embedded with antimicrobials alone may not reduce overall contamination.[97] A consideration, however, is the role that antimicrobial textiles may play for use in environmental surfaces such as privacy curtains, upholstery or bedding compared with apparel or uniforms. The difference in effectiveness between application in these types of healthcare textiles warrants further study.

Other innovative textiles have been shown to inhibit growth and/or contamination. Technical or engineered fabrics have reduced MRSA surface levels to near 0% in splatter, spray and contact challenge tests within 5 min.[99] In addition, Bearman *et al*. documented four- to seven-log reductions for MRSA on technical or engineered fabrics with fluid repellency and antimicrobial properties compared with traditional control scrubs, both at the beginning and end of the nurse work shift.[32] They concluded that the use of an antimicrobial hydrophobic barrier is highly effective in reducing the microbial bioburden on the surface of HCWs' scrubs. An important element of Bearman *et al*.'s study is that it did not find a significant reduction in microbes other than MRSA. However, they discussed the fact that the baseline numbers of Gram-negative bacteria in the hospital may have been too low to allow differences to be identified. When designing a study like this, it is important to identify epidemiologically significant microbes for the setting in which the study is being performed in order to determine if there is a significant difference when comparing two textile types.

As a reminder, the US Food and Drug Administration (FDA) only requires in-vitro testing for manufacturers to make claims about antimicrobial capabilities when they submit for premarket notification.[100] As the FDA does not require clinical testing, many antimicrobial products currently used in thousands of healthcare facilities may be sold without accompanying data validated in clinical or hospital settings. Before purchasing any innovative antimicrobial or active barrier attire, healthcare facilities should determine whether the selected engineering controls have data derived from clinically relevant settings (e.g. crossover and/or randomized study designs in healthcare settings). Facilities also need to consider the antimicrobial agent used and the mechanism of action, including whether it is leaching (ionic association) or a safer non-leaching alternative (covalently bonded).

Summary

The literature illustrates that healthcare textiles, including uniforms or apparel, are a vector for transmission of micro-organisms that cause infections and illnesses in HCWs, patients and the community. While there is a growing platform of published studies on the topic, the impact is underestimated because of a lack of point source investigations of textiles during outbreaks and cases of infection or illness.

Many published papers either begin or end with a statement about the lack of published data in the literature on technical textiles or innovations in apparel. Therefore, healthcare facilities, hospitals, outpatient clinics and academic institutions should use and study newly available controls, and report findings and outcomes in credible published outlets.

PPE has a clear place in protecting HCWs when there are anticipated exposures to blood and body fluids and contact transmissible pathogens. However, exploring innovations in apparel worn daily and textiles used daily may also prevent ongoing, endemic transmission to patients. The science indicates that antimicrobial embedded textiles alone are not enough. Manufacturers can engineer or technically design textiles that reduce the acquisition, retention and transmission of infectious micro-organisms found in blood, body fluids and the environment that can also combat higher levels of soil or bioburden. To ensure best product design, safety, effectiveness and efficacy, this should involve collaborative partnerships between healthcare facilities, research institutes, academic settings, public agencies and manufacturers. We could all benefit by closing the gap between what uniforms or apparel are worn now and what is worn into the future.

Over time, apparel has advanced in industries where there is a risk of fire, with the introduction of textiles that are fire retardant or resistant. It is eminently feasible that in the years ahead, novel fabrics protecting against micro-organisms will become commonplace in healthcare industries.

In closing, a statement by Jagger, of the International Healthcare Worker Safety Center, nearly 10 years ago still holds true today, and can be broadened to include the risks associated with a broader array of pathogens:

> 'The basic measures for protecting HCWs from the life-threatening risk of bloodborne pathogen infection should be viewed everywhere as essential and included in the national health priorities of all nations. The resources for this task are unlikely to be forthcoming unless we re-assess the value we place on HCWs. They are not merely a service commodity; they are an invaluable asset to their countries and to the world community. Without them there would be no health care. All of us benefit from protecting their lives and health.'[86]

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References

1. Jagger J, Balon M. Blood and body fluid exposures to skin and mucous membranes. *Adv Exposure Prev* 1995;**1**:1–9.

2. Jagger J, Powers RD, Day JS, Detmer DE, Blackwell B, Pearson RD. Epidemiology and prevention of blood and body fluid exposures among emergency department personnel. *J Emerg Med* 1994;**12**:753–765.
3. Hawkins G, Stewart S, Blatchford O. Should HCWs be screened routinely for methicillin-resistant *Staphylococcus aureus*? A review of the evidence. *J Hosp Infect* 2011;**77**:285–289.
4. Albrich WC, Harbarth S. Health-care workers: source, vector, or victim of MRSA? *Lancet Infect Dis* 2008;**8**:289–301.
5. Centers for Disease Control and Prevention. *Guideline for infection control in health care personnel*. Atlanta, GA: CDC; 1998. Available at: http://www.cdc.gov/ncidod/dhqp/gl_hcpersonnel.html. Last accessed 15th March 2014.
6. Boyce JM, Opal SM, Byone-Potter G, Medeiros AA. Spread of methicillin-resistant *Staphylococcus aureus* in a hospital after exposure to a health care worker with chronic sinusitis. *Clin Infect Dis* 1993;**17**:496–504.
7. Sherertz RJ, Reagan DR, Hampton KD, *et al*. A cloud adult: the *Staphylococcus aureus*–virus interaction revisited. *Ann Intern Med* 1996;**124**:539–547.
8. Belani A, Sherertz RJ, Sullivan ML, Russel BA, Reumen PD. Outbreak of staphylococcal infection in two hospital nurseries traced to a single nasal carrier. *Infect Control* 1986;**7**:487–490.
9. Kreiswirth BN, Kravitz GR, Schlievert PM, Novick RP. Nosocomial transmission of a strain of *Staphylococcus aureus* causing toxic shock syndrome. *Ann Intern Med* 1986;**105**:704–707.
10. Kassis C, Hachem R, Raad I, *et al*. Outbreak of community-acquired methicillin-resistant *Staphylococcus aureus* skin infections among health care workers in a cancer center. *Am J Infect Control* 2011;**39**:112–117.
11. Centers for Disease Control and Prevention. Update: Human immunodeficiency virus infections in HCWs exposed to blood of infected patients. *MMWR Morb Mortal Wkly Rep* 1987;**36**:285–289.
12. Ippolito G, Puro V, De Carli G; Italian Study Group on Occupational Risk of HIV Infection. The risk of occupational human immunodeficiency virus infection in HCWs: Italian multicenter study. *Arch Intern Med* 1993;**153**:1451–1458.
13. Sartori M, La Terra G, Aglietta M, *et al*. Transmission of hepatitis C via blood splash into conjunctiva. *Scand J Infect Dis* 1993;**25**:270–271.
14. Karmon S, Phillips M. *Blood borne pathogen exposures among nursing staff: causes of exposures and responses*. IDSA Poster #407. New York: New York University School of Medicine, NYU Langone Medical Center; 2010.
15. Bisaga A, Paquette K, Sabatini L, Lovell EO. A prevalence study of methicillin resistant *Staphylococcus aureus* colonization in emergency department health care workers. *Ann Emerg Med* 2008;**52**:525–528.
16. Johnston CP, Stokes AK, Ross T, *et al*. *Staphylococcus aureus* colonization among HCWs at a tertiary care hospital. *Infect Control Hosp Epidemiol* 2007;**28**:1404–1407.
17. Suffoletto BP, Cannon EH, Ilkhanipour K, Yealy DM. Prevalence of *Staphylococcus aureus* nasal colonization in emergency department personnel. *Ann Emerg Med* 2008;**52**:529–533.
18. Ibarra M, Flatt T, Van Maele D, Ahmed A, Fergie J, Purcell K. Prevalence of methicillin-resistant *Staphylococcus aureus* nasal carriage in HCWs. *Pediatr Infect Dis J* 2008;**27**:1109–1111.
19. Otter J, French GL. Bacterial contamination on touch surfaces in the public transport system and in public areas of a hospital in London. *Lett Appl Microbiol* 2009;**49**:803–805.
20. Stepanović S, Cirković I, Djukić S, Vuković D, Svabić-Vlahović M. Public transport as a reservoir of methicillin-resistant staphylococci. *Lett Appl Microbiol* 2008;**47**:339–341.
21. Centers for Disease Control and Prevention. *CDC and Texas Health Department confirm first Ebola case diagnosed in the US*. Atlanta, GA: CDC; 2014. Available at :http://www.cdc.gov/media/releases/2014/s930-ebola-confirmed-case.html. Last accessed 9th February 2015.
22. Association for Professionals in Infection Control and Epidemiology. *Ebola Readiness Poll 2014*. Washington, DC: APIC; 2014. Available at: http://www.apic.org/Resource_/TinyMceFileManager/Topic-specific/Ebola_Readiness_Poll_Results_FINAL.pdf. Last accessed 10th January 2015.
23. Bloomfield SF, Exner M, Signorelli C, Nath KJ, Scott EA; International Scientific Forum on Home Hygiene. *The infection risks associated with clothing and household linens in home and everyday life settings, and the role of laundry*. Available at: http://www.ifh-homehygiene.org/IntegratedCRD.nsf/eb85eb9d8ecd365280257545005e8966/d0e3b0f361079f1780257865003d43b1?OpenDocument. Last accessed 19th March 2015.
24. Neely A, Maley MP. Survival of enterococci and staphylococci on hospital fabrics and plastic. *J Clin Microbiol* 2000;**38**:724–726.
25. Ohl M, Schweizer M, Graham M, Heilmann K, Boyken L, Diekema D. Hospital privacy curtains are frequently and rapidly contaminated with potentially pathogenic bacteria. *Am J Infect Control* 2012;**40**:904–906.
26. Sattar SA, Springthorpe S, Mani S, *et al*. Bacterial transfer to and from fabrics. *J Appl Microbiol* 2001;**90**:962–970.
27. McNeil E. Dissemination of microorganisms by fabrics and leather. *Develop Ind Microbiol* 1964;**5**:30–35.
28. Fijan S, Poljsak-Prijatelj M, Steyer A, *et al*. Rotaviral RNA found in wastewaters from hospital laundry. *Int J Hyg Environ Health* 2006;**209**:97–102.
29. Fijan S, Steyer A, Poljsak-Prijatelj M, *et al*. Rotaviral RNA found on various surfaces in a hospital laundry. *J Virol Methods* 2008;**148**:66–73.
30. Wiener-Well Y, Galuty M, Rudensky B, *et al*. Nursing and physician attire as possible source of nosocomial infections. *Am J Infect Control* 2011;**39**:555–559.
31. Burden M, Cervantes L, Weed D, Keniston A, Price C, Albert R. Newly cleaned physician uniforms and infrequently washed white coats have similar rates of bacterial contamination after an 8-hour workday: a randomized control trial. *J Hosp Med* 2011;**6**:177–182.
32. Bearman GL, 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.
33. Perry C, Marshall R, Jones E. Bacterial contamination of uniforms. *J Hosp Infect* 2001;**48**:238–241.
34. Treakle AM, Thom KA, Furuno JP, Strauss SM, Harris AD, Perencevich EN. Bacterial contamination of health careworkers' whitecoats. *Am J Infect Control* 2009;**37**:101–105.
35. Munoz-Price LS, Arheart KL, Mills JP, *et al*. Associations between bacterial contamination of health care workers' hands and contamination of white coats and scrubs. *Am J Infect Control* 2012;**40**:e245–e248.
36. Callaghan I. Bacterial contamination of nurses' uniforms: a study. *Nurs Stand* 1998;**13**:37–42.
37. Snyder GM, Thom KA, Furuno JP, *et al*. Detection of methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant enterococci on the gowns and gloves of HCWs. *Infect Control Hosp Epidemiol* 2008;**29**:583–589.
38. Speers R, Gaya H, Shooter RA, Patel N. Contamination of nurses' uniforms with *Staphylococcus aureus*. *Lancet* 1969;**2**:233–235.
39. Butler DL, Major Y, Bearman G, Edmond MB. Transmission of nosocomial pathogens by white coats: an in-vitro model. *J Hosp Infect* 2010;**75**:137–138.
40. Rogawski E. *Transfer of multidrug-resistant organisms to HCWs' gloves and gowns after patient contact increases with environmental contamination*. Fifth Decennial International Conference on Healthcare Associated Infections, 18th–22nd March 2010, Atlanta, GA, USA.
41. Whyte W. The role of clothing and drapes in the operating room. *J Hosp Infect* 1988;**11**(Suppl. C):2–17.

42. Pilonetto M, Rosa EA, Brofman PR, *et al*. Hospital gowns as a vehicle for bacterial dissemination in an intensive care unit. *Braz J Infect Dis* 2004;**8**:206–210.
43. Manian FA, Ponzillo JJ. Compliance with routine use of gowns by HCWs (HCWs) and non-HCW visitors on entry into the rooms of patients under contact precautions. *Infect Control Hosp Epidemiol* 2007;**28**:337–340.
44. Babb JR, Davies JG, Ayliffe GAJ. Contamination of protective clothing and nurses' uniforms in an isolation ward. *J Hosp Infect* 1983;**4**:149–157.
45. Wong D, Nye K, Hollis P. Microbial flora on doctors' white coats. *BMJ* 1991;**303**:1602–1604.
46. Loh W, Ng VV, Holton J. Bacterial flora on the white coats of medical students. *J Hosp Infect* 2000;**45**:65–68.
47. Bearman GL, Bryant K, Leekha S, *et al*. Healthcare personnel attire in non-operating room settings. *Infect Control Hosp Epidemiol* 2014;**35**:107–121.
48. Morgan DJ, Liang SY, Smith CL, *et al*. Frequent multidrug-resistant *Acinetobacter baumannii* contamination of gloves, gowns, and hands of HCWs. *Infect Control Hosp Epidemiol* 2010;**31**:716–721.
49. Hill J, Howell A, Blowers R. Effect of clothing on dispersal of *Staphylococcus aureus* by males and females. *Lancet* 1974;**2**:1131–1133.
50. Gaspard P, Eschbach E, Gunther D, Gayet S, Bertrand X, Talon D. Methicillin resistant *Staphylococcus aureus* contamination of HCWs' uniforms in long-term care facilities. *J Hosp Infect* 2009;**71**:170–175.
51. Otter JA, Yezli S, French GL. The role played by contaminated surfaces in the transmission of nosocomial pathogens. *Infect Control Hosp Epidemiol* 2011;**32**:687–699.
52. Scott E, Bloomfield SF. The survival and transfer of microbial contamination via cloths, hands and utensils. *J Appl Bacteriol* 1990;**68**:271–278.
53. Casanova L, Rutala W, Weber J, Sobsey M. Virus transfer from personal protective equipment to healthcare employees' skin and clothing. *Emerg Infect Dis* 2008;**14**:1291–1293.
54. Standaert SM, Hutcheson RH, Schaeffner W. Nosocomial transmission of salmonella gastroenteritis to laundry workers in a nursing home. *Infect Control Hosp Epidemiol* 1994;**15**:22–26.
55. Weernink A, Severin WPJ, Tjernberg I, Dijkshoorn L. Pillows, an unexpected source of acinetobacter. *J Hosp Infect* 1995;**29**:189–199.
56. Das I, Lambert P, Hill D, Noy M, Bion J, Elliott T. Carbapenem-resistant acinetobacter and role of curtains in an outbreak in intensive care units. *J Hosp Infect* 2002;**50**:110–114.
57. Duffy J. *Zygomycosis outbreak associated with hospital linens*. Fifth Decennial International Conference on Healthcare Associated Infections, 18th–22nd March 2010, Atlanta, GA, USA.
58. Morgan DJ, Rogawski E, Thom KA, *et al*. Transfer of multidrug-resistant bacteria to healthcare workers' gloves and gowns after patient contact increases with environmental contamination. *Crit Care Med* 2012;**40**:1045–1051.
59. Dancer SJ. Importance of the environment in methicillin-resistant *Staphylococcus aureus* acquisition: the case for hospital cleaning. *Lancet Infect Dis* 2008;**8**:101–113.
60. Wright SN, Gerry JS, Busowski MT, *et al*. *Gordonia bronchialis* sternal wound infection in 3 patients following open heart surgery: intraoperative transmission from a healthcare worker. *Infect Control Hosp Epidemiol* 2012;**33**:1238–1241.
61. Krueger CA, Murray CK, Mende K, Guymon CH, Gerlinger TL. The bacterial contamination of surgical scrubs. *Am J Orthop* 2012;**41**:E69–E73.
62. Butterfield S. The white coat of the future. *ACP Hospitalist*, August 2011.
63. Gammon J, Morgan-Samuel H, Gould D. A review of the evidence for suboptimal compliance of healthcare practitioners to standard/universal infection control precautions. *J Clin Nurs* 2008;**17**:157–167.
64. US Department of Labor, Occupational Safety and Health Administration. *Worker safety in hospitals*. Washington, DC: OSHA; 2014. Available at: https://www.osha.gov/dsg/hospitals/. Last accessed 19th March 2015.
65. Committee on Personal Protective Equipment for Healthcare Personnel to Prevent the Transmission of Pandemic Influenza and Other Viral Respiratory Infections. *Preventing transmission of pandemic influenza and other viral respiratory diseases: personal protective equipment for healthcare personnel*. Washington DC: Institute of Medicine; 2010.
66. Stanton MW, Rutherford MK. *Hospital nurse staffing and quality of care*. Rockville, MD: Agency for Healthcare Research and Quality; 2004.
67. Association for Professionals in Infection Control and Epidemiology. *Guide to the elimination of methicillin-resistant Staphylococcus aureus (MRSA) transmission in hospital settings*. Washington, DC: APIC; 2007.
68. Siegel JD, Rhinehart E, Jackson M, Chiarello L; Healthcare Infection Control Practices Advisory Committee. *Guideline for isolation precautions: preventing transmission of infectious agents in healthcare settings*. Atlanta, GA: Centers for Disease Control and Prevention; 2007. Available at: http://www.cdc.gov/ncidod/dhqp/pdf/isolation2007.pdf. Last accessed 19th March 2015.
69. Akduman D, Kim LE, Parks RL, *et al*. Use of personal protective equipment and operating room behaviors in four surgical subspecialties: personal protective equipment and behaviors in surgery. *Infect Control Hosp Epidemiol* 1999;**20**:110–114.
70. Pittet D. Improving adherence to hand hygiene practice: a multidisciplinary approach. *Emerg Infect Dis* 2001;**7**:234–240.
71. McGuckin M, Waterman R, Porten L, *et al*. Patient education model for increasing hand washing compliance. *Am J Infect Control* 1999;**27**:309–314.
72. Pittet D, Hugonnet S, Harbarth S, *et al*. Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. Infection Control Programme. *Lancet* 2000;**356**:1307–1312.
73. Kampf G, Kramer A. Epidemiologic background of hand hygiene and evaluation of the most important agents for scrubs and rubs. *Clin Microbiol Rev* 2004;**17**:863–893.
74. Ayliffe GA, Babb JR, Davies JG, Lilly HA. Hand disinfection: a comparison of various agents in laboratory and ward studies. *J Hosp Infect* 1988;**11**:226–243.
75. Hoagland H, Maurice C. A history of protective clothing. *Utility Safety* 2000;**5**:5–12.
76. Herold BC, Immergluck LC, Maranan MC, *et al*. Community-acquired methicillin-resistant *Staphylococcus aureus* in children with no identified predisposing risk. *JAMA* 1998;**279**:593–598.
77. Frank AL, Marcinak JF, Mangat PD, *et al*. Increase in community-acquired methicillin-resistant *Staphylococcus aureus* in children. *Clin Infect Dis* 1999;**29**:935–936.
78. Seybold U, Kourbatova EV, Johnson JG, *et al*. Emergence of community-associated methicillin-resistant *Staphylococcus aureus* USA 300 genotype as a major cause of health care-associated blood stream infections. *Clin Infect Dis* 2006;**42**:647–666.
79. Patel M, Waites KB, Hoesley CJ, Stamm AM, Canupp KC, Moser SA. Emergence of USA-300 MRSA in a tertiary medical centre: implications for epidemiological studies. *J Hosp Infect* 2008;**68**:208–213.
80. Klevens RM, Morrison MA, Nadle J, *et al*. Invasive methicillin-resistant *Staphylococcus aureus* infections in the United States. *JAMA* 2007;**298**:1763–1771.
81. Monecke S, Slickers P, Ellington MJ, Kearns AM, Ehricht R. High diversity of Panton-Valentine leukocidin-positive, methicillin-susceptible isolates of *Staphylococcus aureus* and implications

for the evolution of community-associated methicillin-resistant *S. aureus*. *Clin Microbiol Infect* 2007;**13**:1157–1164.

82. Jarvis WR, Schlosser J, Chinn RY, Tweeten S, Jackson M. National prevalence of methicillin-resistant *Staphylococcus aureus* in inpatients at United States health care facilities, 2006. *Am J Infect Control* 2007;**35**(10):631–637.
83. US Department of Labor, Occupational Safety and Health Administration. *29 CFR Part 1910 Docket No.OSHA-2010-003 RIN No. 1218-AC46 Infectious Diseases*. Washington, DC: OSHA; 2010. Available at: http://www.gpo.gov/fdsys/pkg/FR-2010-05-06/pdf/2010-10500.pdf. Last accessed 19th March 2015.
84. Nicas M, Best D. A study quantifying the hand-to-face contact rate and its potential application to predicting respiratory tract infection. *J Occup Environ Hyg* 2008;**5**:347–352.
85. Loveday HP, Lynam S, Singleton J, Wilson J. Clinical glove use: healthcare workers' actions and perceptions. *J Hosp Infect* 2014;**86**:110–116.
86. Jagger J. Caring for HCWs: a global perspective. *Infect Control Hosp Epidemiol* 2007;**28**:1–4.
87. Mitchell AH. *Occupational exposure to blood & body fluids in U.S. hospitals: implications of national policy*. Doctoral Dissertation. Houston, TX: University of Texas School of Public Health; 2013.
88. Schwarzkopf R, Takemoto RC, Immerman I, Slover JD, Bosco JA. Prevalence of *Staphylococcus aureus* colonization in orthopaedic surgeons and their patients. *J Bone Joint Surg Am* 2010;**92**:1815–1819.
89. Danzmann L, Gastmeier P, Schwab F, Vonberg RP. Health care workers causing large nosocomial outbreaks: a systematic review. *BMC Infect Dis* 2013;**13**:98.
90. Fijan S, Sostar-Turk S. *Hygiene monitoring systems for hospital textile laundering*. London: Hospital Healthcare Europe; 2007/8.
91. Fijan S, Gunnarsen JTH, Weinreich J, Sostar-Turk S. Determining the hygiene of laundering industrial textiles in Slovenia, Norway and Denmark. *Tekstil* 2008;**57**:73–83.
92. Fijan S, Sostar-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.
93. Centers for Disease Control and Prevention. *Laundry: washing infected material*. Atlanta, GA: CDC; 2011. Available at: http://www.cdc.gov/HAI/prevent/laundry.html. Last accessed 10th February 2015.
94. Schweizer M, Graham M, Ohl 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.
95. Boutin MA, Thom KA, Zhan M, Kristie Johnson J. A randomized crossover trial to decrease bacterial contamination on hospital scrubs. *Infect Control Hosp Epidemiol* 2014;**35**:1411–1413.
96. Groß R, Hübner N, Assadian O, Jibson B, Kramer A; Working Section for Clinical Antiseptic of the German Society for Hospital Hygiene. Pilot study on the microbial contamination of conventional vs. silver-impregnated uniforms worn by ambulance personnel during one week of emergency medical service. *GMS Krankenhaushygiene interdisziplinär* 2010;**5**:Doc09.
97. Mitchell AH. Making the case for textiles with a dual mechanism of action. *Infect Control Hosp Epidemiol* 2015. Published online: 20 January 2015 http://dx.doi.org/10.1017/ice.2014.92. Last accessed 19th March 2015.
98. Hardwick M. *VTT003 Textile reduction of MRSA burden: synergistic action of antimicrobial and hydrophobic chemistries*. ID Week Poster #947. Washington, DC: Medstar Research Institute; 2012.
99. Hardwick M, Walsh T, Cotton M. *Fabric challenge assays: new standards for the evaluation of the performance of textiles treated with antimicrobial agents*. In: Bernards M, editor. Pesticide formulation and delivery systems: innovating legacy products for new uses, 1st–3rd November 2011, Tampa, FL, USA. Available at: www.astm.org. Last accessed 15th February 2015.
100. Food and Drug Administration. *Subpart E – Premarket notification procedures*. Silver Spring, MD: FDA; 2014. Available at: http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=807&showFR=1&subpartNode=21:8.0.1.1.5.5. Last accessed 15th February 2015.