The Role of Patient Privacy Curtains in HCAI Transmission: The Effect of a Novel Disinfectant Intervention in Acute Care Hospitals

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Acute care hospitals are the principle setting for transmission of healthcare associated infections (HCAIs). A growing number of the infections are caused by drug- and multi-drug resistant pathogens. The high density and turnover of acute care patients, coupled with increasing antibiotic use, provide a unique challenge to infection prevention.

Despite significant advances in both technology and best practice over the past decade, hospital cleanliness and environmental disinfection remain key battlegrounds in the fight against HCAIs. Privacy curtains are a high-frequency touchpoint surface in the near-patient environment that are readily contaminated with pathogenic micro-organisms. Although demonstrated as vectors for HCAI transmission, they remain often ignored as a threat to patient safety.

The effect of an intervention with disinfectant disposable privacy curtains with broad spectrum log 3 efficacy on HCAI incidence is described. Hospitals adopting Fantex © disinfectant disposable curtains reported an average 28-fold greater decrease in the incidence of HCAIs than hospitals using alternative curtains. After several months of hanging in the hospital environment, microbiological testing of the disinfectant disposable curtain showed no contamination as compared to significant microbial load observed on untreated curtains. Furthermore, unlike untreated curtains, the disinfectant curtains prevented curtain-to-hand cross-contamination.

With bacterial resistance outpacing the development of new antibiotics, technologies that demonstrably reduce infection rates must be appropriately adopted within modern infection control programs to protect patients and lower HCAI incidence within hospitals worldwide.

‘Nosocomial’ or ‘healthcare associated’ infections (HCAI) appear in a patient under medical care in a hospital or other health care facility having been absent at the time of admission. The rates of HCAIs within a hospital represent a key indicator for the quality of services offered, where a high frequency of HCAIs is evidence of poor quality healthcare provision. HCAIs impact on the population in many ways. They affect patients directly, causing increased morbidity and mortality. They may lead to disability and reduced quality of life [Pittet et al., 2008]. They also impact on the healthcare system by extending hospitalization of affected patients and driving up the costs of diagnosis and treatment. HCAIs can also be transmitted from healthcare settings into the community [Collins et al. 2008]. Furthermore, nosocomial infection diagnoses are often subjects of indictment, diminishing the reputation of healthcare institutions in the eyes of the public.

HCAIs present a major threat to patient safety and represent one of the most common adverse events during delivery of health care; complicating 5-10% of admissions to acute care hospitals in industrialised countries [Syndor et al., 2011]. The Centers for Disease Control and Prevention’s (CDC) HAI Prevalence Survey estimated that 722,000 HCAIs were contracted in United States (US) acute care hospitals during 2011. Furthermore, approximately 75,000 patients (11.5%) who contracted a nosocomial infection purportedly died during hospitalization and more than half of all HCAIs occurred outside of the intensive care unit [Centers for Disease Control and Prevention, 2018]. In the United Kingdom (UK), the National Health Service (NHS) treats approximately 300,000 cases of HCAIs across the overwhelming majority of acute and long-term care facilities. Many of these infections are preventable, and conservative estimates implicate nosocomial infection as the direct cause of 5,000 deaths and indirectly contribute to a further 15,000 every year [National Audit Office 2009].

A growing number of HCAIs are caused by drug- and multi-drug resistant (MDR) pathogens. Each year in the US, at least 2 million people acquire serious infections with bacteria that are resistant to one or more antibiotics [Centers for Disease control and Prevention, 2013]. The CDC estimates that, in 2013 alone, 23,000 deaths were caused by drug-resistant bacteria and many more died from other conditions that were complicated by an antibiotic-resistant infection [Centers for Disease control and Prevention, 2013].

The rate of antimicrobial resistance (AMR) emergence is currently outpacing the development of the new drugs needed to treat them. In an age in which many existing antibiotics are completely ineffective against MDR ‘superbugs’, there is concern that medicine is on the cusp of a post-antibiotic era.

AMR poses such a fundamental threat to human health that it has led to a fall in life expectancy in the UK for the first time. According to the UK’s Office for National Statistics (ONS) a female born in 2016 could expect to live 82.9 years, down from 83.7, while males are expected to live to 79.2 instead of 79.9 [Office for National Statistics, 2017]. The UK’s Chief Medical Officer, Professor Dame Sally Davies, has issued a stark warning: “If we do not act now, any one of us could go into hospital for minor surgery in 20 years and die because of an ordinary infection that can’t be treated by antibiotics”. She has also emphasised the importance of improving hygiene: “We need to ad-
dress the growing problem of drug-resistant infections as the global medicine cabinet is becoming increasingly bare. Preventing infections in the first place is key."

Admission to the healthcare system is a risk factor for severe infection [Public Health England 2017; World Health Organization 2010] and nosocomial infection is a leading cause of death [World Health Organisation, 2002]. Hospital surfaces are rapidly contaminated with harmful pathogens, and environmental contamination is often the root cause of infection transmission [Chmelik et al. 2014]. In particular, the near-patient environment has consistently been shown to be a proven source of infection. It contains many high-frequency touchpoint surfaces known to be readily contaminated with pathogenic microorganisms (Figure 1) [Dancer 2008, Trillis 2008].

For example, up to 60% of surfaces in the patient care zone are contaminated with pathogens known to cause HCAIs [Carling and Bartley 2010]. *Clostridium difficile*, MRSA and VRE persist for months on surfaces; facilitating cross-contamination and subsequently infection transmission between healthcare professionals (HCPs) and patients [Cheng et al. 2015]. Many infections are preventable by improving hospital hygiene standards [Loveday et al. 2014].

The combination of increasing HCAI incidence and the rising prevalence of MDR pathogens has transformed a once commonly accepted need to improve hospital hygiene into an urgent healthcare priority. Modern infection prevention and control (IP&C) programs must utilise every innovation available to effectively sanitise the hospital environment and protect patients from unnecessarily contracting HCAIs. Enhancing IP&C programs has been shown to be an effective barrier to the transmission of drug resistant pathogens [O’Connor et al., 2015]. For example, in a multicentre case control study the key role of reinforcing infection control measures in the prevention of infections caused by linezolid-resistant staphylococcal strains was reported [Russo et al., 2015].

**Patient Privacy Curtains and Infection Transmission**

Privacy curtains play a vital role in protecting patient dignity and providing flexible separation of bed spaces. However, they provide unique challenges in terms of hospital cleaning and sanitisation. They are often overlooked as sources of infection despite the fact that they are one of the most frequently touched surfaces in the patient area [Cheng et al. 2015], and have been implicated as the root cause of transmission in a number of studies [Klakus et al. 2008; Mahida et al. 2014; Shek et al. 2017; Trillis et al. 2008].

Healthcare practitioners (HCPs) and patients often touch privacy curtains before, during and after care encounters. Hand hygiene is widely acknowledged to be a cornerstone of good infection prevention practice; however, compliance is an acknowledged problem as protocols are often not fully observed. In one study hospital staff failed to follow procedure in 60% of their interactions with the patient and patient environment [Carling and Bartley 2010].

Furthermore, HCPs are less likely to wash their hands when they touch inanimate objects as compared to patients - promoting the transfer of microorganisms onto items such as curtains [Kramer et al. 2006]. Indeed, studies have found that curtains are frequently contaminated with pathogenic bacteria, including VRE and MRSA [Boyce 2007]. Yet the same curtain often remains in place from one sick patient to the next. Interestingly, patients admitted to rooms previously occupied by infected patients have a substantially greater risk of acquiring the same infection as the room’s previous occupant [Carling and Bartley 2010].

HCAI incidence correlates with standards of IP&C practice [Saloojee and Steenhoff 2001]. In real-world clinical settings, hand hygiene compliance failures do occur, and even exceptional compliance is rendered invalid if the first object handled transfers pathogens to the patient [Pyrek 2012]. Because of this, the type of privacy curtain chosen by a hospital can have real implications for patient safety.

**Linen Privacy Curtains**

Hospital privacy curtains have historically been made of commonplace woven fabrics such as linen. Although now seldom seen in UK healthcare facilities, linen privacy curtains are still used in a large proportion of hospitals worldwide even though it has long been established that they become quickly and heavily contaminated with pathogens [Ohl et al. 2012]. Linen curtains are particularly problematic for infection prevention since they are a soft and absorbent surface in direct proximity to patients. Linen privacy curtains have been shown to act as fomites, in which organisms can grow and multiply. In fact, in one study, after just one week of hanging, 92% of curtains were found to be contaminated by various pathogens [Ohl et al. 2012]. Other studies have shown that microorganisms on linen privacy curtains, including MRSA and *C. difficile*, transfer onto healthcare workers’ hands [Trillis et al. 2008].

Linen curtains were found to be the major source of infection in an outbreak of Carbapenem-resistant *Acinetobac-
Disposable Curtains

Disposable privacy curtains manufactured from non-woven fabrics are generally considered a more hygienic alternative to their traditional equivalents. The polymeric surface (usually polypropylene) is unable to harbour as heavy a pathogenic load as the woven fabric found in linen curtains. However, it is a common misconception that polypropylene disposable curtains remain clean and hygienic during use.

Woven fabrics become visibly dirty more quickly than non-woven on high-touchpoint areas. The false assumption that disposable curtains remain clean often leads to hazardously infrequent changing. In fact, testing of standard disposable curtains shows that they are just as susceptible to contamination with pathogenic microorganisms as linen curtains. Furthermore, pathogens survive on non-disinfectant surfaces for long periods of time as detailed in Table 1 [Havill et al. 2014; Kramer et al. 2006; Stiefel et al. 2011].

Disinfectant Disposable Curtains

Due to the contamination of both linen and standard disposable privacy curtains, many infection prevention practitioners have instead opted to use disinfectant disposable curtains. These are manufactured using non-woven polypropylene and treated with an agent that has antimicrobial properties.

For a disinfectant disposable curtain to reduce contamination and, consequently, the transmission of HCAIs within a hospital, it must offer rapid, long lasting and potent efficacy against a broad spectrum of harmful pathogens.

MATERIALS AND METHODS

Curtains selected for study: Linen curtains selected for study were composed of untreated woven fabric. All of the disposable curtains tested were manufactured from non-woven polypropylene. Standard disposable curtains (manufactured by Behrens and Grosvenor) were untreated. Fantex® disinfectant disposable curtains (Hygenica) were coated with a disinfecting agent called Fantex® whereas Microban® curtains (Marlux Medical) incorporated Microban® - a silver based antimicrobial agent. In addition to this, another silver-containing antimicrobial disposable curtain was also tested (AG curtain).

Microorganisms

Bacteria: Pseudomonas aeruginosa (ATCC 15442), Staphylococcus aureus (ATCC 6538), Escherichia coli (ATCC 10536), Enterococcus faecium (NCTC 12204), Klebsiella pneumoniae (NCTC 13443), Methicillin-resistant Staphylococcus aureus (MRSA) (NCTC 12204), Vancomycin-resistant Enterococcus (VRE) (NCTC 12204), Carbenapen-resistant Acinetobacter baumanii (NCTC 13420), Vancomycin-resistant Enterococcus (VRE) (NCTC 12204), Carbenapen-resistant Enterobacteriaceae (CRE) (NCTC 13443) and Clostridium difficile (vegetative) (ATCC 9869).

Viruses: Feline coronavirus (MERS surrogate), Influenza HK (A2), Herpes simplex type 1, Vaccinia virus (smallpox), Rotavirus (gastroenteritis), Avian infectious laryngotracheitis virus, Avian herpes virus (Marek's disease), Fowl pox virus, Transmissible gastroenteritis of swine virus, Foot & mouth virus, Feline calicivirus (Norovirus surrogate), Canine parvovirus (enteritis), Avian influenza (H7N1) and Avian influenza (H5N1).

Fungi and Yeast: Candida auris (DSM 21092), Candida albicans (ATCC 10231) and Aspergillus niger (IMI 149007).

Efficacy Testing

Agar Diffusion Plate Test (ISO 20645): A 25mm² sample of fabric was placed on two-layer agar plates. The lower layer (bacteria-free) was prepared using 10 ml of trypticase soy agar (TSA) and poured into a petri dish. The upper layer was prepared by adding 5 ml of agar which was inoculated with 1-5×10⁵ colony forming units (CFU)/ml of bacteria. The fabric coupons were pressed onto the agar. Plates were then incubated at 37°C for 18-24 hrs. Antibacterial activity was assessed by zone of inhibition (Zol). An inhibition zone >0mm with no growth under the specimen was defined as "good effect", whereas a 0mm inhibition zone with slight growth in the medium under the specimen indicated a “limited activity”. When growth in the medium under the specimen was moderate to heavy, the...
Antibacterial Activity of Textiles (ISO 20743): Six coupons of the antimicrobial fabric and six control specimens were placed into vials and inoculated by pipetting 0.2 ml of the inoculum at several points on each coupon. The inoculum had a bacterial concentration of 1-3 × 10^5 CFU/ml. Three of the control coupons and three disinfectant fabric coupons were evaluated immediately after inoculation at ‘time zero’ by adding 20 ml of neutralising solution to the vials and shaking out.

The other six coupons were incubated at 37°C for either 1 min, 5 min or 18-24 hrs. Immediately after incubation, 20 ml of neutralising solution was added to the vials. Final microbial concentrations were determined, the reduction in CFU count calculated, and the log reduction determined relative to initial CFU counts and control specimens.

Quantitative Suspension Test for the Evaluation of Bactericidal Activity of Chemical Disinfectants and Antiseptics (EN 1276): The product was tested at the recommended in-use concentration of 1-2% (v/v) under dirty conditions. The disinfectant was diluted in hard water (300 mg.kg⁻¹ CaCO₃) and added to 1 ml of the bacterial suspension (1.5-5.0×10^8 CFU/ml) and 1 ml of interfering substance (bovine serum albumin) at a concentration of 3g/l (w/v) (dirty conditions). After a contact time of 1 or 5 min (at 20°C), 1 ml of the mixture was pipetted into 8 ml of neutraliser solution and the sample was left to rest for 5 minutes. After 2 minutes at 20°C 8 ml of the disinfectant solution was combined in a vial. After 2 minutes at 20°C 8 ml of the disinfectant solution was then added to the vial for a contact time of 5 or 15 min. At the end of the contact time, 1 ml of the mixture was transferred to a test tube containing 8 ml of neutraliser and 1 ml of sterile distilled water. After neutralising the mixture for 5 minutes, 1 ml samples were diluted and poured plated with TSA, in duplicate, prior to incubation at 37°C for 48 hrs and determination of the number of surviving bacteria.

Quantitative Suspension Test for the Evaluation of Fungicidal or Yeasticidal Activity of Disinfectants and Antiseptics (BS EN 1650): The products were tested at a recommended in-use concentration of 1-2% (v/v) under dirty conditions. 1 ml of the fungal suspension with a concentration between 1.5-5.0×10^5 CFU/ml and 1 ml of interfering substance (bovine serum albumin) at concentrations of 3g/l (w/v) (dirty conditions) were combined in a vial. After 2 minutes at 20°C 8 ml of the disinfectant solution was then added to the vial for a contact time of 5 or 15 min. At the end of the contact time, 1 ml of the mixture was transferred to a test tube containing 8 ml of neutraliser and 1 ml of sterile distilled water. After neutralising the mixture for 5 minutes, 1 ml samples were diluted, plated in agar and incubated at 30°C for 48 hrs prior to determination of the number of the surviving pathogens (CFU/ml).

Quantitative Suspension Test for the Evaluation of Virucidal Activity of Disinfectants or Antiseptics used in the Medical Area (BS EN 14476): The test was set up with a disinfectant concentration of 1% (v/v) and a 5-minute contact time at 20°C. 8 ml of the disinfectant and 1 ml of the interfering substance (0.3 g/l of bovine albumin) were mixed with 1 ml of the virus suspension in 24-well plates. The mixture was neutralised, serially diluted and virus titred in 96-well tissue culture plates. The tissue culture infectious dose50 (TCID50) of surviving virus was determined by the method of Karber. The assays were validated by a cytotoxicity control and a formaldehyde internal standard. The virus titre was compared to the recovery of disinfectant-treated virus to measure the reduction in virus titre.

Comparative Testing

Linen Curtains vs. Fantex® Disinfectant Curtains: Sampling was conducted at an inner city hospital. The leading edge of both linen and Fantex® disinfectant curtains were hung within the same ward (ICU, Barnet Hospital, UK) for a period of 4 months. Curtains were bagged when collected from the hospital and swatches from the front pleat of the curtain were tested for the growth of bacteria (cultured on TSA) and fungi (cultured on Sabouraud dextrose agar, SDA).

Antimicrobial Disposable Curtains vs Fantex® Disinfectant Curtains: Testing of Microban® fabric alongside Fantex® fabric by an independent accredited laboratory (MGS Laboratories Ltd) was conducted according to BS EN ISO 20645.

Fingertip Transmission of Contaminants via Curtain Fabric: Circles of curtain fabric 11.3cm in diameter were inoculated with a 1×10^3 CFUs of Staphylococcus aureus and left to stand for 1 minute at room temperature (20°C ± 2°C). 1×10^5 bacteria is a typical maximum level of contamination observed on the palmar surface of the fingers of HCPs [Ayliffe et al. 1988], with counts usually found to be lower than this [Lucet et. al. 2002]. Gloved fingers and thumb were then held on the test fabric for 15 seconds after which the fingers and thumb were placed onto a TSA agar plate for 1 minute. This was conducted for both Fantex®-coated fabric as well as for untreated control fabric. After incubation, the plates were photographed. To calculate a log reduction, circles of curtain fabric 11.3cm in diameter were inoculated with 1×10^6 CFUs of Staphylococcus aureus and left to stand at room temperature (20°C ± 2°C) for 1 minute. A CFU count of 1×10^5 or more is typically observed on hands visibly soiled with blood or faecal matter [Ayliffe et al. 1988]. Gloved fingers and thumb were then held on the fabric for 15 seconds. Fingertips and thumb-tips were then rubbed in neutraliser for 1 minute. The resulting solution of neutraliser was diluted to 10^-6 and then dilution was plated. 3 volunteers were used. This was done for both Fantex®-coated fabric as well as for the untreated control. Log reduction was calculated by subtracting the Mean Log of the Test from the Mean Log of the
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Control. Lab work was performed by an independent accredited laboratory (MGS Laboratories Ltd).

HCAI Incidence Data Analysis: Mandatory HCAI surveillance reporting data pertaining to the incidence of MRSA, MSSA and C. difficile infections in all UK hospitals were obtained from the Public Health England (PHE) database. For hospitals utilizing the Fantex® disinfectant curtain intervention (n=32), the NHS trust-apportioned reports detailing the number of infections were analysed for both the 12 months prior- and post- intervention. As a control, the infection incidence data for non-intervention hospitals (non-adopters of Fantex® disinfectant curtains) were also analysed over the same time period.

Laboratory Tests: All tests conducted to internationally accredited standards were performed by MGS Laboratories Ltd (UKAS number 4393).

Statistical Analysis: Percentage changes in infection incidence for NHS trusts were calculated using the following formula: (no. of infections reported during the 12 months before curtains installation/ no. of infections reported during the 12 months after curtain installation) x 100. In addition, the median average was calculated for the data set.

RESULTS

Determining the Antimicrobial Activity of Fantex® Disinfectant Curtains

Tests were performed to assess the antimicrobial activity of Fantex® solution and Fantex®-coated fabric. All tests were performed in accordance to international test standards.

ISO 20743- Antibacterial Activity of Textiles

The efficacy of Fantex®-coated fabric against Staphylococcus aureus, Klebsiella pneumoniae, Methicillin-resistant Staphylococcus aureus (MRSA), Vancomycin-resistant Enterococcus (VRE) and Carbapenem-resistant Enterobacteriaceae (CRE) was determined using the internationally accredited EN ISO 20743 protocol (Table 2).

<table>
<thead>
<tr>
<th>Microorganism</th>
<th>Log Reduction</th>
<th>Contact time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td>&gt;3.2*</td>
<td>1 min</td>
</tr>
<tr>
<td><em>Klebsiella pneumonia</em></td>
<td>3.8*</td>
<td>1 min</td>
</tr>
<tr>
<td>Methicillin-resistant <em>Staphylococcus aureus</em> (MRSA)</td>
<td>&gt;3.0*</td>
<td>1 min</td>
</tr>
<tr>
<td>Vancomycin-resistant <em>Enterococcus</em> (VRE)</td>
<td>&gt;2.8*</td>
<td>1 min</td>
</tr>
<tr>
<td>Carbapenem-resistant <em>Enterobacteriaceae</em> (CRE)</td>
<td>3.0*</td>
<td>1 min</td>
</tr>
<tr>
<td><em>Candida auris</em></td>
<td>&gt;3.5**</td>
<td>5 min</td>
</tr>
</tbody>
</table>

*All organisms were killed in under 1 minute
**All organisms were killed in under 5 minutes

Table 2 Determination of antibacterial activity of textile products according to ISO 20743

<table>
<thead>
<tr>
<th>Microorganism</th>
<th>Efficacy (ZoI*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Escherichia coli</td>
<td>Good effect</td>
</tr>
<tr>
<td>Methicillin-resistant <em>Staphylococcus aureus</em> (MRSA)</td>
<td>Good effect</td>
</tr>
<tr>
<td>Clostridium difficile (vegetative)</td>
<td>Good effect</td>
</tr>
<tr>
<td>Candida albicans</td>
<td>Good effect</td>
</tr>
<tr>
<td>Aspergillus niger</td>
<td>Good effect</td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td>Good effect</td>
</tr>
</tbody>
</table>

*Zone of inhibition produced by curtain fabric demonstrating effective protection

Table 3 Determination of antibacterial activity according to ISO 20645 agar diffusion test

Figure 2 Results of ISO 20645 conducted on agar plated with *S. aureus*. Fantex®-coated fabric swatch with a clear zone of inhibition surrounding it. (1) Untreated polypropylene with no zone of inhibition and growth under the fabric (2). These results are typical of all organisms tested to ISO 20645.
Fantex®-coated fabric demonstrated a log 3 efficacy against all bacterial species tested in under 1 minute of contact time. For S. aureus, MRSA, VRE, the antimicrobial fabric killed all inoculated organisms within 1 minute of contact time. The yeast Candida auris was also tested and showed a log kill in excess of 3 in a 5-minute contact time.

### ISO 20645 - Agar Diffusion Plate Test

As a qualitative indicator of the efficacy of the disinfectant curtains against micro-organisms, an agar diffusion plate test was conducted according to ISO 20645. The test organisms for this assay were E.coli, MRSA, C. difficile, C. albicans, A. niger, and S. aureus (Table 3, Figure 2). For all test organisms, a clear zone of inhibition was produced by the disinfectant curtain fabric. Figure 2 shows the disinfectant curtain’s antibacterial activity against S. aureus as a typical example of the zone of inhibition seen against all test organisms. No zone of inhibition was seen around the untreated fabric which served as a control.

### BS EN 1276/ BS EN 1650- Evaluation of Bactericidal activity and Fungicidal or Yeasticidal Activity of Disinfectants and Antiseptics

Bactericidal and yeasticidal suspension tests were also performed to assess the antimicrobial activity of Fantex®

<table>
<thead>
<tr>
<th>Microorganism</th>
<th>Log reduction</th>
<th>Contact time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>&gt;5.2*</td>
<td>1 min</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>&gt;5.44*</td>
<td>1 min</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>&gt;5.17*</td>
<td>1 min</td>
</tr>
<tr>
<td>Enterococcus hirae</td>
<td>&gt;5.18*</td>
<td>1 min</td>
</tr>
<tr>
<td>Enterococcus faecium</td>
<td>&gt;5.11*</td>
<td>1 min</td>
</tr>
<tr>
<td>Methicillin-resistant Staphylococcus aureus (MRSA)</td>
<td>&gt;5.53*</td>
<td>1 min</td>
</tr>
<tr>
<td>Carbapenem-resistant Acinetobacter baumanii</td>
<td>&gt;5.37*</td>
<td>1 min</td>
</tr>
<tr>
<td>Klebsiella pneumonia</td>
<td>&gt;5.22*</td>
<td>1 min</td>
</tr>
<tr>
<td>Clostridium difficile (vegetative)</td>
<td>5.1*</td>
<td>5 min</td>
</tr>
<tr>
<td>Vancomycin-resistant Enterococcus (VRE)</td>
<td>&gt;5.08*</td>
<td>5 min</td>
</tr>
<tr>
<td>Carbapenem-resistant Enterobacteriaceae (CRE)</td>
<td>&gt;5.33*</td>
<td>5 min</td>
</tr>
<tr>
<td>Candida albicans</td>
<td>&gt;4.09**</td>
<td>5 min</td>
</tr>
<tr>
<td>Candida auris</td>
<td>&gt;4.54**</td>
<td>5 min</td>
</tr>
</tbody>
</table>

* “Pass” according to BS EN 1276; Fantex® concentration 1-2%; dirty conditions

### Table 4 Test data according to BS EN 1276 and BS EN 1650 Quantitative suspension test for the evaluation of bactericidal (1276) and yeasticidal (1650) activity of chemical disinfectants and antiseptics

<table>
<thead>
<tr>
<th>Microorganism</th>
<th>Efficacy</th>
<th>Contact time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feline coronavirus</td>
<td>4.17 log reduction*</td>
<td>5 min</td>
</tr>
<tr>
<td>Influenza HK (A2)</td>
<td>0.15%**</td>
<td>10 min</td>
</tr>
<tr>
<td>Herpes simplex type 1</td>
<td>0.15%**</td>
<td>10 min</td>
</tr>
<tr>
<td>Vaccinia virus (smallpox)</td>
<td>0.15%**</td>
<td>10 min</td>
</tr>
<tr>
<td>Rotavirus (gastroenteritis)</td>
<td>0.1%***</td>
<td>5 min</td>
</tr>
<tr>
<td>Avian infectious laryngotracheitis virus</td>
<td>0.01%***</td>
<td>15 min</td>
</tr>
<tr>
<td>Avian herpes virus (Mareks disease)</td>
<td>0.01%***</td>
<td>15 min</td>
</tr>
<tr>
<td>Fowl pox virus</td>
<td>0.04%***</td>
<td>15 min</td>
</tr>
<tr>
<td>Transmissible gastroenteritis of swine virus</td>
<td>0.04%***</td>
<td>180 min</td>
</tr>
<tr>
<td>Foot and mouth virus</td>
<td>1.0%***</td>
<td>30 min</td>
</tr>
<tr>
<td>Feline calicivirus (norovirus surrogate)</td>
<td>0.1%**</td>
<td>5 min</td>
</tr>
<tr>
<td>Canine parvovirus (enteritis)</td>
<td>0.2%**</td>
<td>15 min</td>
</tr>
<tr>
<td>Avian influenza (H7N1)</td>
<td>2.0%***</td>
<td>30 min</td>
</tr>
<tr>
<td>Avian influenza (H5N1)</td>
<td>3.0%**</td>
<td>10 min</td>
</tr>
</tbody>
</table>

* “Pass” as tested according to BS EN 14476 Quantitative suspension test for the evaluation of virucidal activity in the medical area; Fantex concentration 1%

**Effective concentration of Fantex as assessed using quantitative surface testing
***Effective concentration of Fantex as assessed using quantitative suspension testing
disinfectant coating the disposable curtains. A large range of organisms (n=25) including bacteria, viruses, moulds and yeasts was tested. When tested according to BS EN 1276 (bactericidal) and BS EN 1650 (yeasticidal) standards, a dilution of as little as 1% Fantex® demonstrated a greater than log 5 and log 4 kill, respectively (Table 4).

The viricidal activity of Fantex® was tested according to BS EN 14476 and quantitative surface/suspension testing at a concentration of 1%. Fantex® showed good viricidal activity against the organisms tested, effective concentration depending on whether the test organism was enveloped and non-enveloped (Table 5).

The antimicrobial activity of Fantex® disinfectant curtains against a range of pathogens after several months of being hung within a hospital was also determined according to ISO 20743 and ISO 20645. The results showed high antimicrobial efficacy on curtains removed from hospitals at the end of their lifetime.

### Comparative Testing

Linen, untreated disposable, and antimicrobial disposable curtains were tested for contaminants to examine the impact of Fantex® on reducing contamination on the disinfectant curtains.

#### Disinfectant Curtains Vs Linen Curtains

Linen and Fantex® disinfectant curtains from an inner city hospital were sampled for contaminants. An average of 30 CFUs/paddle were observed for the linen curtains tested. Identification of the organisms ranged from CNS Staphylococcus species, S. aureus including MRSA, several colonies of mould, and several Gram negatives. Disinfectant curtains showed no measurable contamination after 6 months.

**Table 6** Curtains contamination analysis of a plain polypropylene disposable curtain (manufactured by Behrens) where ‘++’ = moderate/heavy growth; ‘+’ = light growth; ‘(+)=very light growth. The curtains showed moderate to heavy contamination of bacteria (cultured on TSA) and fungi (cultured on SDA) emanating from the fabric of sampled areas of the curtain. No contamination was found on the fabric samples of Fantex® Disinfectant Curtains

<table>
<thead>
<tr>
<th>Sample</th>
<th>Microbiological Condition</th>
<th>Identification of contaminants</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>++</td>
<td>Bacteria and fungi (Aspergillus niger, Aspergillus sp)</td>
</tr>
<tr>
<td>2</td>
<td>+</td>
<td>Bacteria and fungi (Aspergillus sp Beige mould)</td>
</tr>
<tr>
<td>3</td>
<td>++</td>
<td>Bacteria incl. Bacillus sp and fungi (Pink Yeast sp, Aspergillus sp)</td>
</tr>
<tr>
<td>4</td>
<td>(+)</td>
<td>Bacteria including Bacillus sp and fungi (Trichoderma sp)</td>
</tr>
<tr>
<td>5</td>
<td>(+)</td>
<td>Bacteria and Fungi (White mould)</td>
</tr>
<tr>
<td>6</td>
<td>+</td>
<td>Bacteria including Bacillus sp and fungi (Trichoderma sp, Aspergillus sp)</td>
</tr>
</tbody>
</table>
months of usage. Out of the 67 disinfectant curtains tested, only 1 colony of *Staphylococcus* species was observed. A further 40 curtains from the Emergency Room and ICU were tested and only 1 unidentified bacterial colony was observed.

**Disinfectant Curtains Vs Untreated Disposable Curtains**

Fantex® disinfectant curtains and untreated disposable curtains were removed from the ICU of Barnet Hospital (UK) after 4 months of hanging for comparative contamination testing by an independent accredited laboratory (MGS Laboratories Ltd). As demonstrated in Figure 4, there was no contamination emanating from the sampled Fantex® disinfectant curtain fabric; whereas the standard disposable curtains (manufactured by Behrens and Grosvenor) carried a considerable microbial load (Figure 4, Table 6).

**Fantex® Disinfectant Curtains Vs Antimicrobial Disposable Curtains**

A disposable curtain incorporating Microban® (Marlux) was obtained and tested to ISO 20645 alongside Fantex® fabric by an independent laboratory as set out in Table 7. The Microban® active constitutes particulate silver incorporated into the fabric. The manufacturer claims log 2 efficacy against a non-specific microorganism over a 24-hour contact time.

Silver containing curtains (Marlux and AG) were sent to Independent labs for verification of their antimicrobial activity and the results obtained indicate minimal activity within the timeframe required. Where as Fantex® Disinfectant Curtains achieved log >3.0 bactericidal activity in 1 minute of contact time, both silver containing curtains at best only achieved log 1.3 bactericidal activity after 18-24 hours of contact with pathogen (Table 7).

Furthermore, test microorganisms grew vigorously in contact with the Microban® fabric samples, failing to support the manufacturer’s efficacy claims. In contrast, the Fantex® fabric demonstrated ‘good effect’ against pathogens in contact with the sample and in the surrounding environment (illustrated by the zone of inhibition) (Table 8).

**Fingertip Transmission of Contaminants via Curtain Fabric**

In order to replicate an in-use scenario of the transfer of contaminants from curtains to fingertips, microbiological analysis of gloved fingertips was conducted after handling curtain fabric inoculated with *S. aureus*. The level of bacterial contamination applied to the curtains is typical of that observed on visibly clean hands. The difference in the level of contaminants transferred to fingertips after interaction with treated and untreated curtain fabric was also examined.

There was a dramatic decrease in the number of CFUs on the plates where gloved hands interacted with Fantex®-treated fabric when compared to those which interacted with untreated control fabric (figure 5). The test was repeated 3 times with 3 different volunteers and the same results were obtained for each repeat. Figure 5 shows a typical example of the results observed. In addition, further analysis demonstrated that, on gloved fingertips, a Log >4.7 reduction was achieved after interaction with Fantex®-coated fabric when compared to the untreated control fabric.

These results demonstrate that micro-organisms present on curtains can be transferred to the fingertips of those interacting with untreated curtains, but not to the fingertips of those interacting with disinfectant curtains (with zero CFUs resulting from interaction with disinfectant-coated fabric).

**HCAI Incidence Analysis**

The overwhelming majority of NHS hospitals utilised privacy curtains. A comparison of HCAI incidence reported by hospitals that had adopted Fantex® disinfectant curtains versus non-intervention hospitals using linen, plain disposable or other antimicrobial disposable curtains was performed.

85% of the hospitals that adopted disinfectant privacy curtains observed a reduction in HCAIs during the 12 months...
post-intervention. Of these hospitals, the median average reduction in HCAI incidence reported within the first year of intervention was 20.1%. Overall, a median average of 94 HCAI cases per hospital were recorded in the year prior to the introduction of disinfectant curtains, decreasing to 78 HCAIs in the year following their installation (Figure 6).

The significance of the 20.1% decrease in infection incidence reported by hospitals that implemented disinfectant curtains can be better contextualised when compared with the baseline reduction registered at hospitals without the intervention over the same period. The median reduction in infection incidence reported by hospitals within the non-intervention group was just 0.7% — a 28-fold lower reduction than reported by the intervention group hospitals that adopted disinfectant curtains (Figure 7).

**DISCUSSION**

**Infection Incidence and Mortality Rate Reporting**

A wide variety of microorganisms can cause HCAIs, leading to a range of different diseases. In the UK, reports estimate that 9% of all in-patients have a nosocomial infection at any one time; equivalent to at least 300,000 HCAIs per year, with an associated cost to the NHS of £1 billion [Public Health England 2016]. However, robust comparable data broken down by organism (other than for MRSA, MSSA, *E. coli*, *C. difficile*) are not currently available for the NHS in England. This makes it impossible to quantify with any certainty the impact of an infection control intervention or practice on HCAI incidence.

Likewise, an up-to-date and accurate report of the total number of patient deaths that may have resulted from HCAIs is unavailable because surveillance reporting for the incidence of all nosocomial infections is not yet mandatory. Indeed, there are still no robust comparable data on the extent and risks of at least 80% of healthcare-associated infections, and the annual HCAI treatment cost is acknowledged to be an underestimate [Public Accounts Committee 2009].

The latest mortality estimates for the NHS are taken from a report published in February 2000, in which the National Audit Office (NAO) performed a rough estimation that each year approximately 20,000 deaths (5,000 direct, 15,000 indirect) result from infections acquired during hospital stays [National Audit Office 2000]. Few NHS trusts have attempted to refine or validate these figures and they currently remain the only nationwide mortality estimate available.

More recent statistics on UK mortality show that there are an estimated 9,000 annual deaths due to *S. aureus* and *C. difficile* infections alone [National Institute for Health and Care Excellence 2014]. Although not all of these deaths can be attributed to nosocomial infections, the overall figure suggests that the original estimate from the NAO report is somewhat conservative in the context of the total number of deaths from HCAIs caused by all microorganisms.

Interestingly, similar reporting limitations exist in the US where the total annual cost of HCAIs to the US health system is considered to be as high as $45 billion [Centers for Disease Control 2009]. It is estimated that there are 722,000 HCAIs per year within US acute care hospitals [Centers for Disease Control 2018]. The latest mortality statistics are derived from the CDC’s HAI Prevalence Survey which estimated that 75,000 patients (11.5%) who contracted a nosocomial infection died during hospitalisation in 2011. However, this figure is extrapolated from a survey of only 436 HCAI cases [Centers for Disease Control 2018].

In both the US and the UK, the publishing of reliable mortality statistics shall remain elusive until respective health authorities mandate reporting on HCAIs as either a direct cause or contributory factor in all deaths in which deceased patients have previously been diagnosed with a nosocomial infection.

**Limitations of the HCAI Incidence Study**

Studies evaluating the impact of a singular component of a multimodal infection control program often share similar limitations. In addition to the issue of incomplete HCAI surveillance data and the absence of credible reports on associated deaths, the following limitations also exist for a study such as this one: firstly, the data obtained was not
Figure 6 Comparison chart of the number of reported HCAI cases in UK hospitals using Fantex® disinfectant curtains before and one year after introduction.

Figure 7 Comparison of the median HCAI reduction (in one year) between hospitals using Fantex® technology (marked as gray) vs hospitals that had not implemented this technology (marked as black).
Conclusion

This study reports that hospital intervention with Fantex® disinfectant curtains correlates with a median 20.1% reduction in HCAIs (versus a median 0.7% HCAI incidence decrease in the non-intervention group). Broad-spectrum residual Fantex® efficacy results in disinfectant curtains remaining free of contamination and considerably reduces the spread of contaminants to the hands of those that interact with them. Conversely, untreated alternatives are readily contaminated and act as fomites which propagate the spread of contaminants to hands upon contact. Further research is required to elucidate the precise degree of causation in the relationship between the demonstrated effectiveness of disinfectant curtains in reducing cross-contamination and the marked decrease in infection incidence reported by adopting hospitals.

However, it is important to note that the role of environmental contamination in the transmission of infection within hospitals is well established [Boyce 2007; Chemaly et al. 2014; Pyrek 2012]. Furthermore, in some studies, the extent of transmission has been found to be directly proportional to the level of environmental contamination [Chemaly et al. 2014; Dancer 2008; Trillis 2008], and improved cleaning/disinfection of environmental surfaces has been shown to reduce the spread of pathogens [Loveday et al. 2014].

Currently, the National Patient Safety Organisation’s (NPSA’s) Healthcare Cleaning Manual guidelines recommend, as a minimum, daily cleaning of the majority of areas within the near-patient environment, including: floors, bed rails, tables, furniture, doors, etc. However, these guidelines also recommend that, unless visibly soiled or stained, similarly frequently touched privacy curtains are to be changed at least every: 4 months in very high-risk areas, 6 months in high risk areas, 12 months in significant risk areas, and 2 years in low risk areas [National Patient Safety Agency 2009]. Although the CDC recognises privacy curtains to be a high frequency touch point surface neither they, nor the Occupational Safety and Health Administration (OSHA), make formal change-out recommendations. The CDC guidelines simply state that infection control practitioners must “coordinate an appropriate cleaning and disinfecting strategy” which leads to considerable variation in current policies between hospitals.

As privacy curtains are known to become contaminated with pathogens within a week of being hung [Ohl 2012] and have been implicated in a number of outbreaks [Klakus et al. 2008; Mahida et al. 2014; Shek et al. 2017; Trillis et al. 2008], changes to guidelines should be urgently considered in the interests of improving patient safety.

Changing linen or standard disposable curtains on a weekly basis is not a practical or cost-effective option, and this may contribute to the current compromise between protecting privacy and patient safety. The data described in this study indicate that disinfectant curtains with residual efficacy (≥Log 3 within 1 minute) effectively maintain patient dignity while reducing the environmental contamination associated with increased nosocomial infection incidence. Considering the impending AMR Crisis, these data warrant the consideration of IP&C practitioners engaged in modernising infection control programs to effectively sanitise the hospital environment and protect patients from drug- and multi-drug resistant pathogens.

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