Biocide resistance and transmission of *Clostridium difficile* spores spiked onto clinical surfaces from an American healthcare facility

Calie Dyer[1], Lee P. Hutt[2], Robert Burky[3], & Lovleen Tina Joshi[2 *#]

[1]Medical Microbiology, School of Medicine, Cardiff University, UK

[2]University of Plymouth, Faculty of Medicine & Dentistry, ITSMED, Plymouth, UK

[3]Adventist Health Hospital, Yuba City, California, USA

#Address correspondence to Tina Lovleen Joshi, tina.joshi@plymouth.ac.uk

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Abstract

Clostridium difficile is the primary cause of antibiotic-associated diarrhea globally. In unfavourable environments the organism produces highly resistant spores which can survive microbicidal insult. Our previous research determined the ability of *C. difficile* spores to adhere to clinical surfaces; finding that spores had marked different hydrophobic properties and adherence ability. Investigation into the effect of the microbicide sodium dichloroisocyanurate on *C. difficile* spore transmission revealed that sub-lethal concentrations increased spore adherence without reducing viability. The present study examined the ability of spores to transmit across clinical surfaces and their response to an in-use disinfection concentration of 1,000-ppm of chlorine-releasing agent sodium dichloroisocyanurate. In an effort to understand if these surfaces contribute to nosocomial spore transmission, surgical isolation gowns, hospital-grade stainless steel and floor vinyl were spiked with 1×10^6 spores/ml of two types of *C. difficile* spore preparations: crude spores and purified spores. The hydrophobicity of each spore type versus clinical surface was examined via plate transfer assay and scanning electron microscopy. The experiment was repeated and spiked clinical surfaces were exposed to 1,000-ppm sodium dichloroisocyanurate at the recommended 10-min contact time. Results revealed that the hydrophobicity and structure of clinical surfaces can influence spore transmission and that outer spore surface structures may play a part in spore adhesion. Spores remained viable on clinical surfaces after microbicide exposure at the recommended disinfection concentration demonstrating ineffectual sporicidal action. This study showed that *C. difficile* spores can transmit and survive between varying clinical surfaces despite appropriate use of microbicides.

IMPORTANCE

Applied and Environmental Microbiology

Clostridium difficile is a healthcare-acquired organism and the causative agent of antibiotic-associated diarrhoea. Its spores are implicated in faecal to oral transmission from contaminated surfaces in the healthcare environment due to their adherent nature. Contaminated surfaces are cleaned using high-strength chemicals to remove and kill the spores; however, despite appropriate infection control measures, there is still high incidence of *C. difficile* infection in patients in the US. Our research examined the effect of a high-strength biocide on spores of *C. difficile* which had been spiked onto a range of clinically relevant surfaces including isolation gowns, stainless steel and floor vinyl. This study found that *C. difficile* spores were able to survive exposure to appropriate concentrations of biocide; highlighting the need to examine the effectiveness of infection control measures to prevent spore transmission, and consideration of the prevalence of biocide resistance when decontaminating healthcare surfaces.

Introduction

The anaerobic spore-forming Gram-positive bacterium *Clostridium difficile* is the primary cause of antibiotic-associated diarrhea globally (1). *C. difficile* asymptomatically forms part of the microbiota of 1-3% healthy adults (2, 3); however, if the microbiota of the intestine is disrupted, for example as a result of broad- spectrum antibiotic treatment, colonisation of the colon by vegetative cells of *C. difficile* can proceed and escalate into the onset of *C. difficile* infection (CDI) (4). When fulminant infection ensues the patient will suffer from inflammation and diarrhoea. Further complications of CDI include pseudomembranous colitis, sepsis and the fatal toxic megacolon (5).

Hypervirulent PCR ribotypes such as BI/027/NAP1 have spread intercontinentally and caused epidemics in Western countries further adding to CDI incidence (6, 7). Many reports highlight the increasing impact of CDI to public health and the associated economic burden.

59 For example, mortality rates in the United States increased from 25 to 57 per million people
60 for the periods 1999-2000 and 2006-2007, respectively (8). In total approximately 14,000
61 deaths occurred in 2007 and this statistic increased still further with an estimated 29,300
62 deaths in 2011 (9). In 2008 alone the estimated cost related to CDI within the United States to
63 health-care facilities was $4.8 billion, ignoring the additional cost to other facilities such as
64 care homes (10). A similar pattern of statistics can be seen in England, with an increase from
65 1,149 *C. difficile*-related deaths in 2001 rising to 7,916 in 2007 (11).

66 In response to increasing CDI infection rates, stringent infection control procedures were
67 implemented within hospital environments in England which resulted in a decline in
68 mortality to 1,487 in 2012. This figure surpasses that of MRSA and non-specified
69 *Staphylococcus aureus* infection mortality (262 in 2012) (12) and thus is still a major source
70 of concern globally. Despite implementation of appropriate surveillance and infection
71 control procedures the organism still causing significant levels of morbidity and mortality
72 across nosocomial environments (13).

73 Incidence of CDI is directly affected by the ability of *C. difficile* to produce resistant spores
74 which can survive on organic and inorganic surfaces for months and remain viable (6). A
75 major source of CDI and transmission in the healthcare environment is through the faecal to
76 oral route; often via the contamination of surfaces. As many as 1×10^7 spores per gram faeces
77 are released into the environment by infected patients through airborne dispersal and soiling
78 further adding to the bioburden (14). Possible causes of transmission include inappropriate
79 biocide use, lack of adherence to infection control guidelines and varying standards of
80 practice across healthcare facilities globally (15, 16, 17).

81 Chlorine-releasing agents (CRAs) are the predominant form of biocide used in healthcare
82 facilities to disinfect surfaces; namely sodium hypochlorite (NaOCl) and sodium

dichloroisocyanurate (NaDCC) (18). These microbicides are fast-acting in aqueous solutions and are relatively inexpensive (19). Low concentrations of 50-ppm available chlorine have shown to kill >99% of vegetative bacterial cells *in vitro*. In addition, when 275-ppm chlorine was applied to a clinical environment there was a significant reduction in hospital-acquired infections from non-spore forming bacteria (20, 21). However, the inactivation of spores requires much higher concentrations with the current recommendation for application of NaDCC in hospitals in England being 1,000-ppm available chlorine for 10 minutes to deactivate spores of *C. difficile* and *Bacillus* species (22, 23). Although the working concentration of NaDCC has shown to be effective in liquid culture (24), its application to working surfaces is less efficient for inactivation of spores (25) and this reduced activity is exacerbated by the presence of organic substances, such as bodily fluids and faeces, which have a neutralising effect on the biocide (26). The mechanism of action of chlorine-releasing biocides is poorly understood; however, it has been suggested that their action may be due to strong oxidative ability, their effect on cell membranes and inhibition of enzymatic reactions (27).

Our previous study showed that adherence of *C. difficile* spores to inorganic surfaces increased when spores were exposed to sub-lethal concentrations (500-ppm available chlorine) of sodium dichloroisocyanurate (27). This increase was more pronounced for strain DS1748 (002 ribotype) which is not known to produce an exosporium outer layer (28) and suggests that when spores are exposed to sub-lethal levels of biocide they may inadvertently become more adherent to inorganic surfaces. The purpose of the present study was to assess the transfer ability of *C. difficile* spores from clinical surfaces pre- and post-biocide exposure. Surfaces tested include hospital isolation gowns, hospital grade stainless steel and vinyl flooring routinely used within the United States. Spore recovery from spiked clinical surfaces was investigated using a plate transfer assay. Clinical surfaces spiked with spores were

exposed to NaDCC to determine sporicidal efficacy and the presence of spores on each clinical surface pre and post NaDCC treatment was examined using scanning electron microscopy.

Results

Transfer of *C. difficile* spores from liquid form to hospital surgical gowns

To examine the ability of *C. difficile* spores (U and P derived from strains DS1748, R20291 and DS1813) to adhere to, and subsequently transfer from hospital surgical gowns, spores were applied directly to the surgical gowns in liquid for 10 s, 30 s, 1 min, 5 min and 10 min before being removed and discarded (Figure 1, Figure 4A and C). This experiment was designed to mimic transfer of infectious bodily fluids in the clinical setting and assess the potential for onward transmission to patients. There was no significant difference between the amount of spores (U and P) recovered from the gowns and the contact time of the spores to the gowns; suggesting that the process of spore transfer between surfaces occurred within the first 10 seconds of contact with the gown (two-way ANOVA; $p = 0.696$). From Figure 1 it appears as though the recovery of DS1748 P Spores increased with contact time; however, this was not statistically significant (one-way ANOVA; $p = 0.144$). Generally, U spore recovery was significantly higher than that of P spores (two-way ANOVA; $p < 0.001$); however, the exception to this trend was the increased recovery of DS1813 P spores when compared to U spores of the same strain (one-way ANOVA; $p < 0.001$). There were no significant differences in spore recovery between DS1748 and R20291 for either U spores or P spores.

Spore recovery from spiked clinical surfaces after direct contact with hospital gowns

131 To establish whether hospital-grade stainless steel surfaces and vinyl flooring surfaces act as
132 fomites for *C. difficile* spore transmission in the clinical setting, sterile sections of hospital
133 surgical gowns were placed in direct contact with hospital-grade stainless steel and vinyl
134 flooring spiked with 1 x 10^5 spores and spore recovery from the surgical hospital gowns
135 assessed. The contact times were reduced to 10 s, 30 s and 1 min due to results presented in
136 Figure 1 which confirm that the length of contact time had no significant effect on spore
137 recovery. Similarly, there remained no significant difference in spore recovery from steel and
138 vinyl between the contact times used and the amount of spores recovered from the strains
139 examined (Figure 2) (two-way ANOVA; $p = 0.892$ and $p = 0.904$ for steel and vinyl,
140 respectively). Spore recovery of U DS1748 was significantly higher from both stainless steel
141 surfaces (one-way ANOVA; $p = 0.034$) and vinyl flooring (one-way ANOVA; $p < 0.001$)
142 when compared to the other strains. DS1748 P spore recovery was higher on stainless steel
143 (one-way ANOVA; $p < 0.001$) and vinyl flooring (one-way ANOVA; $p < 0.001$) than of
144 R20291 and DS1813. DS1748 P spore recovery was approximately 10-fold higher than that
145 of the U Spore equivalent (two-way ANOVA; $p < 0.001$).
146
147 **Sporicidal efficiency of sodium dichloroisocyanurate (NaDCC)**
148 Two types of spore suspension from three *C. difficile* strains (DS1748, R20291 and DS1813)
149 were exposed to the recommended in-use concentration of NaDCC in solution (1,000-ppm)
150 and spore viability was determined. From Figure 3 it can be seen that there was no recovery
151 of spores which had been treated in liquid form and then spiked onto gowns. Moreover,
152 recovery of NaDCC-treated U spores from the spiked and directly-treated hospital surgical
153 gowns were lower across the three strains tested when compared to non-treated spores, with
154 the lowest relative recovery from strain R20291 (Student t-test; $p < 0.005$). Scanning Electron
155 Microscopy (SEM) images in Figure 4A and 4C support this by showing adhered spores on

the fibres of the gowns from strain R20291 before and after treatment with the recommended concentration of NaDCC. Interestingly, Figure 4B shows a single P spore of R20291 after NaDCC treatment with a visible exosporial layer, while Figure 4D shows a U spore of R20291 after treatment that has no visible evidence of an exosporial layer. These differences in spore exosporium show distinct morphological variations within the R20291 strain; but may not necessarily be as a result of NaDCC exposure. It is possible that any damage to the exosporium after NaDCC exposure is not visible via SEM (Figures 4B); thus there is a possibility that NaDCC may have chemically altered the exosporium structure without changing the spore's overall three-dimensional appearance (28).

Decreased sporicidal activity was observed for strains tested with NaDCC on the varying clinical surfaces (Figure 3). Similar results were observed with DS1813 P spores, but not for P spores of DS1748 and R20291. There was detectable recovery of R20291 U Spores (~73 to ~23 SFU) after NaDCC treatment on stainless steel; although this was not significantly different when compared to the lack of recovery of the other U strains tested (Mann-Whitney Test; $p = 0.40$). Despite the lack of DS1813 spore recovery from stainless steel surfaces after NaDCC exposure (Figure 3C), spores were still present on the steel surfaces indicating lack of viability (Figure 5A).

After NaDCC exposure no DS1748 or R20291 P spores were recovered from the vinyl flooring, whereas U spores from these strains were recovered (Figure 3A and B). SEM results revealed the presence of spores of both types on the vinyl (Figure 5B and D). The recovery of R20291 U spores significantly decreased (Student's t-test; $p = 0.001$) but not for DS1748 (Figure 3A and B). In contrast, the recovery of both U and P spores of DS1813 did not change significantly after NaDCC treatment (Student's t-test; $p > 0.05$ for both U spores and P spores; Figure 3C).

Discussion

Gowns have been used by healthcare professionals to mitigate the risk of transmitting infectious materials between patients, hospital visitors and other healthcare workers (31). Many gowns have shown differences in barrier and textile performance and it is these variations that play a role in the dissemination of microorganisms across healthcare facilities (32). With the advent of modern technology single-use isolation gowns made from fluid-resistant materials, such as polypropylene, are now widely used as a form of barrier protection; however, there is some debate as to their efficiency (31, 33, 34). Our results demonstrated that *C. difficile* spores were able to transfer and adhere to fibres of the polypropylene spun gowns when spiked in a liquid medium. As there was no significant difference between the contact time of the spores and the recovery of spores from the gown, it appears as though the process of spore transfer occurred rapidly within the first 10 seconds of contact when examining spore recovery from spiked liquid, hospital grade stainless steel and vinyl flooring, respectively. This suggests a clear need to ensure appropriate decontamination of surfaces that a contaminated gown may come into direct contact with in a clinical setting.

The ability of microorganisms to travel through fabrics is related to the physico-chemical properties of the gowns and the characteristics of the microorganism (32). Another interesting observation from this study is the rapid ability of the spores to move from one hydrophobic surface to another hydrophobic surface i.e. fluid-resistant gowns and stainless steel which suggests that the more hydrophobic spores interacted better with the stainless steel surfaces than the gowns (Table 1, Figure 1). Whether this is related to steel surface structure as opposed to gown structure, or the hydrophobic interactions between (i) the individual strains (which possess varying relative hydrophobicity; Table 1) (ii) the liquid and (iii) each test surface warrants further investigation at the molecular level. It is also clear that the single-use

gowns act as fomites for *C. difficile* spore transmission. Not only do spores of all strains rapidly attach to the gown fibres from liquid and dry clinical surfaces but the single-use gowns are then ineffective at trapping spores within their fibres and preventing the onward transmission of spores as demonstrated by spore recovery from the gowns (Figures 1& 2). While this ability differs between strains, it does suggest that the adherence ability of the spore to individual gown fibres may be affected by spore hydrophobic properties and exosporium layer which is known to aid spore adherence on hospital surfaces (Table 1; 28). Results also suggest that *C. difficile* spores, after microbicidal exposure to NaDCC at the recommended contact time and concentration, can continue to remain viable, adhere and transmit via hospital gowns (Figure 4A & 4C; 1, 28, 35). This highlights the importance of ensuring that single-use surgical isolation gowns are used appropriately in infection prevention and control; i.e. that gowns are adorned upon entering and disposed of when exiting a single room to prevent onward spore transmission and incidence of CDI (36).

Despite using recommended concentrations of NaDCC to decontaminate gowns, stainless steel surfaces and floor vinyl after spore exposure, spores were still visibly attached to each surface and were viable upon culture (Figures 4 & 5). Decontamination and appropriate cleaning of surfaces is critical in managing the spread of CDI to patients from spores (37). It can be speculated that the hydrophobic properties and weave of the gown fabric may have prevented exposure of spores to NaDCC which explains the increased spore recovery; however this would need to be examined further by exploring the use of fluorescence-based spore viability tests (38). The smooth surfaces of steel and vinyl would theoretically make NaDCC treatment more effective by increasing the test surface area; however, the occurrence of viable spores on both treated steel and vinyl surfaces conflicts with this hypothesis and clearly evidences spore resistance to NaDCC. This resistance was found for all three strains tested and was not limited to hypervirulent R20291 027 PCR ribotype strains (7) (Table 1).

Our results confirm that working concentrations of sporicides (with active concentrations of chlorine) applied at the appropriate contact times may not kill *C. difficile* spores. The ability of microbicides, such as CRA's, to kill *C. difficile* spores has been examined previously with similar results (7, 25, 26, 38).

Spores which possess an exosporium-like structure have been demonstrated to have increased adhesion to surfaces *in vivo* and *in vitro*; associated with increased hydrophobicity of the spore (28, 35, 39). The exact function of the exosporium-like structures on certain strains of *C. difficile* spores has yet to be fully elucidated; however, its role in adhesion to intestinal mucosal cells and in *Bacillus* spore adhesion has been more clearly defined (35, 39, 40). Our previous study established that exosporium-positive spores (DS1813) were more resistant to NaDCC at sub-lethal concentrations than exosporium-negative spores (DS1748) (1, 28), which appears to correlate with the theory that the exosporium layer confers a protective barrier to the spore, preventing it from being damaged (41). It has also been hypothesised that exposure of spores to NaDCC at inappropriate concentrations and contact times can alter and increase spore adhesion ability (1). In the present study, while we observed a lack of exosporium-negative DS1748 and exosporium-positive DS1813 spore recovery from hospital stainless steel, SEM image (Figure 5A) revealed the presence of DS1813 spores adhered onto the stainless steel surface, and the presence of possible damaged spores of DS1748 (Figure 5C). Indeed, the presence of a small number of spores following NaDCC treatment could still produce recovery of zero viable spores. Moreover, the viability of spores from all strains tested was also observed after NaDCC treatment of vinyl flooring (Figure 3). This strongly indicates that recovery of spores from stainless steel and vinyl, two very different materials, has been affected by biocide exposure, either due to biocidal killing or reduced spore adherence; however, the exact mechanism of spore adherence and biocidal activity of NaDCC upon the exosporium layer and spore ultrastructure has yet to be determined.

255 As seen in Figures 4 and 5, there are exosporium-like projections present on R20291 spores
256 that increase the material surface-spore contact area which correlates to data from other
257 studies (41). It is possible that these projections may increase spore adherence and perhaps
258 biocide resistance by protecting the core from chemical effects. Moreover, as NaDCC was
259 completely effective when spores were exposed in liquid form (Figure 3) when compared to
260 the spore recovery post exposure from spiked surfaces, attests to the potential the exosporium
261 may have for protection of the spore from biocide exposure. Interestingly, hypervirulent
262 DS1813 and R20291 strains have shown an increased adherence ability throughout this study
263 comparative to DS1748; suggesting exosporium- positive spores adhere better and more
264 rapidly with first-contact to the test surface (Table 1). Additionally, unpurified R20291 spores
265 were recovered from all surfaces tested post-NaDCC exposure which demonstrates the
266 spore's ability to remain viable after biocide exposure (Fig 2 & 3). This concurs with
267 previous studies that have demonstrated CRA resistance in PCR Ribotypes 017, 012 and 027
268 (R20291) (7). Mechanical removal to remove spores from clinical surfaces has been shown to
269 be effective in studies, however, this may not be appropriate with gowns as they are designed
270 for single-use; therefore effective and immediate disposal of surgical gowns after use needs
271 to be considered when preventing transmission of CDI (6, 25). The impact of the microbicide
272 upon spore structure and resistance warrants further research to fully understand the
273 mechanisms of resistance and to establish up-to-date and effective decontamination
274 protocols. Moreover, our research suggests that the *C. difficile* exosporium may play a key
275 role in biocide resistance of spores and thus could be a potential target for development of
276 novel sporicidal disinfectants.

277 **Materials and Methods**

278 **Growth conditions, *Clostridium difficile* strains and spore production**

279 *C. difficile* cultures were incubated anaerobically at 37 ^{o}C for 48 hours in a BugBox Plus
280 anaerobic workstation (Ruskinn Technology Ltd. United Kingdom) using an 85% nitrogen,
281 10% carbon dioxide and 5% hydrogen gas mix. Clinical isolates of *C. difficile* (PCR
282 Ribotypes 027 and 002) used in this study are described in Table 1 and were obtained from
283 the Anaerobic Reference Unit, University Hospital Wales, Cardiff, UK. Unless otherwise
284 stated, all organisms were stored as spores at 4 ^{o}C. All experiments described were conducted
285 in triplicate. *C. difficile* spores were produced according to two methods to generate
286 unpurified/crude and purified spore preparations; spores produced *via* Perez et al 2005 (42)
287 methodology were designated as unpurified (U) spores due to being harvested via water-
288 washing and containing vegetative and spore forms of the organism. These were deemed
289 representative of *C. difficile* commonly encountered within clinical environments. Spores
290 were produced on reduced brain heart infusion (BHI) agar and BHI broth (Oxoid Ltd,
291 Basingstoke, United Kingdom) each supplemented with the germinant 0.1% (w/v) sodium
292 taurocholate (28).

293 Purified spores (P spores) were produced as described by Sorg and Sonenshein (2010) (43).
294 Briefly, *C. difficile* strains were cultured on reduced BHI agar with 5 g/L yeast extract and
295 0.1% L-cysteine and were examined after four days anaerobic incubation for characteristic
296 colonies. Spores were harvested using sucrose density-washing. Spore purity was confirmed
297 via phase contrast microscopy. Spore concentration was determined via drop count as
298 described by Miles *et al*. (44) and mean spore-forming units (SFU) per ml calculated (28).

299 **Preparation of clinical surfaces**

300 Single–use hospital surgical gowns were produced by MediChoice, order no. 77752XL (45),
301 made from fluid-resistant spunbond-meltdown-spunbond (SMS) polypropylene laminate at
302 AAMI PB70:2012 (46) standard at level 2. To test the transfer of spores to and from the

gowns, gowns were aseptically cut into 7×7 cm sections and testing performed within a drawn circle of 2 cm diameter to confer with the surface area of the hospital grade 2B stainless steel discs and vinyl flooring used in this study.

Spore Transfer to Hospital Surgical Gowns

To test the number of spores transferred to the hospital surgical gown after direct contact, U Spores and P Spores from strains DS1748, DS1813 and R20291 (Table 1) were produced at 1 x10^4 spores/ml. From these, 100 µl were spiked onto the gown surface in triplicate experiments and allowed to remain in static contact for 10 s, 30 s, 1 min, 5 min and 10 min before being removed and discarded. After contact with spores, each section of gown was aseptically mounted onto a plunger pre-affixed with a steel disc so that the disc was aligned with the test area. A plate transfer test was then performed as described in Joshi *et al*., (28). A force of 100g was used as a simulated "touch" pressure.

Spore Transfer from spiked "high-touch" surfaces to Hospital Surgical gowns

To test the number of spores transferred to the surgical hospital gown from dry "high-touch" surfaces (hospital grade stainless steel and vinyl flooring), U and P spores were produced at concentrations of 1 x10^6 spores/ml. Sterilised hospital grade steel discs and vinyl flooring were inoculated with 100 µl of spores and allowed to dry completely for 120 min in a Category 2 Biosafety laminar flow cabinet. Sections of gown were then placed in contact with the steel and vinyl under 100g pressure for 10 sec, 30 sec and 1 min and the gown was then pressed onto the appropriate agar plate for 10 sec at 100 g pressure (28). All agar plates were then incubated for 48 hrs at 37 ^oC under anaerobic conditions. Following incubation colonies were counted and SFU per ml were calculated.

Exposure of Spores to Sodium Dichloroisocyanurate disinfectant

Spore suspensions (U and P) from strains DS1748, R20291 and DS1813 at a concentration of 1 x 10^6 spores per ml were exposed to 1000-ppm NaDCC for 10 minutes in liquid form (recommended contact time), neutralised with sodium thiosulfate and deposited onto sterile gowns. Spores were recovered as described previously (1, 22). Secondly, spores were also spiked onto the gown surface, as described in the spore transfer section above, and spores were spiked onto the surfaces of hospital stainless steel and hospital vinyl flooring, respectively, for each biological repeat and allowed to dry for 120 min in a Category 2 Biosafety laminar flow cabinet. The three spiked surfaces were then directly exposed to 100µl NaDCC at 1000-ppm for 10 minutes and neutralised with 1% sodium thiosulphate before plate transfer experiments were performed and spore recovery recorded. Three technical repeats of each experiment were performed. Control experiments where spores were exposed to sodium thiosulfate, sterile deionised water and NaDCC alone were also performed.

Scanning electron microscopy

Gowns, steel and vinyl were analysed using scanning electron microscopy for the presence of characteristic spores before and after treatment with NaDCC. Spores which had not been exposed to NaDCC were used as a comparative control. Test surfaces were sputter coated with metal using a gold palladium sputtering target (60% Au and 40% Pd from Testbourne Ltd) and argon as the sputtering gas. Images were taken on a scanning electron microscope (Zeiss Sigma HD Field Emission Gun Analytical SEM) using an accelerating voltage of 5 kV. Over 100 individual spores were viewed per sample at magnifications of x 4, 890 and x 83,380.

Statistical Analysis

Data are expressed as means ± SEM. Paired T-tests, One way ANOVA, 2-way ANOVA and Mann-Whitney U tests were performed using Minitab 17.

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Tables: Table 1 *Clostridium difficile* strains used in the present study.

C. difficile strain	PCR Ribotype	Source	Exosporium Presence	Relative Hydrophobicity
DS1813	027	Hinchingbrooke	Positive	77%
R20291	027	Stoke-Mandeville	Positive	62%
DS1748	002	Leeds	Negative	14%

Figure legends

511 Figure 1: Recovery of two different *C. difficile* spore types (Unpurified [U] and Purified [P])
512 from spiked hospital surgical gowns. Spores were derived from strains DS1748, R20291 and
513 DS1813 and spores recovered after being exposed to the gowns at contact times ranging from
514 10 s to 10 min. Plots represent mean ± SEM (n = 3).

515 Figure 2: Transmission ability of two different *C. difficile* spore types between clinical
516 surfaces. Spores derived from strains DS1748, R20291 and DS1813 were spiked onto
517 hospital stainless steel and vinyl surfaces and their ability to transfer to hospital surgical
518 gowns was tested. Unpurified (U) and purified (P) spores were recovered via transfer test
519 from (A) hospital grade stainless steel and (B) hospital vinyl flooring using hospital surgical
520 gowns applied at a pressure of 100g. Contact times ranged at 10s, 30 s and 1 min. Plots
521 represent mean ± SEM (n = 3).

522 Figure 3: Recovery of unpurified and purified *C. difficile* spores from spiked clinical
523 surfaces after treatment with 1000-ppm NaDCC for 10 min. Transfer testing was used to
524 recover U and P spores of *C. difficile* strains (A) DS1748, (B) R20291 and (C) DS1813 from
525 hospital surgical gowns after contact with: spores suspended in NaDCC applied to sterile
526 gown, spiked gown exposed to NaDCC, spiked hospital stainless steel and hospital vinyl
527 flooring exposed to NaDCC. The inoculum was used as the positive control (water only) and
528 was also suspended in sodium thiosulfate to ensure no cross reactivity. Plots represent mean
529 ± SEM (n = 3).

530 Figure 4: Scanning electron micrographs of *C. difficile* spores present on spiked hospital
531 surgical gowns before and after treatment with NaDCC at 1,000-ppm for 10 min. Images
532 depict untreated (A) R20291 U spores on surgical gown fibres and (B) R20291 P single spore
533 and NaDCC treated (C) R20291 U spores on surgical gown fibres, (D) R20291 U single
534 spore. Arrows highlight spores adhered to gown fibres before (A) and after NaDCC treatment

in (C), and morphological changes in exosporium before (B) and after NaDCC treatment (D). Scale bars in B and D are 200 nm, in A 2 µm, and in C 10 µm.

Figure 5: Scanning electron micrographs of *C. difficile* spores present on spiked hospital stainless steel and floor vinyl before and after treatment with NaDCC at 1,000 ppm for 10 min. Images are NaDCC-treated (A) DS1813 P spores on stainless steel; (B) DS1748 U Spores on floor vinyl; (C) DS1748 U spores on stainless steel and (D) R20291 U spores on floor vinyl. Arrows highlight areas in the exosporium layer. Scale bars in A, B and D are 1µm, and in C 200 nm.