"Evaluation of improved housekeeping compliance and the use of microfibre cleaning cloths on reducing environmental reservoirs of antibiotic resistant organisms and *Clostridium difficile* in health care facilities"

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II. Dedications

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1. Abstract

Contaminated environmental surfaces can be a means of transmission of *Clostridium difficile* spores in health-care facilities.

The study objectives are to assess the value of the UV marker as an audit tool for improving housekeeping compliance and to compare microfiber and cotton cloths for removal of *Clostridium difficile* spores from surfaces.

A lotion visible only under short-wave UV light (UV Marker) was applied to different surfaces within the patient's washrooms on consecutive week days, over a twenty-four week period. The Study included three Arms: Arm one: the staff received feedback during the 24 week period, Arm two received feedback for the first 12 weeks and Arm three was given feedback for the last 12 weeks based on UV Marker results. Viable counts were used to assess the efficiency of microfiber and cotton cloths in removing and retaining *Clostridium difficile* spores.

The visual audit resulted in a cleaning compliance of 55%; whereas, feedback with the UV Marker led to a housekeeping compliance of 90%.

Microfiber cloths were found to be superior in removing and retaining *Clostridium difficile* spores.

The UV marker is a better audit tool than visual inspection for improving cleaning compliance of housekeeping staff. The use of microfiber cloths may enhance efficiency of microbial removal during surface cleaning.

2. Introduction

2.1. Overview of environmental issues related to nosocomial transmission.

Some medical conditions require long term hospitalization. As a result, patients are exposed to colonization or even infection with healthcare-associated pathogens. (Eckstein *et al*., 2007). These patients can often spread these microbes from their skin and mucosa, into the environment (Eckstein *et al*., 2007). Although it is generally considered that carriage of micro-organisms on the hands of healthcare workers after direct contact with infected patients could be an important source for cross-contamination between patients, some recent studies demonstrated that contaminated environmental surfaces can be an additional means of transmission of some healthcare-associated pathogens (Eckstein *et al*., 2007, Boyce, 2007).

Different variables can be responsible for the transmission of pathogens in a health-care setting from the environment to the patient, such as the capability of certain pathogens to survive on dry surfaces in the environment, the probability of being in contact with patients and hospital staff, and the concentration of the microorganism available to be transmitted to patients. (Boyce, 2007). Several investigators have demonstrated that the transmission of nosocomial pathogens can be diminished by reducing the environmental source (Boyce, 2007; Martinez *et al.*, 2003).

2.2. Microorganisms involved in health-care associated infections.

Methicillin Resistant *Staphylococcus aureus* (MRSA), Vancomycin Resistant Enterococcus (VRE), and *Clostridium difficile* can remain in a viable state on dry surfaces for long periods of time (Martinez *et al.*, 2003).

2.2.1. Vancomycin resistant enterococcus (VRE)

These organisms acquire resistance to Vancomycin through horizontal transmission rather than selection from susceptible population of bacteria. The finding of these bacteria in a given unit is the consequence of the presence of patients who were colonized before the admission to the healthcare facility. Environmental contamination may eventually increase the rate of infection or colonization with VRE as a result of cross-contamination between patients in the hospital environment. (Martinez *et al.*, 2003).

The list of risk factors for infection with VRE include among others, enteral feeding, the use of some antibiotics such as vancomycin, cephalosporins, and proximity to another VRE colonized or infected person. Also rooms with contaminated high- touch surfaces could be a potential source of contamination with VRE. (Martinez *et al.*, 2003). Outbreaks of VRE have occurred in different facilities after direct transmission from improperly cleaned equipment to patients, such as rectal thermometers probes, electronic ear probe thermometers and contaminated EKG leads. (Boyce, 2007).

A retrospective case-control study concluded that patients, placed in a room where VRE contamination from the environment persists, were at increased risk than controls to acquire VRE infection. These findings suggest that adequate cleaning of the patient's rooms may prevent transmission of pathogens between patients. (Boyce, 2007)

A study has been carried out in the MICU, at the New England Medicine Center; Boston, Mass. PFGE typing on the isolates demonstrated that patients who were colonized by VRE during the time they stayed in MICU and a smaller group of patients who showed colonization with VRE on admission differ only in one band from each other; or, in most of the cases were identical (type 1). The environmental isolates belonged to type 1 or type 2 classifications. They were obtained in a room from a light switch, a toilet flusher, a bath faucet and a telephone handle. Type 1 strain was isolated from a patient who stayed in that room for a month (Martinez *et al.*, 2003). As a result of these findings a meticulous cleaning protocol was put in place. No isolations of VRE were obtained from the environment in this MICU unit after the intervention (Martinez *et al.*, 2003).

2.2.2. Methicillin-resistant *Staphylococcus aureus* (MRSA).

Health care workers are often exposed to the microorganisms present in the environment; even though they may not be in direct contact with infected patients, they can carry the bacteria on their gloves after touching contaminated surfaces in patients rooms infected with MRSA. (Boyce, 1997). Some studies demonstrated that patients who had been in contact with contaminated equipment such as ultrasonic nebulizers or contaminated ventilation grills acquired Methicilin Resistant *Staphylococcus aureus* (MRSA) infection. (Boyce, 2007).

An interesting study was evidence for the important contribution that the environment makes to the spread of microorganisms in the healthcare setting. Bhalla *et al*. (2004) reported that volunteers contaminated their hands with *Staphylococcus aureus* after touching bed rails and overbed tables in patients rooms.

Interestingly, another group of volunteers touched the same kind of surfaces in non-occupied rooms after patients discharge and final cleaning. The percentage in hands contamination compared to the first group was significantly lower. (Bhalla *et al.*, 2004).

The origin of the staphylococcal infection remains unknown. An important source could be the intestinal colonization with *S. aureus*. The presence of this microorganism in the stool of hospitalized patients could become the reservoir that is shed to other skin sites and the environment, including surfaces and medical devices (Bhalla *et al.*, 2007) . It is thought that virulent strains might be more prone to colonize the intestine and the skin sites. To better understand the connection between intestinal colonization by *S. aureus* and increased infection of the skin sites, a study has been carried out (Bhalla *et al.*, 2007). The researchers found that 77% of the participants carried *S. aureus* in stool and 88% concomitantly carried S. *aureus* in nares. These results revealed that patients with nares and intestinal colonization were expected to acquire skin infection more easily than those carrying *S. aureus* only in their nares (Bhalla *et al.*, 2007). The latter group of patients had less chance to contaminate the environment than the former; yet, devices and wounds may become infected after contacting the patient's skin. They hypothesized that colonization of the intestinal tract with *S. aureus* may be a potential source of environmental contamination. (Bhalla *et al.*, 2007).

2.2.3. Clostridium difficile

2.2.3.1. *C.difficile*: background

Clostridium difficile is an opportunistic emerging nosocomial pathogen. This anaerobic, spore-forming bacillus can produce two types of toxins that damage the gastrointestinal tract cell wall, disruption of the bowel normal flora allowing *C. difficile* to survive in a niche and to produce toxins causing a variety of medical conditions from mild self-limiting diarrhea to more serious manifestations such as pseudo membranous colitis, toxic megacolon and bowel perforation (Whitaker *et al.*, 2007, Blossom and Donald, 2007). These diseases are collectively known as *C. difficile*-associated disease (CDAD) (Blossom and Donald, 2007). In Manitoba, *C. difficile* has been a reportable organism since April 2006. Manitoba Health, Communicable Disease Control Branch reported 844 cases of CDAD as of December 2009 (Manitoba Health Communicable Disease Control, February 2010).

2.2.3.2. *C. difficile*-associated disease (CDAD)

C. difficile constitutes the most frequent cause for antibiotic-associated disease. It is commonly found in elderly patients with watery stools who have been receiving antibiotics for a persistent medical condition. This complication was not considered a disease entity in the past, but a side effect of antimicrobial administration to the patient (Blossom and Donald, 2007).

2.2.3.3. *C. difficile*: toxins

Toxins A (enterotoxin) and B (cytotoxin) are associated with different pathogenicity mechanisms. There is evidence of the production of a binary toxin (CDT) by hypervirulent

strains of *C.difficile,* resistant to fluoroquinolones. While CDT causes more severe disease and increases the mortality rates, its role in *C. difficile*-related infections is currently unknown. (Carter *et al.*, 2007).

2.2.3.4. *C. difficile*: epidemic strain

The recent increase of CDAD in Quebec hospitals and various sites in the United States was determined to be caused by the presence of a hypervirulent strain responsible for multiple outbreaks of infection in different hospital settings. It was typified as North American Pulse Type 1, restriction enzyme analysis type BI and PCR ribotype 027 (NAP 1/BI/027) (Blossom and Donald, 2007). NAP 1 can produce the large amount of clostridial toxins A and B in addition to the binary toxin. The role of this toxin in human disease needs to be identified. Regardless, the origin of the increased virulence of this strains due to enhanced production of Toxin A and B, presence of binary toxin or an unknown virulence factor, NAP1/BI/027 seems to cause more severe clinical disease than other strains (Blossom and Donald, 2007).

2.2.3.5. *C. difficile*: role of sporulation in environmental contamination

The oral route is the most common means of transmission of *C. difficile* infection. After ingestion, the vegetative form does not survive the acid pH of the stomach. Only 1% of the ingested inoculum reaches the small bowel, initiating intestinal colonization and producing toxin-mediated diarrhea (Poutanen and Simor, 2004).

C. difficile spores are resistant to the acid environment so they can easily pass through the stomach to finally germinate in the small intestine where bile acids were thought to be responsible for inducing the conversion of spores to vegetative forms (Jump *et al.*, 2007, Poutanen and Simor, 2004)

Vegetative forms are susceptible to aerobic conditions; therefore after causing disease, they may die if they are shed in feces, or they may switch to a spore form, as a way of adapting to unfavorable environmental conditions (Jump *et al.*, 2007). The sporulation rate is defined as the fraction of a cell population that switches to spore form. (Fawley *et al.*, 2007). It is worth noting that spore forming pathogens are the most common microorganisms present in the environment.

While vegetative and spore forms of *C. difficile* can be spread from colonized patient's stools to the environment, the spore form will prevail in adverse conditions such as presence of oxygen, drying and exposure to disinfectants (Fawley *et al.*, 2007). A study demonstrated that sporulation rate for non-epidemic strains are lower than that of epidemic strains of *C.difficile* (Fawley *et al.*, 2007). The vegetative form was found susceptible to cleaning agents and germicides at a strong working concentration; conversely, only chlorine at 5000 ppm could effectively kill spores (Fawley, 2007). When the strains were not exposed to any cleaning agent or germicide, the mean sporulation rate, was significantly lower than in strains exposed to agents containing detergent alone, a combination of detergent and hypochlorite, or hydrogen peroxide (Fawley *et al.*, 2007). These findings suggest that agents that do not kill *C. difficile* spores at recommended concentrations may induce the persistence of spores in healthcare settings. (Fawley *et al.*, 2007).

Some research findings support the idea that *C. difficile* asymptomatic carriers and patients with CDAD may contribute near evenly to environmental contamination (Riggs *et al.*, 2007). Asymptomatic carriage may reach high levels in outbreaks, especially in patients who require long term hospitalization and recurrent antibiotic treatments (Riggs *et al.*, 2007). It is considered that surfaces in rooms that accomodate asymptomatic patients could be an important source of

C. difficile spores. Therefore, during outbreaks the cleaning of these particular rooms should be thorough enough and include the use of a sporicidal cleaning agent (Riggs *et al.*, 2007). Other infection control implications such as placing the infected patients for sufficient time in contact precautions rooms, should be taken into account in the circumstance of an outbreak (Riggs *et al.*, 2007).

2.2.3.6 Environmental cleaning: impact on the incidence of Antibiotic Resistant Organisms (AROs)

Many health care facilities noted an increase in *C. difficile*-associated disease cases starting in 2003. This raise in the incidence of AROs led the infection control department at the University Community Hospital in Tampa, Florida, to determine the origin of this infection, to set up a new protocol to impede *C. difficile* transmission and finally to reduce the number of patients with CDAD in the hospital environment (Whitaker *et al.*, 2007). One probable factor responsible for such increase in CDAD cases might have been the use of disinfectants with poor activity on AROs. However, some studies reported that terminal cleaning was not successful in eradicating hospital- associated pathogens from the environment, regardless of the potency of the cleaning agent in use (Carling *et al.*, 2008a).

This dilemma will never be resolved, if housekeeping personnel do not improve the thoroughness of daily cleaning and the compliance with healthcare setting's cleaning protocols. (Alfa *et al.*, 2008; Carling *et al.*, 2008a). Moreover, the fact that improving cleaning services helped to stop outbreaks of *C. difficile* and MRSA infections, provides an evidence for the connection between environmental contamination with *C. difficil*e and the transmission of these hardy bacteria (Carling *et al.*, 2005, Tomiczek and Downey, 2006).

In order to evaluate the implications of an adequate terminal cleaning in patients rooms before another patient was admited, Eckstein *et al.*, 2007 performed baseline cultures that were obtained from different surfaces within the patients environment. Housekeeping staff received information on the culture results and educational intervention. This group of researchers found that before the intervention, 80% of the rooms of patients with VRE infection had one or more environmental cultures positive, these results came back negative from the Laboratory after the cleaning protocol was changed. The resolution to take action in order to improve the quality of the cleaning service, was crucial in starting a favourable change in cleaning thoroughness and improved maintenance of high touch surfaces (Eckstein *et al.*, 2007)

2.3. Monitoring compliance with housekeeping protocols.

While the important role that thorough environmental cleaning might play in eliminating or reducing the cases of hospital-associated pathogens infections has been reported by previous studies (Carling *et al.*, 2005, Carling *et al.*, 2007, Carling *et al.*, 2008a, Carling *et al.*, 2008b, Boyce, 2007, Martinez . 2003, Tomiczek and Downey, 2006, Dettenkofer and Spencer, 2007)

the impact of a sustainable change in the attitude of hospital housekeeping personnel requires further investigation.

A prospective study by Alfa *et al.*, (2008) compared compliance with housekeeping protocols for rooms of patients with CDAD who were on isolation precautions with the cleaning compliance in the rooms of patients who had diarrhea not due to CDAD. They demonstrated the value of using the UVM (UV- visible Marker). They used a UV- visible marker and a hand-held UV light that showed the presence of the marker on different environmental surfaces, after allowing 24h for housekeeping staff to perform their duties. They followed 20 patients over 6 months; 10 patients were on isolation precautions that had diarrhea with laboratory confirmation of CDAD, while the other 10 subjects had diarrhea not due to CDAD; thus, they were not on contact precautions.

Their findings showed that there was a lack of cleaning compliance; moreover, they reported that 72% of the time when the UV-Marker was applied on the toilets, there was no evidence of removal of the marker from the surfaces tested using the UV light (Alfa *et al.*, 2008).

Similar results have been shown by Carling *et al.* (2007) when they evaluated environmental cleaning in the intensive care units of sixteen hospitals using a UV marker. They evaluated 197 patients' bathrooms; a good level of cleaning was expressed as the percentage of objects cleaned. Overall, the result obtained was 61%, while the outcome of this study for bathrooms was 47, 6%. They presented different values for the sink (92.1%), tray tables (86.9%) and toilet seats

(82.7%); in addition, they were cleaned 85% of the time. Conversely, half of the 14 highly touched objects nearly reached 50%.

More recently, the idea of improving environmental cleaning based on a sustained compliance with the protocols and a high level of thoroughness is gaining ground; further studies are required to provide Hospital Infection Control Departments with a better tool to assess housekeeping performance (Carling *et al.* 2008a, Alfa *et al.*, 2008).

2.4. Microfiber vs. Cotton cloths: Role of microfiber cloths for effective environmental cleaning

In the past, cotton cloths and mops were used for cleaning the floors and surfaces in the hospital setting. In the last few years, microfiber mops have been introduced as an alternative for better cleaning in health care facilities (Rutala *et al.*, 2007).

Recently, a mopping technique using microfiber has been introduced in healthcare facilities to clean floors. Microfiber products arose in Japan more than 30 years ago but reappeared in Europe in 1996. It is predicted that microfiber mops will replace the conventional, cotton string mop in the regular market (Rutala *et al.*, 2007). Cotton mops require disinfectants and a large amount of water to be discarded after no more than 3 patients rooms have been mopped (Rutala *et al.*, 2007).

To be considered a good means of disinfecting surfaces in the healthcare setting, a cleaning cloth, whether it is made of cotton or microfiber, should not transfer bacteria from one

environmental surface to another (Moore, 2006). As per manufacturer's recommendations, microfiber could remove and retain dust and particles from surfaces, and not release them unless the cloth is immersed in hot water. This property would allow microfiber to prevent the transfer of bacteria attached to dust in the environment from one surface to another (Blue wonder™, 2000-2009). In order to obtain the best performance, it has been recommended by the company to use moistened microfiber cloths.

The fact that microfiber wipes need only water to obtain an optimal effect on surfaces dramatically reduces the need for chemical cleaning agents. Despite this finding, the use of disinfectants and decontaminants in the housekeeping protocols may still be required for optimal elimination of hospital-acquired pathogens. The implementation of disinfectants and decontaminants in the housekeeping protocols might be considered the best tool to gain the battle against hospital-acquired pathogens. However, disinfectants and decontaminants may cause irritation to skin, eyes, respiratory mucosa and lungs of patients, healthcare workers and visitors. Utilization of this new kind of cleaning cloth may contribute to the protection of the environment (Olson Technology, 2009), if the use of chemicals can be reduced.

Since microfiber cloths components cannot kill bacteria (Blue wonder™, 2000-2009), a new microfiber cloth should be used in each room to prevent the transmission of microorganisms between different areas (Rutala *et al.*, 2007). Microfiber cloths require an exposure of the cloth for 3 minutes to boiling water to guarantee the killing of any bacteria they may have acquired when used in non-healthcare settings. (Blue wonder, 2000-2009).

The reprocessing of reusable microfiber cloths requires adequate laundering conditions. The effectiveness of this process is crucial in order to lower the potential risk of cross-contamination in the hospital setting.(Rutala *et al.*, 2007).

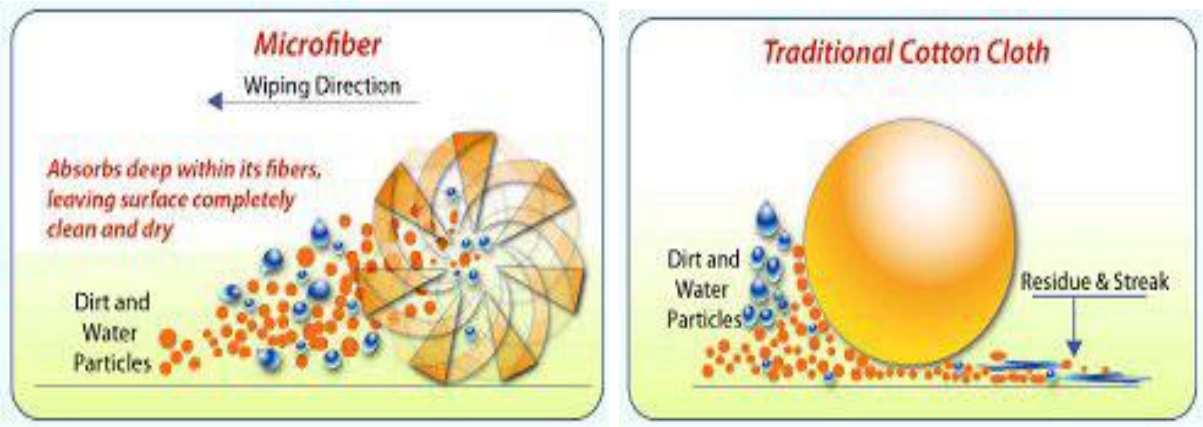
Microfibers are built from a dense material manufactured as a result of blended polyester and polyamide (nylon). These fibers offer a cleaning area 40 times greater than a standard cotton fiber. Its components are negatively charged so that particles such as microorganisms, which are positively charged, are easily attracted (Rutala *et al.*, 2007). Static electricity created as a result of the above mentioned charges on the microfiber structure, would allow this new type of cloth to trap dust, which is the most common environmental factor that attracts bacteria cells in the environment (Olson Technology, 2009).

Microfiber cloths are constituted of millions of wedge-shaped cross sections, which can attract, trap and remove particles from the environment. In contrast, cotton cloths have a regular and smooth structure and a large area of contact, promoting the transfer of microorganisms from a wiped surface to the following one (Olson Cleaning Technology, 2009; Moore, 2006). This factor should be considered as a drawback in the use of cotton cloths, as the cleaning of these cloths demands a thorough disinfection to eliminate residual organisms. Moreover, the frequency of the cloth reprocessing in the hospital setting is usually not at the desirable level (Moore, 2006). (Figure 1)

The microfiber edges easily break down as a result of the motion during cleaning. As a consequence of this mechanism, the capillary force activates, forcing the dirt to remain locked into the knit of the cloth (Olson Cleaning Technology, 2009). When the cloth is wet the force created inside the tubes is strong enough to prevent the small particles from escaping the interweave (Rutala *et al.*, 2007).

Given the intertwined structure of its components the fiber can absorb 6 times its weight in water. (Rutala *et al.*, 2007). The increased absorbency of this material is remarkable and allows for a

better cleaning of large wet surfaces, reducing the size and/or number of cloths required to clean dirty patients areas, such as washrooms. Besides, the absorption of larger volume of fluid, compared to cotton cloths, reduces the number of times that the housekeeping staff has to wring the rags out after being used on wet surfaces. (Figures 1a. and 1b.)



Retrieved from http://www.centraltradingagency.com/ March 2010

Figure 1: Microfiber vs. Cotton cloths: mechanism of action

Overall, the implementation of microfiber cloths as a new tool in environmental cleaning within the hospital setting has been reported to save time and resources (Olson Cleaning Technology, 2009). Some research has been conducted by Olson Cleaning Technologies in Sweden, and they found that the microfiber cloths produced by this company certainly remove bacteria (*E. coli*) from the environment. However, there have been no studies published using *C. difficile* and spores to evaluate the features of the microfiber cloths.

2.5. Research needs related to *C. difficile* and antibiotic resistant organisms.

1. Health care facilities lack effective means of monitoring compliance of housekeeping staff with cleaning protocols.
2. There is very little published evidence on the efficacy of microbial removal using newer technology such as microfibre cleaning cloths.

Additional and conclusive data are needed in this area.

2.6. Hypothesis

We hypothesize that:

- Providing weekly feedback for housekeeping staff using the UVM audit tool will result in at least 90% compliance with the cleaning protocols that will be sustained at least in 90% of the time.
- The use of microfiber cloths for cleaning will provide ≥1 Log better bioburden reduction compared to cotton cloths

2.7. Objectives of the study

1.1. To determine if sustained compliance with cleaning protocols can be achieved using UVM as a tool to provide feedback to housekeeping staff.

1.2. To determine if microfiber cleaning cloths are more efficient in eliminating *C. difficile* spores from the environment compared to regular cotton cloth.

3. Materials and Methods

3.1. Cleaning audit: Clinical study

Materials: A lotion visible only under short-wave UV light (UV Marker) and a UV lamp, was used in this part of the Study (UV-Marker Study). (Figure 2.)

Figure 2: UVM: Glitterbug® from Brevis Corp., USA-UV light-.

Methods: The UV-Marker (UVM) Study was divided in two phases. Each phase comprised 12 weeks when the UVM was applied to four different surfaces within the patients' washrooms: the underside of the toilet seat, the sink, the soap dispenser and the door knob. A cotton swab was used to apply the UVM on each of the surfaces. The marks were consistent in size and shape, since the total number of applications and readings were carried out by a single individual.

Eighty patients' rooms were tested on six wards. Twenty rooms on average were tested every week. Every 4 weeks, the evaluation of the entire number of rooms for each ward was completed.

The total number of rooms for each ward was divided in 4, so that every week a different group of rooms was assessed. Consequently, at the end of the study each room was evaluated at least 6 times. Isolation rooms were not checked for cleaning compliance. Every day the marker was applied clockwise, on a different location of each site above mentioned. A total of 320 sites were checked on consecutive week days. The total number of sites tested was 7680 over a twenty-four week period. The study included three Arms: for Arm 1, feedback on cleaning was given to the staff over the twenty-four week time period; Arm 2 received feedback for the second twelve-week period based on UVM results, whereas Arm 3 received feedback for the first twelve-week period. A score of zero (100% removal from surfaces), 1 and 2 (some removal from surfaces) and 3 (0% removal from surfaces) was implemented to assess cleaning compliance (Table 1, Figure 3.), as described previously by Alfa *et al*, 2008.

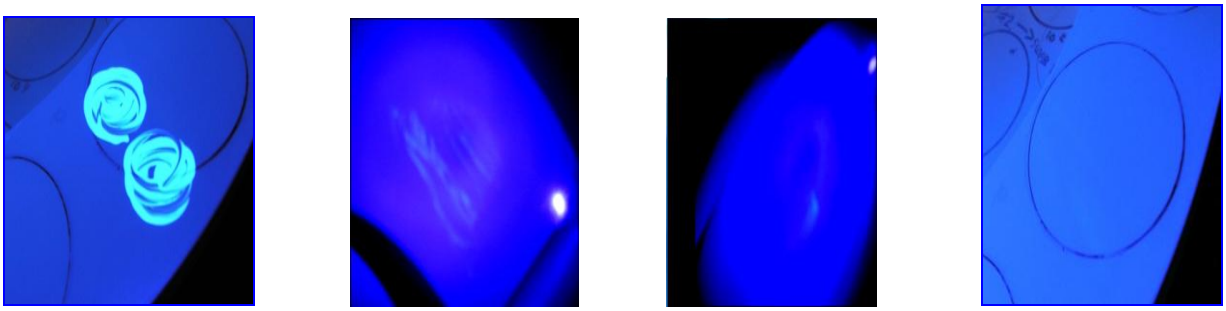
A survey was conducted before the start of the study with the housekeeping staff. They set 90% cleaning compliance as their goal for the study. Every week the staff received feedback from their supervisor and from the study group. A graph showing the score obtained by each Arm was exhibited on a visible board on each ward and in the housekeeping department. The staff were aware of the wards included in the study; however, they did not know which rooms and sites were checked by the study researcher in a particular week.

Table 1: semi-quantitative score for assessing the residual marker

Score	Residual UVM	Summary Category
3	All of the UVM remains (i.e. no removal despite cleaning).	No cleaning
2	More than half of the UVM remains (i.e. some removed due to cleaning).	Some cleaning
1	Less than half of the UVM remains (i.e. most has been removed by cleaning).	
0	None of the UVM remains (i.e. completely removed by cleaning).	Complete cleaning

'0': corresponds to the absolute value that was recorded when any trace of UVM was detected by the UV-light after a 24 h. period. It was considered 'complete cleaning' (100% compliance) when the marker was entirely removed by cleaning from the surface.
'1': represents the relative value that was recorded when some amount of UVM was detected by the UV-light after a 24 h. period. It was considered 'partial cleaning', less than 50% of the UVM remained on the surface, despite cleaning.
'2': corresponds to the relative value that was recorded when some amount of UVM was detected by the UV-light after a 24 h. period. It was considered 'partial cleaning'; more than 50% of the UVM was identified on the surface, regardless of cleaning.
'3': absolute value that was recorded when the UVM was left intact on the surface and was completely identified by the UV-light after a 24 h. period. It was considered 'no cleaning' (0% compliance), when the UVM was not removed by cleaning in any percentage.

Score 3 Score 2 Score 1 Score 0



0% cleaning compliance 100%cleaning compliance

<50% cleaning compliance >50% cleaning compliance

Figure 3: UVM score

3.2. Cleaning tools: Comparison of microfiber to cotton cloths

Materials

- **Bacterial strain***: C. difficile* 765 spore preparations were used for testing removal from surfaces and transfer between different surfaces of bacteria.
- **Microfiber cloths** provided by Johnson Diversey (Oakville, ON) were used to assess the ability of the above mentioned cloths to remove bacteria from surfaces and transfer microorganisms from one surface to another one.
- **Cotton cloths** (diapers from Kushies-baby-bebe. Storey Creek- Ontario, Canada), were utilized to compare their ability for removal and transfer of bacteria versus microfiber cloths.
- **Surfaces tested:** ceramic tiles, arborite (Formica, matte finish).Home Depot Warehouse (Winnipeg-Canada)
- **Drill apparatus:** To mimic the manual force and movement used for cleaning surfaces, we developed a test apparatus similar to that described by Williams *et al,* 2007, as shown in Figure 4. A drill held by a stand carried a drill bit, with a rubber stopper that acted as the carrier for the test cloth. The scale positioned underneath the stopper measured pressure exerted on the test surface. The pressure was calculated as mass over area, the RPM was determined by a digital laser tachometer.
    - Drill body IKA RW 16 basic-Fisher Scientific-cat# 14-259-208 attached to the drill stand.

- Traceable walkaway digital timer controller-Fisher Scientific-cat# 15-077-964
- Denver-2001 MAXX electronic precision balance
- Aluminum Support jacket--VWR-cat# 89032-282
- Digital tachometer model DT2236B-photo contact

Equipment connection and assembly:

The traceable walk away digital controller was connected to the drill to regulate the number of revolutions by turning the drill off after the preset time (5 seconds). Each drill bit was attached to a rubber stopper that had a 16 cm^2 cloth, held in place by an O ring.

The digital tachometer was placed at a proper distance from the drill apparatus, so that the laser could detect the laser sensitive tape placed on the drill bit shaft. (Figure 4).

Methods:

1. The bacterial spore production was a modification of the method described by Freeman *et al.*, 2005. *C. difficile* 765 stock preparations were stored as frozen stocks. The microorganism was sub cultured twice and the incubation time between subcultures was 48 hours. After two consecutive subcultures, ten plates with blood agar media (sheep blood) were inoculated with the actively growing bacteria. The plates were incubated anaerobically in an anaerobic chamber at 35°C for seven days. On day seven one inoculated plate was taken out of the anaerobic chamber and Gram stained to look for the presence of spores. A qualitative measure of the proportion of spores formed relative to the number of vegetative forms present on the smear, was used to confirm that an adequate level of spores was present.

In most cases the finding of over 80%-90% of spores present on the smear was indicative of a medium to high spore producer strain of *C. difficile*. When the proportion of spores on the smear was very low, the plates were incubated for another week in the anaerobic chamber prior to harvesting the spores.

On day fourteen, the ten plates were checked for the presence of spores and for contaminants. Under normal circumstances, when the plates grew pure cultures of *C. difficile* 765, the ten plates were sub cultured onto 50 blood agar plates and incubated in the anaerobic chamber at 35°C for seven days. After a week one plate was checked for the presence of spores using the Malachite green stain methodology. When the proportion of spores related to vegetative forms of *C. difficile* 765 reached 80%, the rest of the plates were taken out of the anaerobic chamber. Ten plates were scraped into one ml of sterile reverse osmosis water (RO water); after pooling a total of 50 plates a final volume of 5 ml of RO water contained the final suspension of *C. difficile* 765 spore preparations.

The addition of equal volume of Ethanol 95% to the suspension assured the persistence of *C. difficile* in the spore form. The suspension was placed on a platform rocker with gentle mixing for one hour at a low setting to ensure spores had thorough exposure to Ethanol. The spore suspension was aliquoted in eppendorf tubes and stored in the refrigerator at 4°C.

2. *C. difficile* 765 viable counts

C. difficile 765 spore preparations previously produced were spun for ten minutes in an ultracentrifuge at 14000 RPM and 4°C. After centrifugation, the supernatant was carefully replaced with the same volume of sterile Artificial Test Soil (ATS). The inoculum was mixed by vortexing for one minute, three times sonication for 5 seconds followed by one minute vortexing. The suspension was serially diluted 1:10 from 10^{-1} thru 10^{-5} in sterile phosphate buffer solution (PBS) pH 7.5. One hundred *u*l of the 10^{-2} thru 10^{-4} dilutions were inoculated onto *Clostridium difficile* monobactam norfloxacin (CDMN) (OXOID Nepean, ON) agar using the spread plate technique. The spore counts were carried out with three replicates. CDMN plates were incubated in the anaerobic chamber at 37°C for 48 hours and counted.
Grey smooth soft colonies present on plates showing between 20 and 200 colony forming units (cfu) were counted and the cfu/ml was calculated. The final results were reported as the mean ±standard deviation.

3. Inoculation of cloths

Microfiber and cotton cloths were cut into 16 cm^2 pieces and autoclaved for 15 minutes in a liquid cycle. All inoculation steps of the experiment were conducted under the Class II B Biological Safety Cabinet (BSC). The inoculated test cloths were placed on a large piece of sterile aluminum foil using sterile forceps.

4. Elution from cloths

After 24 h drying time, the cloths were placed in 50 ml sterile conical tubes containing 10 ml sterile PBS. The elutents were mixed by vortexing for one minute, three times sonication for 5 seconds followed by one minute vortexing.

5. Viable counts

The suspension was serially diluted 1:10 from direct tube thru 10^{-2} in PBS, pH 7.5. One hundred *u*l of each dilution was inoculated onto CDMN agar using the spread plate technique. The spore counts were carried out with three replicates. CDMN plates were incubated in the anaerobic chamber at 37°C for 48 hours and counted. Grey smooth soft colonies present on plates showing between 20 and 200 colony forming units (cfu) were counted and the cfu/ml was calculated. The final results were expressed as the mean ±standard deviation.

6. Inoculation of surfaces

One hundred *u*l of 10^5 or 10^6 cfu/ml suspensions was inoculated onto the centre of the test surface. The test surfaces were allowed to dry overnight inside the BSC.

Elution from test surfaces and viable counts were done in the same way as explained above for test cloths.

7. Drill apparatus operation

After the experiment was conducted, the drill bit attached to the rubber stopper was unhooked from the drill body and taken to the BSC. The cloths were carefully released from the O rings with sterile tweezers and processed as explained in 4. and 5.

The drill bit attached to the rubber stopper was screwed to the drill body. The timer was set at 5 seconds and the drill at 60-65 RPM, (the tachometer confirmed the RPMs). The tested surfaces were placed on the balance and held in position with double-sided tape. The test surface and test cloth were positioned by adjusting the support jack under the balance until to desired reading was displayed on the digital readout of the balance. The area of contact was equal to: $\boldsymbol{\pi r^2}$. The pressure exerted on the surface was calculated as mass / area ($g/cm^{2)}$. (Figure 4.)

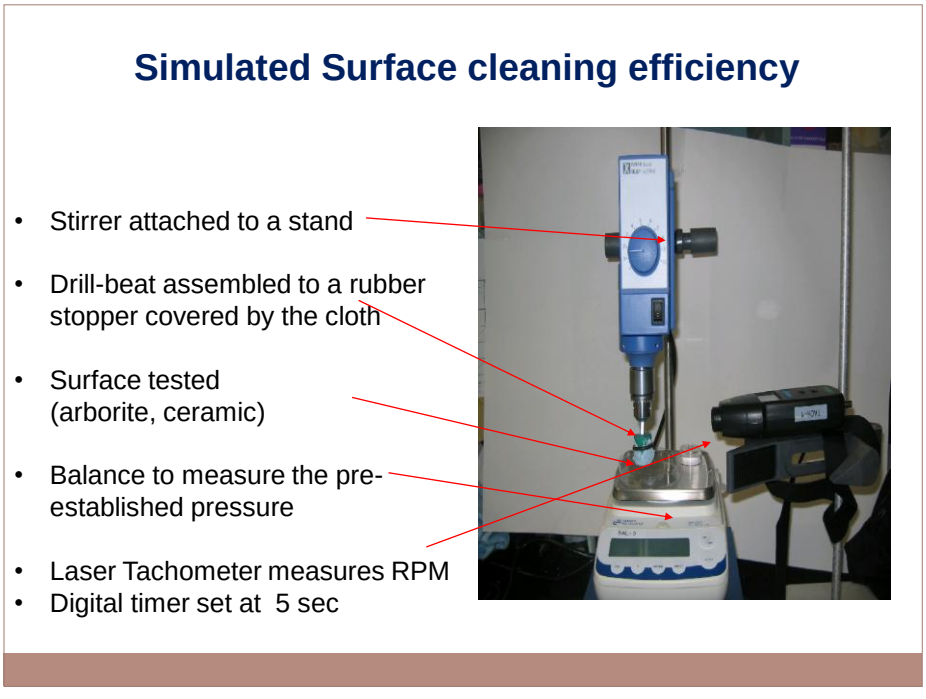


Figure 4: Drill apparatus: description.

8. Laundry experiment

Microfiber and cotton cloths were inoculated with a known concentration of *C. difficile* spores, as described above (refer to 3) and sent to the housekeeping department for washing along with the regular cloths that they use for daily cleaning.

Positive and negative controls were run at the same time. After going through the laundry process a spore count was performed on the cloths. Two positive controls were included in the testing; one was introduced in the laundry machine in conjunction with the rest of the samples. The cloth was placed inside a cryovial where no cleaning agent could reach it. These tubes represented the heat killing control (i.e. no wash off effect).

Microfiber and cotton cloths used by the staff were processed before and after being laundered using the above described methodology (refer to 4.-5.). The drying time for the testing samples was 24 h. The ward use microfiber and cotton cloths were cut in squares (16 cm^2). Three squares were processed right away and cultured. The other 3 were placed in mesh bags and sent to laundry with the rest of the inoculated samples, the following day, where they were washed and dried along with the regular daily load. After the washing process, the eluate extracted from the ward use samples, inoculated samples and controls were processed and cultured on CDMN plates at 35°C in the anaerobic chamber for 48h. In addition, the samples were planted on blood agar plates for aerobic growth, incubated at 37°C in a regular incubator for 24 h.

The colonies of aerobic and anaerobic bacteria grown on the above mentioned culture media were enumerated and classified according to the characteristics shown on a Gram stain smear. When Gram negative rods were the prevalent organism on the aerobic plates, they were identified.

Statistical analysis

The clinical study results were analyzed using a t test (unpaired test) at the 95% level of significance. We used Excel software 2007 for graphing and Graph Pad Prism for calculations on the difference between the means of each group of data to be compared.

The removal and transfer of spores in different conditions and the inoculated cloths submitted to laundry were analyzed using a t test (unpaired test) at the 95% level of significance. Calculations and studies on the differences between the means of each group of data obtained were performed by Excel software 2007 and Graph Pad Prism 5.02. Each experiment comprises a set of 3 replicates and was performed at least three times.

Log transformation of the viable counts were used to compare reduction in the bioburden. Colony forming units (CFU) were used to evaluate results with t test and to calculate percentages of inoculum left on test surfaces or retained by test cloths relative to the original inoculum.

4. Results

4.1. Cleaning audit: Clinical study

Housekeeping cleaning compliance with established protocols in the healthcare setting is as essential as the use of newer and more efficient technologies to clean surfaces within the patient's environment. Our study analyzed the impact of using a UV visible mark to audit the cleaning performance of the staff, in addition to the routinely used visual audit. To confirm the baseline compliance with cleaning a 2 month control study was done. After the control study we began the actual study to assess the impact of feedback on cleaning compliance. The UV Study was divided in 3 Arms. Each Arm was composed of two wards and the results shown represent the averaged data from both wards.

A pre-study baseline assessment was carried out by housekeeping Supervisors using the UV Marker audit on the toilet seat, the sink, the soap dispenser and door knob in the patient's bathrooms, to evaluate the staff performance, which indicated a result of 55% cleaning compliance. Verbal feedback was given to the staff members individually. After this intervention we implemented our methodology for 8 weeks. During this time period, no feedback was given to the staff on any ward. The cleaners knew that a study was going to be put in place. We considered the data obtained from this preliminary evaluation as the control data without feedback for our study. No information or explanation on the study was given to any staff member. During this time period a survey was conducted within the staff members to know the level of cleaning compliance that they considered desirable.

The target of 90% was decided as the goal to be achieved, using the UVM as a new tool to assess cleaning compliance. The results obtained for control without feedback on average for the 3 Arms of the study was 66.7% cleaning compliance (Figure 5a, 5b, 5c).

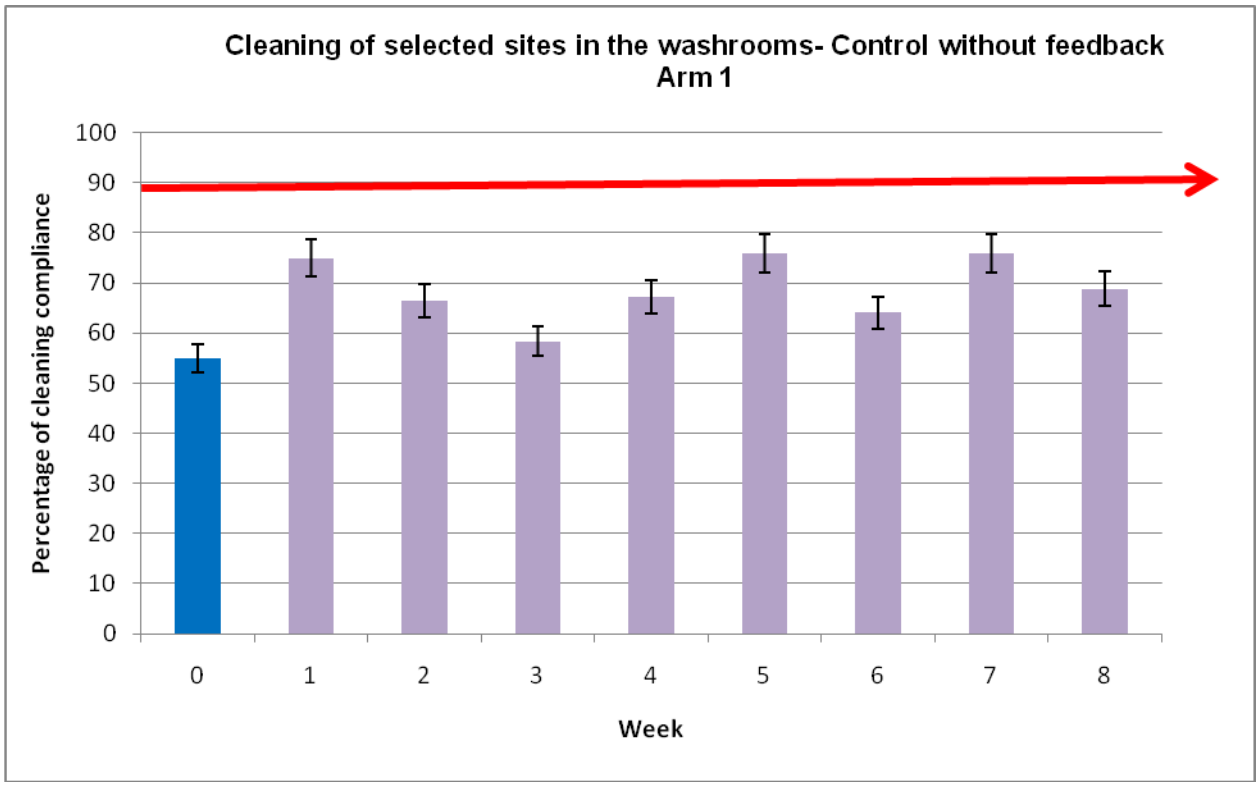


Figure 5a- Cleaning of selected sites in the washrooms-Control without feedback- Arm1

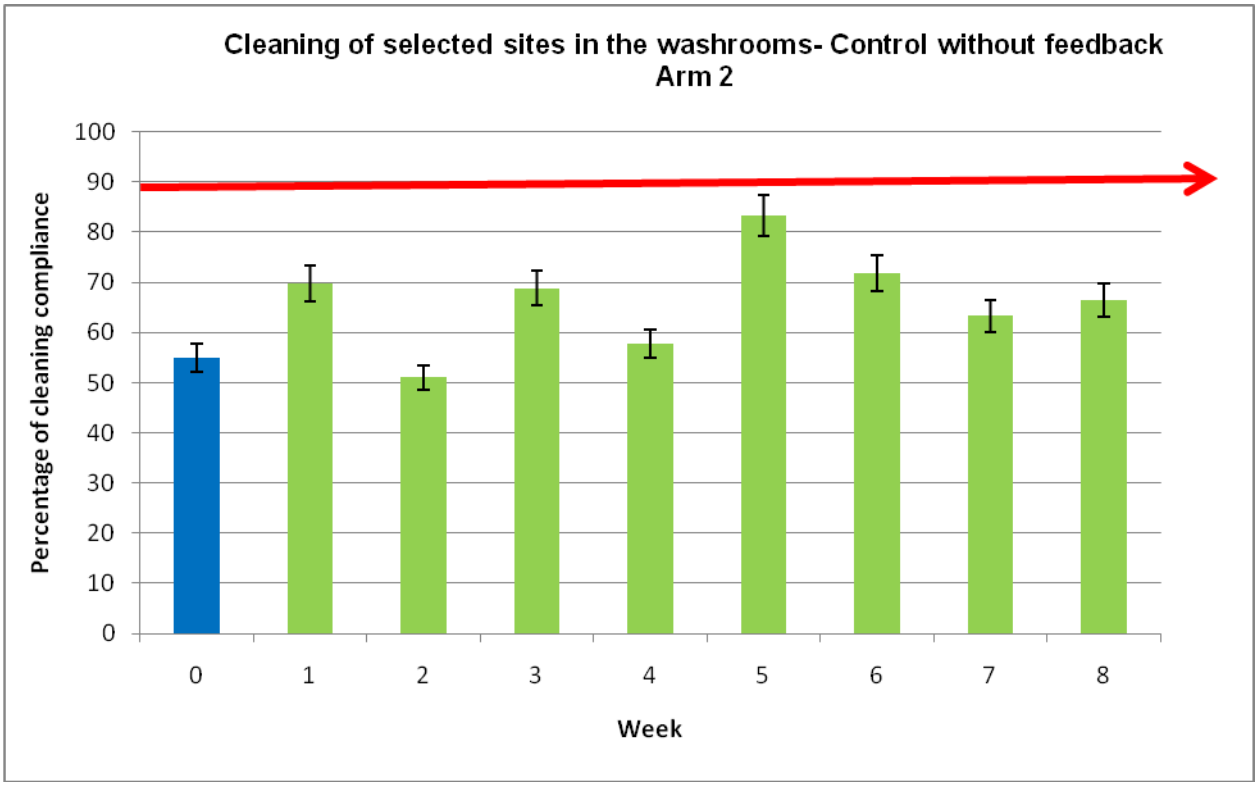


Figure 5b: Cleaning of selected sites in the washrooms-Control without feedback- Arm 2

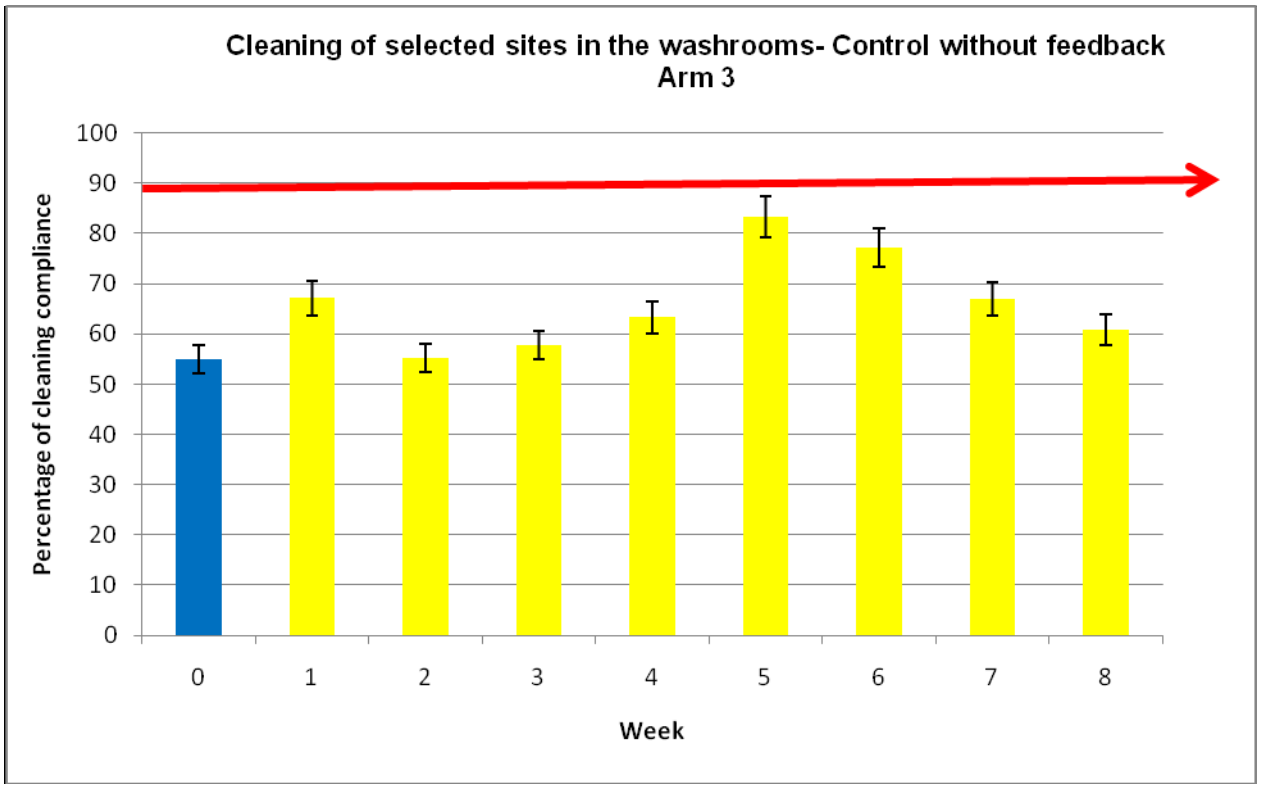


Figure 5c: Cleaning of selected sites in the washrooms-Control without feedback - Arm 3

- *Cleaning compliance along the 24 weeks periods of the research study*

Arm 1 was the control group with continuous feedback. They received feedback for the entire 24 week study period (Figure 6). The blue bar on Figure 6 represents the pre-study level assessed by the housekeeping supervisor based on the UVM audit with individual feedback (55%). Each bar represents the average cleaning compliance achieved by the 8 housekeeping staff members (HKS) (i.e. 6 HKS and 2 groups of casual employees (each group was considered one HKS) for a total of 8 HKS) who performed cleaning on these wards. They required 5 weeks from the beginning of the study implementation to achieve the desired target of cleaning compliance. They maintained the level of compliance over 80% in 83.3% of the time and they reached the study target in 58.3% of the time, during the first phase of the study. (Table 2).

For the second phase of the study, this group of housekeeping staff (HKS) reached a level of cleaning compliance greater than 80% in 75% of the time and they reached the study target in 33% of the time (Table 2).

It should be noted that Arm 1 was the only one that reached 100% cleaning compliance in 12.5% of the study time (3 out of 24 weeks) (Figure 6).

The work shifts staffed by casual employees in relation to the total HKS shifts was 15.3% for the first 12 weeks and 16.9% for week 13 to 24 for Arm 1.

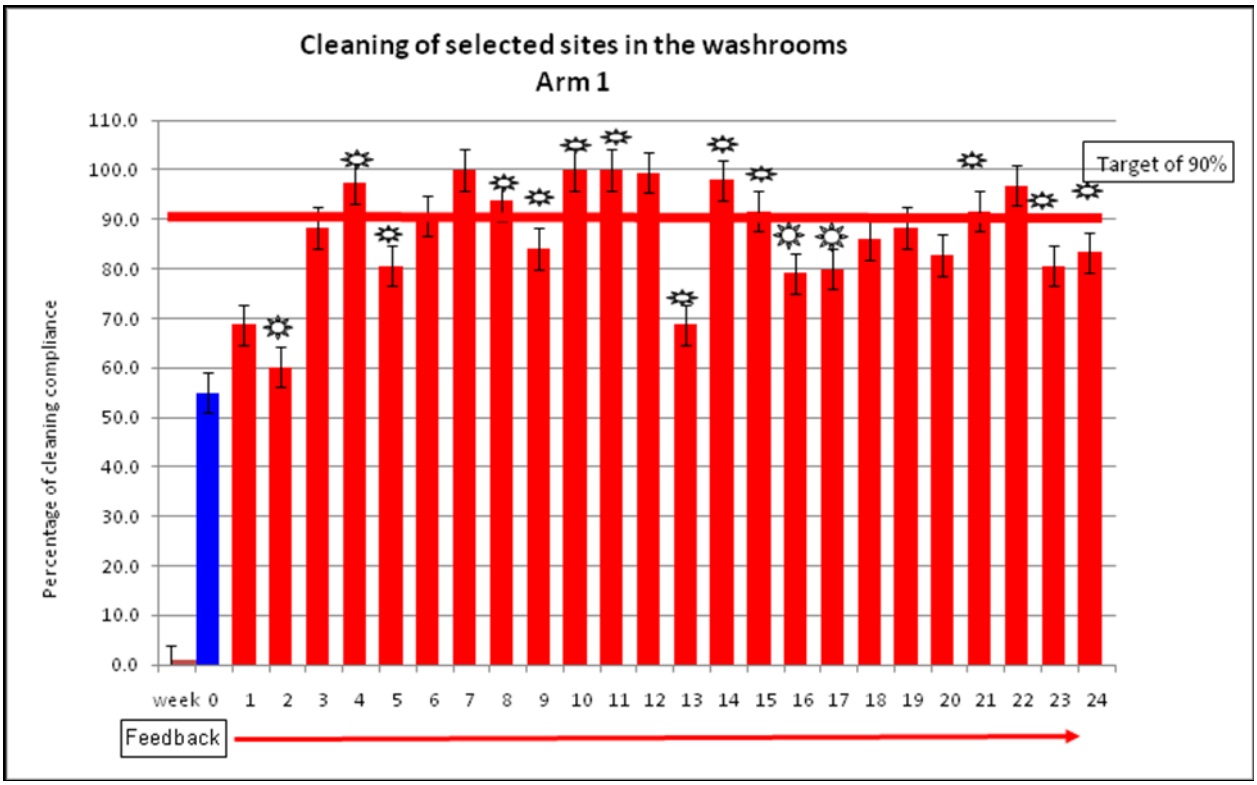


Figure 6- Cleaning of selected sites in the washrooms-Arm 1

☼ Indicates the presence of casual employees. They accounted for 15.3% of the total EFT shifts with respect to permanent employees for the first 12 weeks and 16.9% of the total EFT shifts for the second 12 weeks.

The blue bar shows the pre-study level of cleaning compliance assessed by housekeeping supervisors based on the UVM audit with individual feedback.(55%)

Arm 1 was considered the control group with continuous feedback . Two wards were included in this Arm. Each red bar represents the score expressed in percentage obtained for both wards combined on each week of the study. The staff received feedback for a 24 week period. The cleaning target was accomplished in 58.3% of the time, for the first phase and 33.3% for the second phase of the study.

Arm 2 included 9 HKS and 2 casual groups, a total of 11 HKS. They did not receive feedback for the first 12 weeks of the study. They started getting feedback on the second 12 weeks of our research study (Figure 7). The blue bar on Figure 7 represents the pre-study level assessed by the housekeeping supervisor based on the UVM audit with individual feedback (55%). Their performance was not influenced by the graph posted on the wards by the study researcher showing the feedback for the second 12 weeks of the study. They sustained the level of compliance although 100% cleaning compliance was never reached in either phase of the study.

Despite the fact that these HKS were not informed on their performance when the study started, their cleaning improved compared to pre-study levels. They maintained a level of compliance above 80% in 50% of the time and over 90% in 16.7% of the time for the first phase of the study. When the results for the second phase of the study were analyzed we found that this group of HKS reached a target of above 80% of cleaning compliance in 41.7% of the time (Table 2). After week 2 their percentage of cleaning efficiency was always better than the pre-study level assessment (i.e. sustained compliance but at the 80% level).

Casual staff accounted for 28.1% of the total EFT with respect to permanent employees for the first 12 weeks and 23.9% of the total EFT for the second 12 weeks.

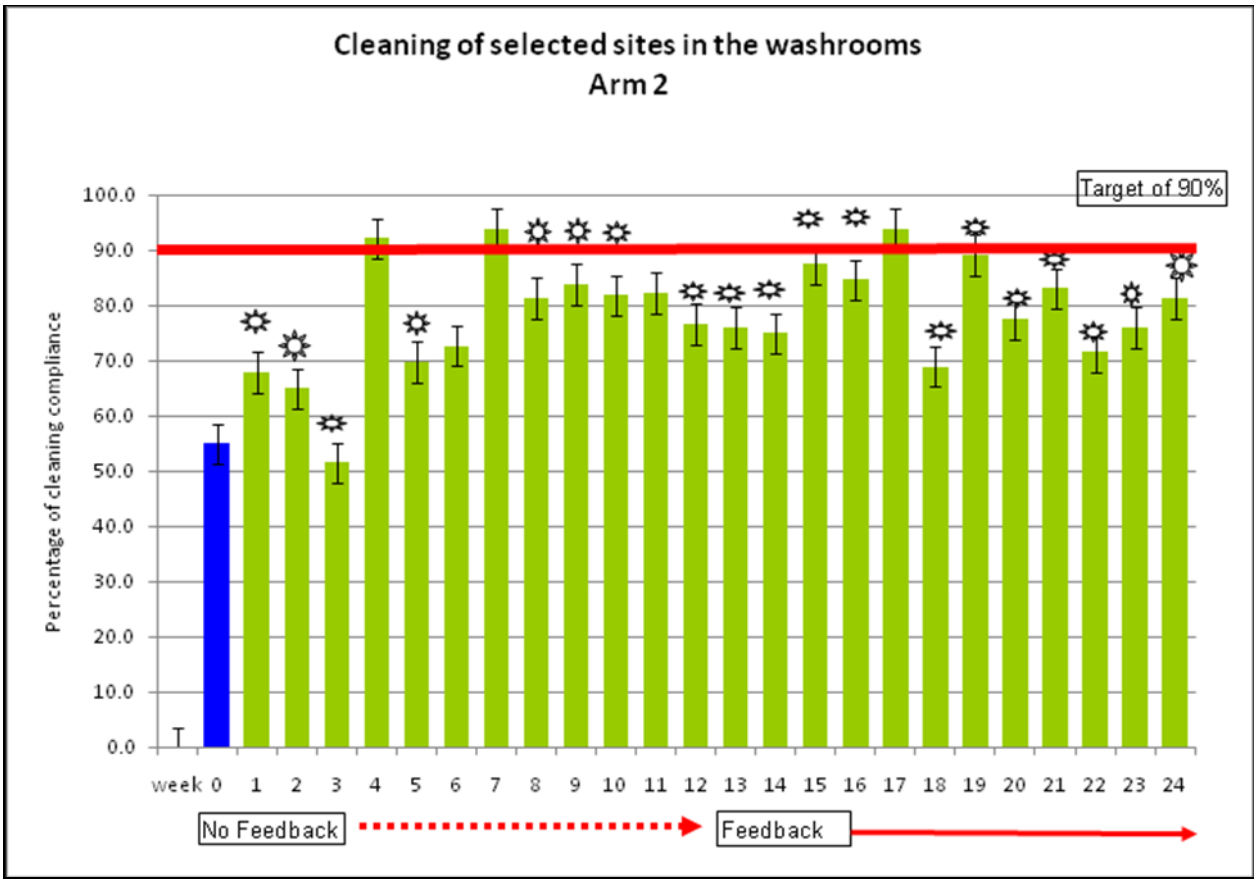


Figure 7- Cleaning of selected sites in the washrooms-Arm 2

☼ Indicates the presence of casual employees. They accounted for 28.1% of the total EFT with respect to permanent employees for the first 12 weeks and 23.9% of the total EFT for the second 12 weeks.

The blue bar shows the pre-study level of cleaning compliance assessed by housekeeping supervisors based on the UVM audit with individual feedback (55%).

Two wards were included in this Arm. Each green bar represents average for one week. The staff received feedback for the second 12 week study period. The cleaning target was accomplished in 16.7% of the time, for the first and second phases of the study.

Arm 3 received feedback for the first 12 weeks, and then feedback was discontinued. However, despite the feedback, this group never reached the desired target of cleaning compliance (Figure 8). The blue bar on Figure 8 represents the pre-study level assessed by the housekeeping supervisor based on the UVM audit with individual feedback (55%). This group of HKS needed to experience the whole first phase of the study, in order to achieve the desired target.

It is worth noting that after they finished the first 12 weeks and entered the next 12 week phase where they did not receive feedback, the cleaning compliance overall average results did not drop considerably. Moreover, the target level of cleaning compliance was achieved in 8.3% of the time on the second phase. Even though they never reached 100% cleaning compliance in either phase of the study, their performance was found to be above 80% in 33.3% of the time for the first 12 weeks and 25% for the last phase of the study. (Table 2). Unlike Arm 1 and Arm 2, Arm 3 registered a score of 53.8% on week 9, which is a score even lower than the value obtained for the pre-study level of cleaning compliance.

Casual employees accounted for 38.5% of the total EFT with respect to permanent employees for the first 12 weeks and 42.0% of the total EFT for the second 12 weeks.

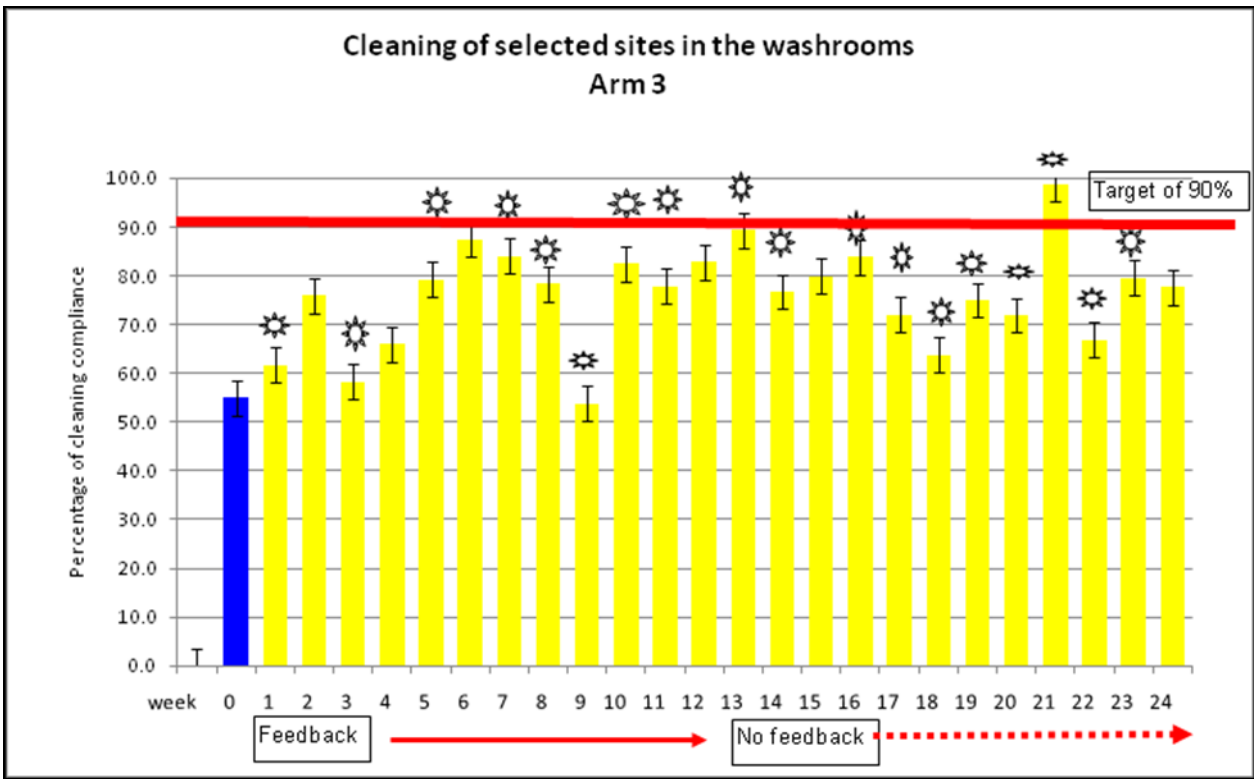


Figure 8 - Cleaning of selected sites in the washrooms-Arm 3

✡ Indicates the presence of casual employees. They accounted for 38.5% of the total EFT with respect to permanent employees for the first 12 weeks and 42.0% of the total EFT for the second 12 weeks.

The blue bar shows the pre-study level of cleaning compliance assessed by housekeeping supervisors based on the UVM audit with individual feedback (55%). The scores obtained for both wards were combined and each yellow bar represents the average cleaning compliance for one week. The staff received feedback for the first 12 weeks of the study period. The cleaning target was never accomplished by this group of HKS for the first 12 weeks; however, they increased their cleaning compliance to the desired target in 8.3% of the time during the second phase; they achieved above 80% of cleaning compliance in 33.3% of the time for the first 12 weeks of the study and 25% of the time for the last period of the study.

Table 2: Target of <60%, ≤80%, and ≤90% reached by Arm 1, 2 and 3

Weeks 1-12			
Cleaning compliance level	**% Compliance achieved for cut off level**		
	Feedback	No feedback	Feedback
	ARM 1	**ARM 2**	**ARM 3**
≤ 60%	**8.3**	**8.3**	**16.7**
≥ 80%	**83.3**	**50.0**	**33.3**
≥ 90% *	**58.3**	**16.7**	**0.0**
Weeks 13-24			
Cleaning compliance level	Feedback	Feedback	No feedback
	ARM 1	**ARM 2**	**ARM 3**
≤ 60%	**0.0**	**0.0**	**0.0**
≥ 80%	**75.0**	**41.7**	**25.0**
≥ 90% *	**33.3**	**0.0**	**8.3**

* The cleaning compliance level selected as the achievable target by the housekeeping staff prior to the study

The overall cleaning compliance for Arm 1 for the first phase of the study (weeks 1-12) was 88.6% and for the second (weeks 13-24) was 85.6% (Figure 5). Arm 2 achieved a total cleaning compliance of 75.8% for the period including weeks 1-12, while their achievement for the last 12 weeks of the study was 80.4%. Arm 3 reached 74.2% overall cleaning compliance for the first 12 weeks of the study and 78.0% for the second period of 12 weeks. Figure 9 shows the overall average cleaning compliance for all stages in the study.

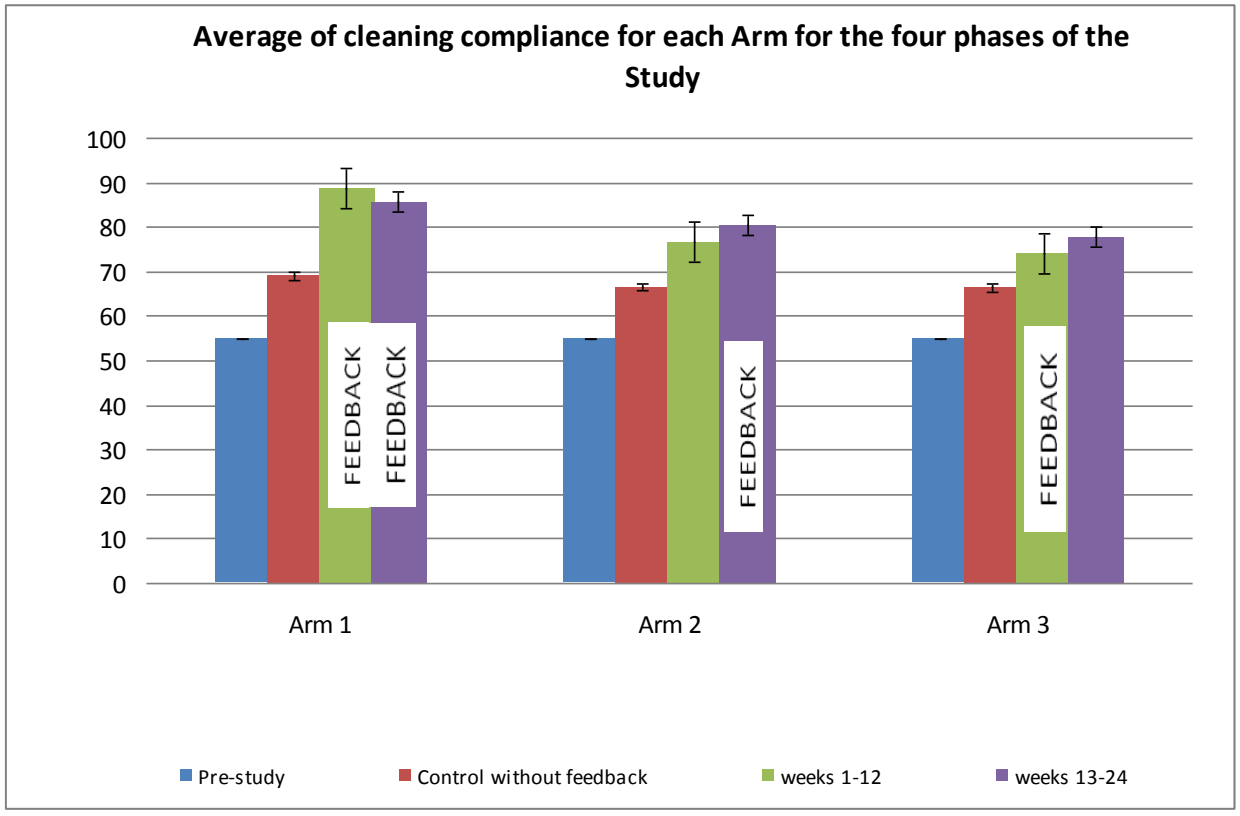


Figure 9: Comparison of the overall cleaning compliance results per Arm achieved during the four phases of the UVM study

- *Evaluation of cleaning compliance using two score ranges.*

We implemented the score of 0, 1, 2 and 3 for assessing cleaning compliance, as explained in Part I: *Methods*

To better analyse the results obtained from the implementation of this new audit methodology in monitoring cleaning compliance, the data was stratified into two groups consisting of: UVM score of 0 and UVM score < 3. This essentially represents total cleaning where all the marker was removed and the score was zero, as well as another group where any cleaning (i.e. UVM score of 0, 1, 2) was detected.

The results for Arm 1 are shown in Figure 10. If cleaning was defined as UVM of 0, the overall percentage of cleaning compliance was 77. 8% for the first 12 weeks of the study and 58.8% for the second 12 weeks.

The results for Arm 2 are shown in Figure 11. If cleaning was defined as UVM of 0, the overall cleaning compliance result was 61.9% for the first 12 weeks and 53.1% for the second 12 weeks of the study.

The results for Arm 3 are shown in Figure 12. If cleaning was defined as UVM of 0, this Arm achieved 60.2% cleaning compliance for the weeks 1 to 12 and 38.4% for weeks 13 to 24.

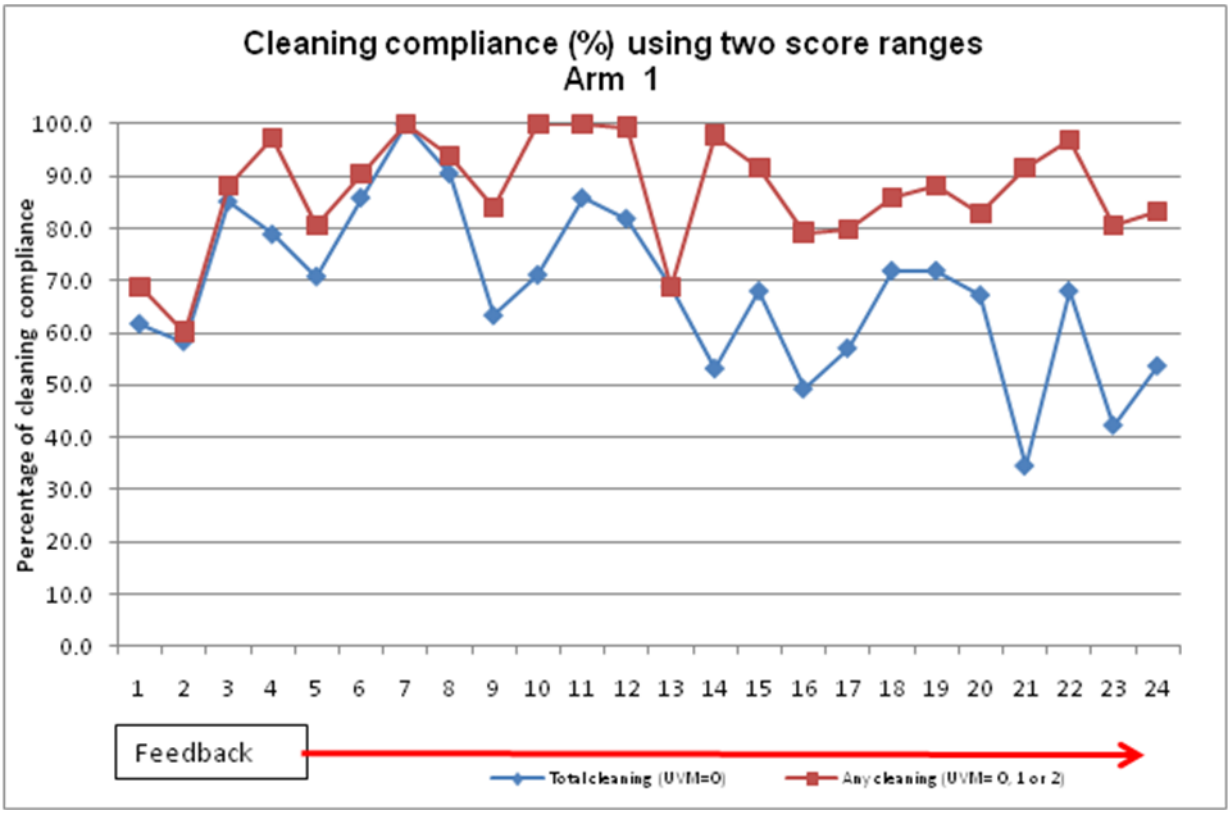


Figure 10: Cleaning compliance (%) using two score ranges for Arm 1

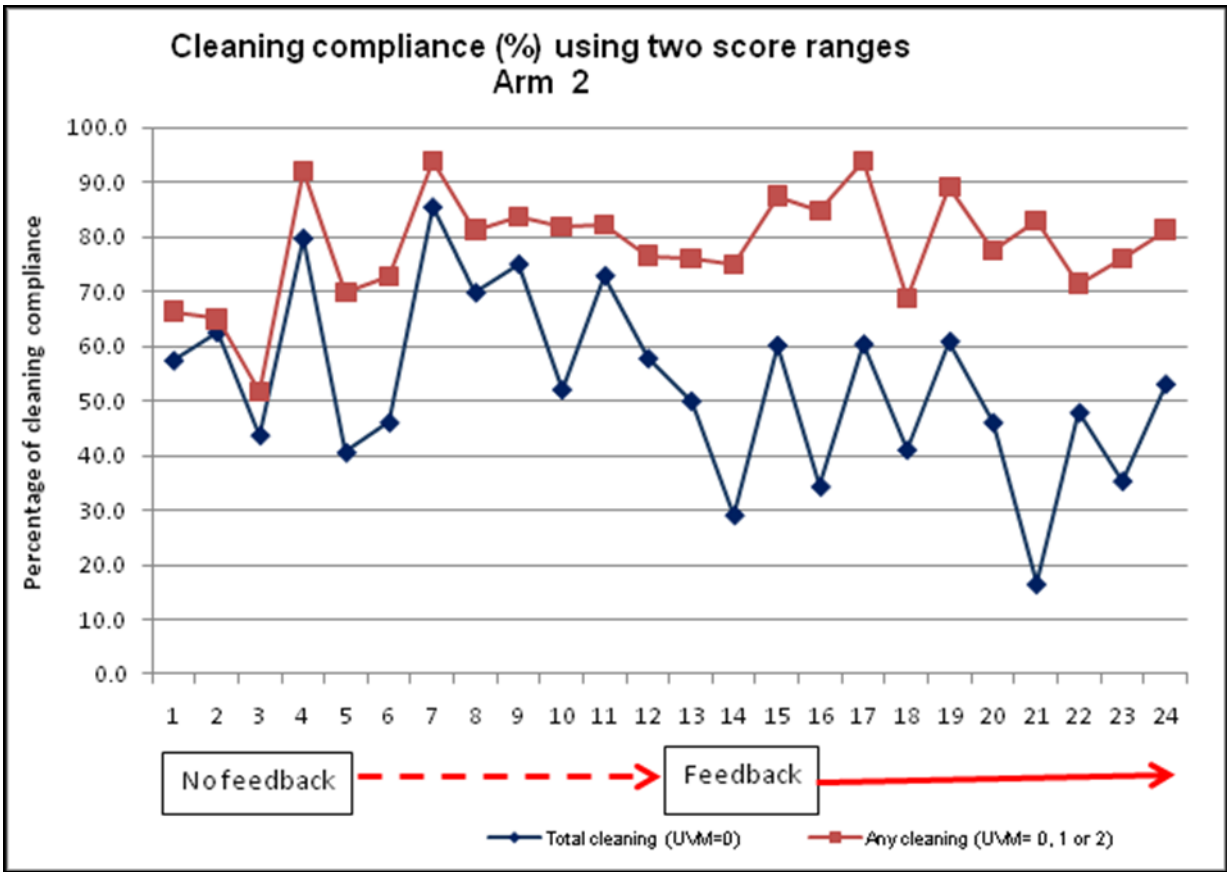


Figure 11: Cleaning compliance (%) using two score ranges for Arm 2

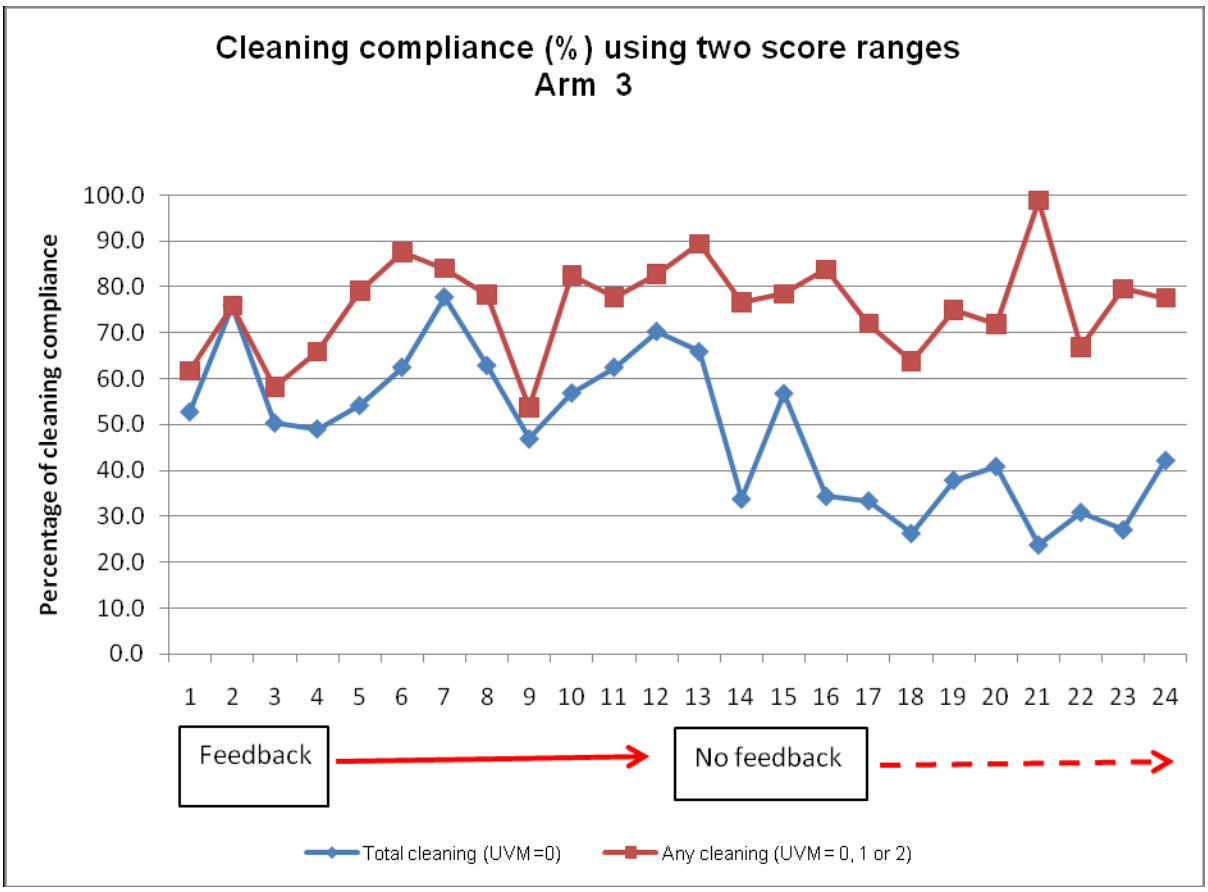


Figure 12: Cleaning compliance (%) using two score ranges for Arm 3

- *Evaluation of the overall cleaning compliance per site for Arm 1,2 and 3*

Overall, the UVM audit indicated that the site best cleaned was the sink, followed by the toilet seat, the door knob and the soap dispenser (Figure 13).

Results stratified into weeks 1-12 and weeks 13-24 of the study, allowed us to analyze the scores obtained for each study phase (Figure 14). Again, it is apparent that the soap dispenser and door knob are the sites with poorer cleaning.

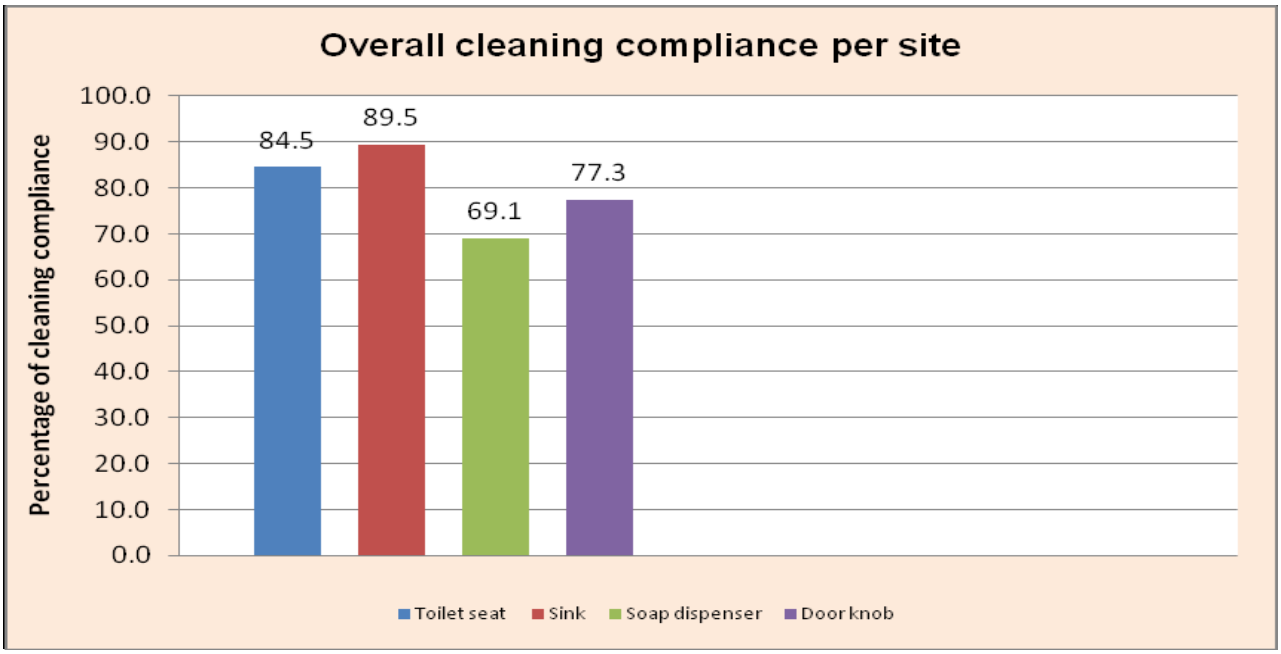


Figure 13: Overall cleaning compliance per site audited.

Regardless feedback provided the overall results for the four sites evaluated on the patients rooms were as follows: toilet seat (84.5%), sink (89.5%), soap dispenser (69.1%) and door knob (77.3%)

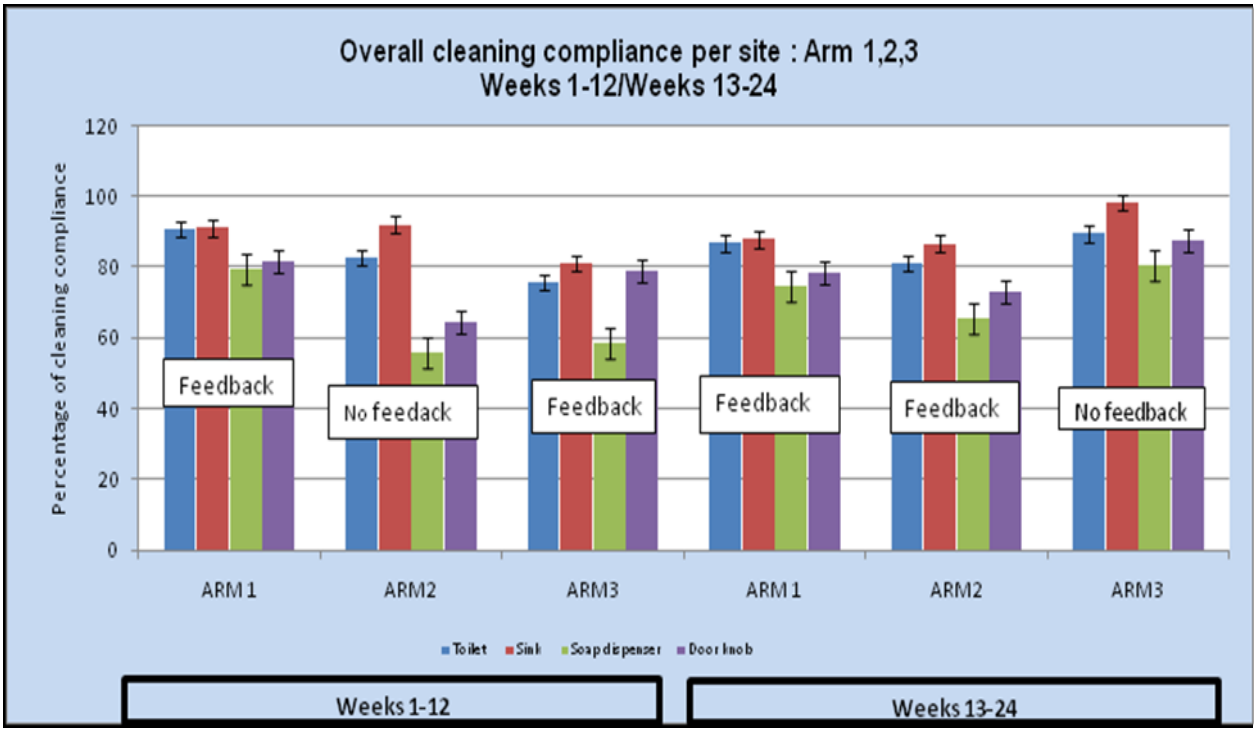


Figure 14: Overall cleaning compliance per site for Arm 1, 2 and 3

- *Evaluation of the individual cleaning compliance per site for Arm 1,2 and 3*

Thirty housekeeping staff members were involved in this study. To simplify the reporting of individual results, only two cleaners were chosen to demonstrate the efficacy of the UVM as a tool for monitoring different performances within the employees in two different scenarios. To better illustrate our research, we chose the HKS who reached the highest score and the one who showed the lowest percentage of cleaning compliance. Results were presented for the first and second phases of the study, separately.

Arm 1: HKS 2 (highest score achieved in Arm 1) cleaned 59 rooms along the study period. The results reached were 98.8% for the sink , the toilet seat, and the door knob; 83.3 % for the soap dispenser for the first phase of the study when this HKS was receiving feedback. The results for the second phase when feedback was also provided were: 95.2% (sink), 94.9% (toilet seat), 91.7% (door knob) and 84.2% (soap dispenser). The overall decrease in cleaning compliance between the two study periods was 3.4% for HKS 2 (Figure 15)

HKS 7 (lowest score achieved in Arm 1) worked in 30 rooms on the other ward that was part of this Arm during the study. The results obtained for the first 12 weeks of the study were the following: 91.7% (toilet seat), 83.3% (sink), 75.0% door knob and 58.3% soap dispenser. Whereas for the second 12 weeks of the study, the scores reached by HKS 7 were: 60.3% for the toilet seat, 71.4% for the sink, 50.0% for the door knob and 53.6% for the soap dispenser. The overall decrease in cleaning compliance between the two study periods was 18.3% for HKS 7. (Figure 15)

HKS 2 and HKS 4 worked on the same ward; HKS 2 trained HKS 4. HKS 4 represents the group of casual employees; this group achieved 84.3% overall cleaning compliance for the first 12 weeks of the study. The scores for the 4 sites were: 84.3% (toilet seat), 88.2% (sink), 82.3% door knob and 82.4% soap dispenser. When we analyzed the results for the second 12 weeks, this group showed an overall increase of 2.2% cleaning compliance between the two study periods. The scores for the 4 sites were: 89.3% (toilet seat), 89.3% (sink), 78.6% door knob and 89.3% soap dispenser. The overall increase in cleaning compliance between the two study periods was 2.3% for HKS 4.

HSK 5 and HKS 7 worked on the same ward. HKS 5 trained HKS 7. HKS 5 obtained 93.9% overall cleaning compliance for the first part of the study and 81% from week 13 to 24. The results per site for the first 12 weeks were: 92.2% (toilet seat), 95.6% (sink), 92.2% door knob and 95.6% soap dispenser and for the second 12 weeks were: 82.7% (toilet seat), 79.4% (sink), 85.3% door knob and 76.5% soap dispenser. The overall decrease in cleaning compliance between the two study periods was 12.9% for HKS 5.

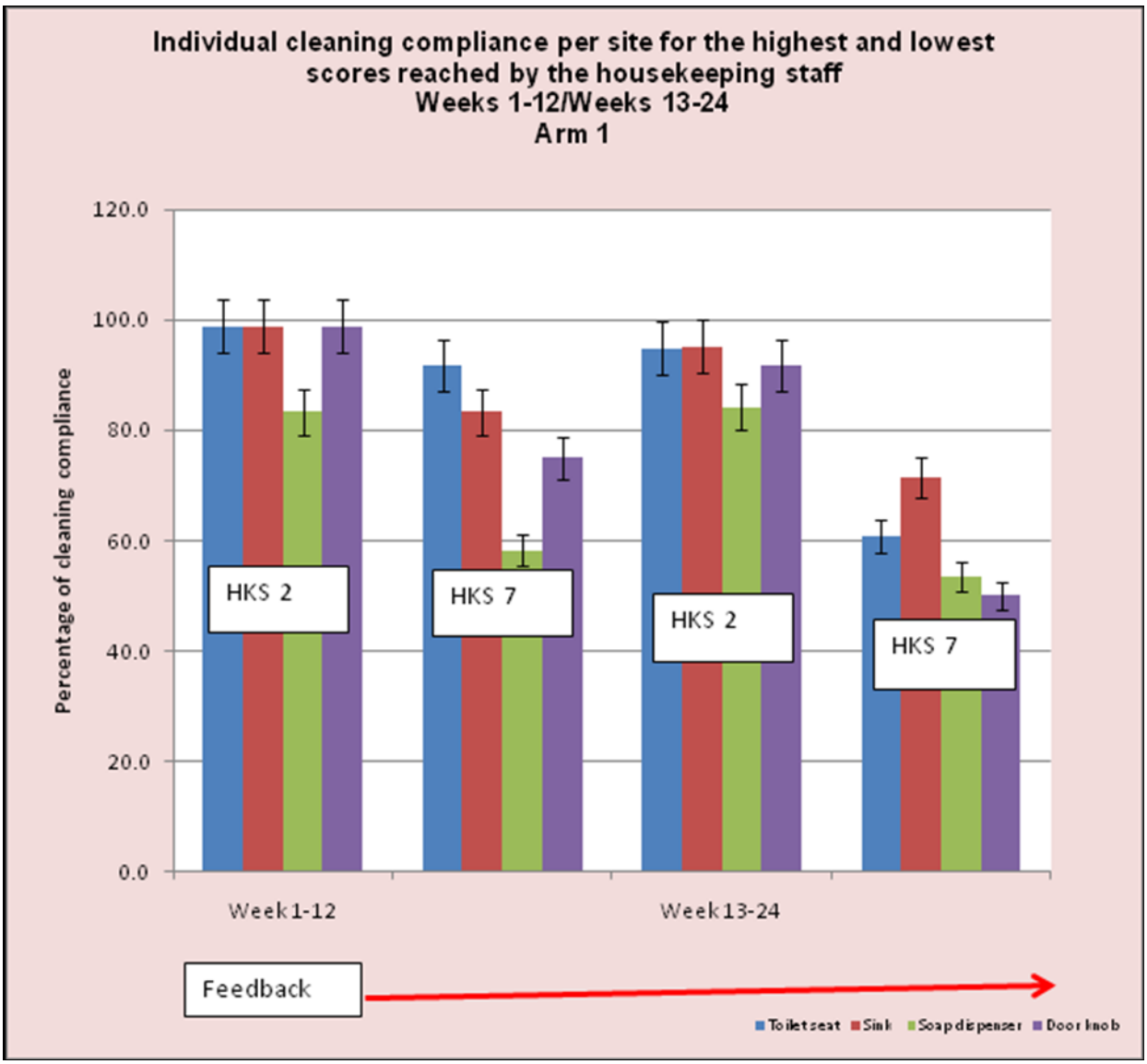


Figure 15: Individual cleaning compliance per site for two different performances along the study period- Arm 1

Arm 2: HKS 24 (highest score achieved) cleaned 38 rooms along the study period. The average cleaning compliance results reached were 100% (sink), 87.5% (toilet seat), 98.2 % (door knob) and 81.0% (soap dispenser) for the first phase of the study when this HKS was not receiving feedback; the results are presented in Figure 16. The results for the second phase when feedback was provided were: 96.7% (sink), 90.9% (toilet seat), 89.5% (door knob) and 90.9% (soap dispenser). HKS 24 trained HKS 23 (group of casual employees) working in the same ward that was part of Arm 2. HKS 23 achieved 81.3% for the first 12 weeks and 74.9% for the second 12 weeks, while feedback was provided to them.

HKS 30 (lowest score achieved) worked in 16 rooms during the study. The results obtained for the first 12 weeks of the study are shown in Figure 16 and were the following: 83.3% (toilet seat), 77.3% (sink), 28.8% door knob and 16.5% soap dispenser. Whereas for the second 12 weeks of the study, the scores reached by HKS 30 were: 66.7% for the toilet seat, 93.3% for the sink, 60.0% for the door knob and 13.3% for the soap dispenser. The overall increase in cleaning compliance between the two study periods was 0.3% for HKS 24 and 6.9% for HKS 30 (Figure 16).

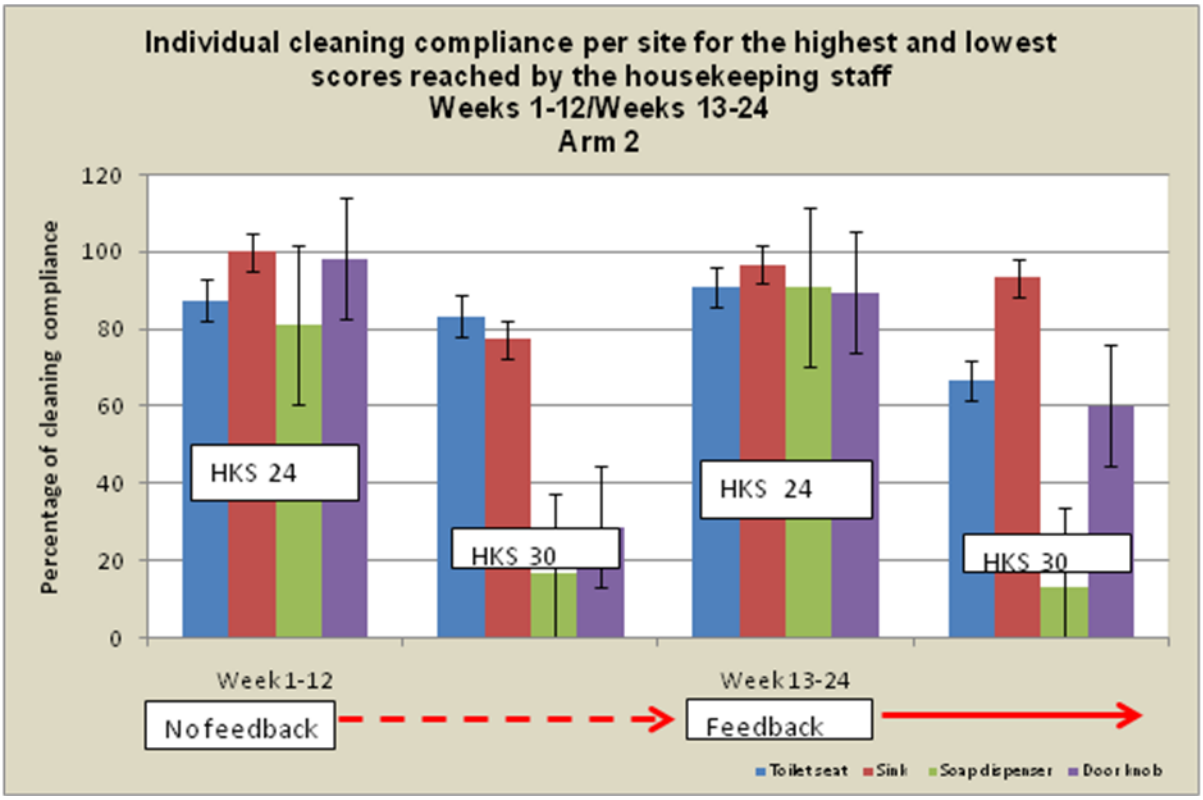


Figure 16- Individual cleaning compliance per site for two different performances along the study period- Arm 2

Arm 3: HKS 16 (highest score achieved) cleaned 48 rooms along the study period. The results reached were 72.6% (sink), 90.3% (toilet seat), 82.6% (soap dispenser) and 94.1% (door knob) for the first phase of the study when this HKS was receiving feedback. The results for the second phase when feedback was discontinued were: 96.0% (sink), 90.9% (toilet seat), 95.3% (door knob) and 84.0% (soap dispenser).

HKS 15 (lowest score achieved) worked in 14 rooms during the study. The results obtained for the first 12 weeks of the study were the following: 80.0% (toilet seat), 60.0% (sink), 90.0% (door knob) and 60.0% (soap dispenser). Whereas for the second 12 weeks of the study, the scores reached by HKS 15 were: 25.0% (toilet seat), 50.0% (sink), 50.0% (door knob) and 50.0% (soap dispenser). The overall increase in cleaning compliance found between the two study periods was 6.7% for HKS 16 and a decrease of 28.8% was reported for HKS 15. (Figure 17).

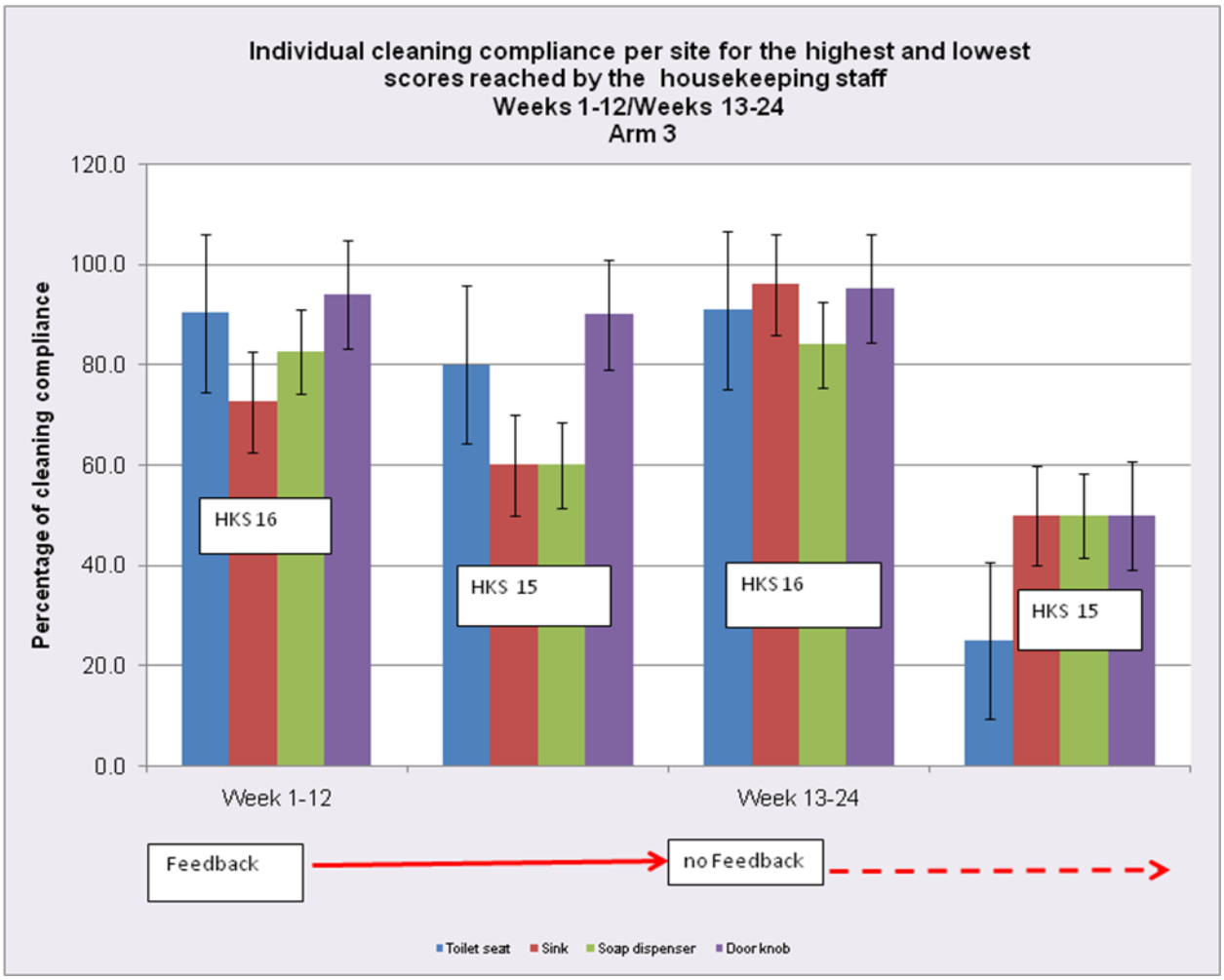


Figure 17- Individual cleaning compliance per site for two different performances along the study period- Arm 3

4.2. Cleaning tools: Comparison of microfiber to cotton cloths

We examined the efficacy of microfiber and cotton cloths to remove *C. difficile* spores from wet surfaces to another moist surface in the environment. We tested 2 surfaces commonly present in the patient's environment: ceramic and arborite for removal of spores.

For the rest of the experiments we only used ceramic, as toilet bowls and sinks are predominantly made of this sort of stoneware.

In order to mimic the pressure and movement of surface cleaning under reproducible conditions, we assembled an apparatus that could provide a defined number of rotations under stable pressure. The test cloths were mounted on the rubber stopper and held by O-rings. Each test cloth was rotated on the test surface for 5 seconds (Figure 4). On average, the pressure exerted on the surface ranged from 150-180 g/cm2. The number of rotations applied to the rubber stoppers were detected by a digital laser tachometer. The speed of rotation ranged from 57 to 65 RPM.

- *Efficacy of microfiber and cotton cloths to remove C. difficile spores from ceramic and arborite.*

We inoculated ceramic surfaces (2.2 x 2.2) cm^2, with 3.378 ± 0.13 Log_{10}/cm^2 *C. difficile* spores suspension in ATS to provide an organic challenge. The inoculated dry test surface was pre-wetted by spritzing with PBS. The population of spores picked up by the test cloths after rubbing the inoculated surface was 2.433 ± 0.10 Log_{10}/cm^2 for microfiber cloths and 2.541 ± 1.85 Log_{10}/cm^2 for cotton cloths.

The remaining bacteria population on the inoculated ceramic surface that had been wiped was 0.838 ± 0.80 Log_{10}/cm^2 for both microfiber and cotton cloths. Similar testing was performed using arborite test surfaces. The results are shown in Figure 18.

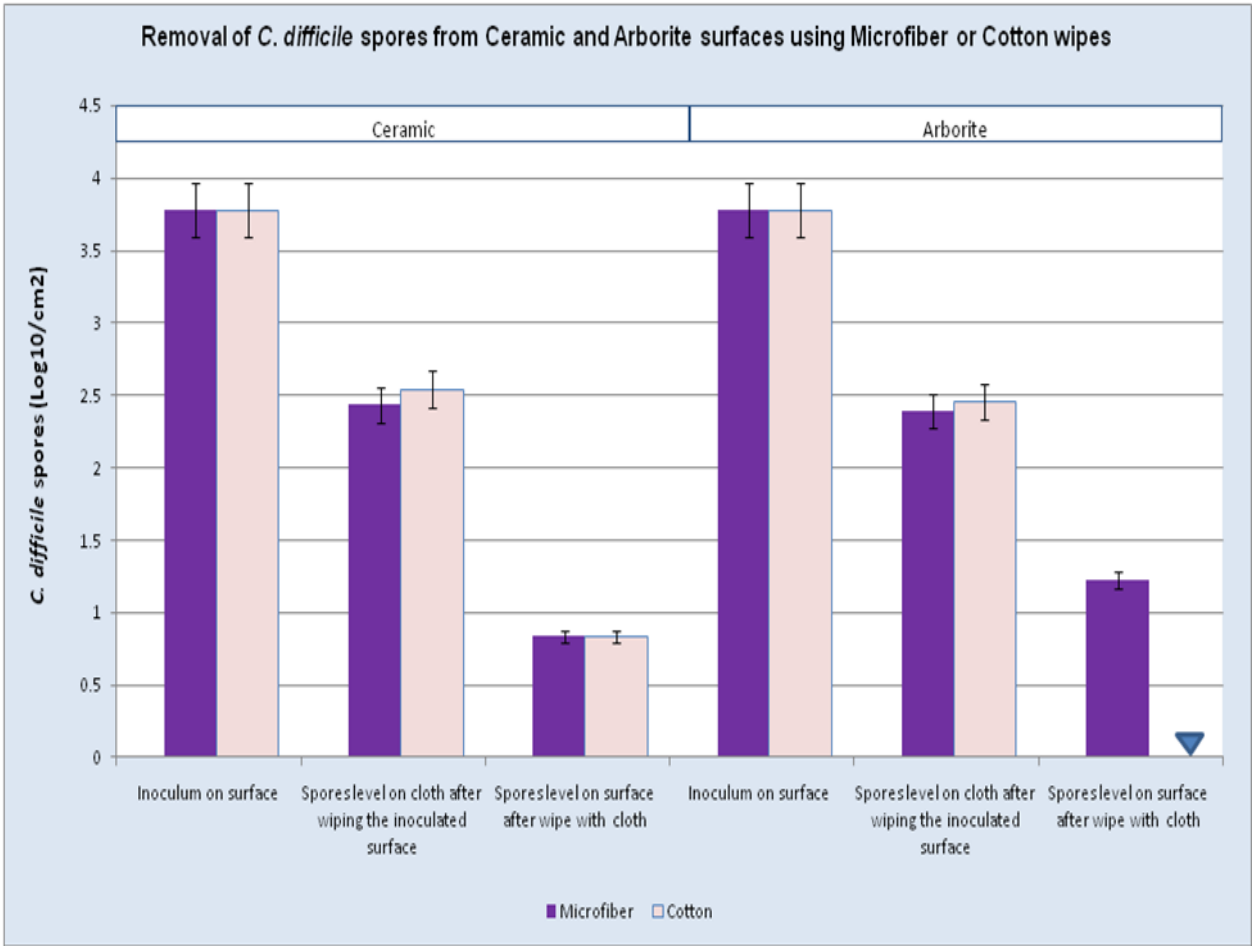


Figure 18: Efficiency of microfiber and cotton cloths to remove *C. difficile* spores from ceramic and arborite surfaces

▼Level of spores on surface after wipe with cotton cloth was under the limit of detection.

The transfer of *C. difficile* spores between two pre-wetted surfaces was evaluated using the drill apparatus. Ceramic and Arborite surfaces of 16cm^2 area were inoculated with 3.378 ± 0.13 Log_{10}/cm^2 *C. difficile* spore suspension in ATS. The surfaces were allowed to dry overnight inside the BSC.

The final results were expressed as the mean ±standard deviation of triplicate tests.

- *Transfer of C. difficile spores from pre-wetted ceramic surface to a second wetted ceramic surface.*

We used only Ceramic surface to demonstrate the ability of microfiber and cotton cloths to remove spores from the first inoculated surface (surface 1) and transport them to a new clean surface (surface 2). Viable counts were performed after the transfer was completed to determine the amount of spores present on the test cloths and surface 2. The spores remaining on surface 1 were also analysed. Positive controls were run to determine the amount of *C. difficile* spores that could be released from microfiber and cotton cloths when a known concentration of inoculums was placed on them. Negative controls were also included to verify that the test surfaces were free of contamination.

The testing was done under two conditions: the first one used PBS to wet the test surfaces and test cloths; the second used hydrogen peroxide 0.01% (Per Diem) instead of PBS. Per Diem is the disinfectant utilized by our hospital housekeeping services to clean surfaces in patient's rooms and washrooms. The results of testing using PBS as the wetting agent are shown in Figure 19. The use of Per Diem yielded different results from PBS for experiments conducted following the same testing protocol to moisten the cloths and surfaces (Figure 20). Although cotton cloths transferred spores to the second surface regardless of the wetting agent used, there was no transfer of spores by microfiber cloths when Per Diem was used.

The Log reduction obtained using microfiber was 0.811 Log_{10}/ cm^2 higher than the one reached when cotton cloths were used for removal of spores from inoculated ceramic surfaces.

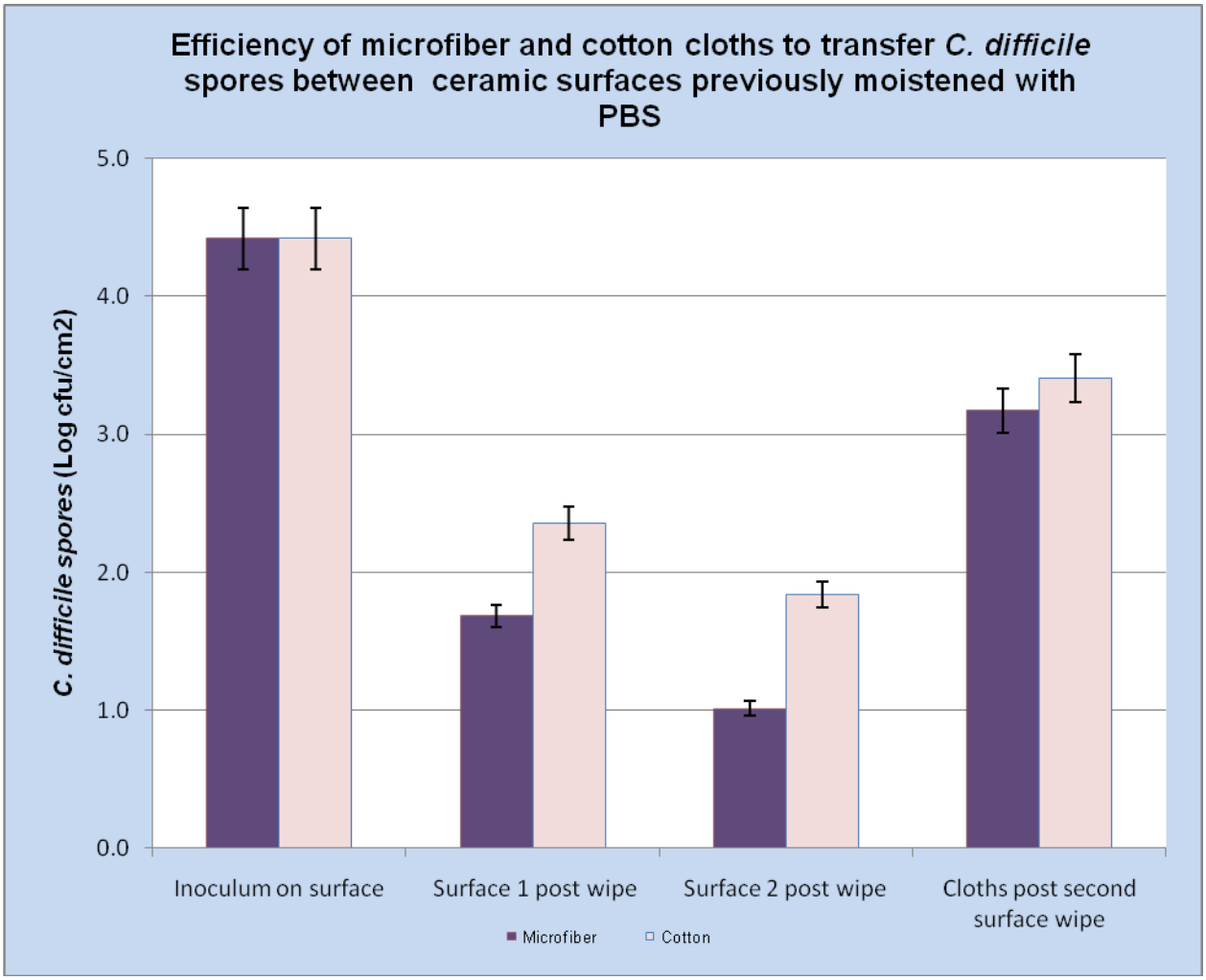


Figure 19: Efficiency of microfiber and cotton cloths to transfer *C. difficile* spores between ceramic surfaces previously moistened with PBS

The drill apparatus was used to mimic the action of manual cleaning. Ceramic surfaces were cut in squares (4.84 cm^2) were inoculated with 4.418 ± 0.06 Log_{10}/cm^2. The surfaces were air dried under the BSC overnight. The following day, they were wetted by spritzing with PBS right before applying the drill apparatus's pressure on them.
Viable counts were performed on the elutents obtained from the original surface (surface 1), the second ceramic test surface that had been mechanically wiped using the drill apparatus (surface 2) and the elutents extracted from the test cloths.

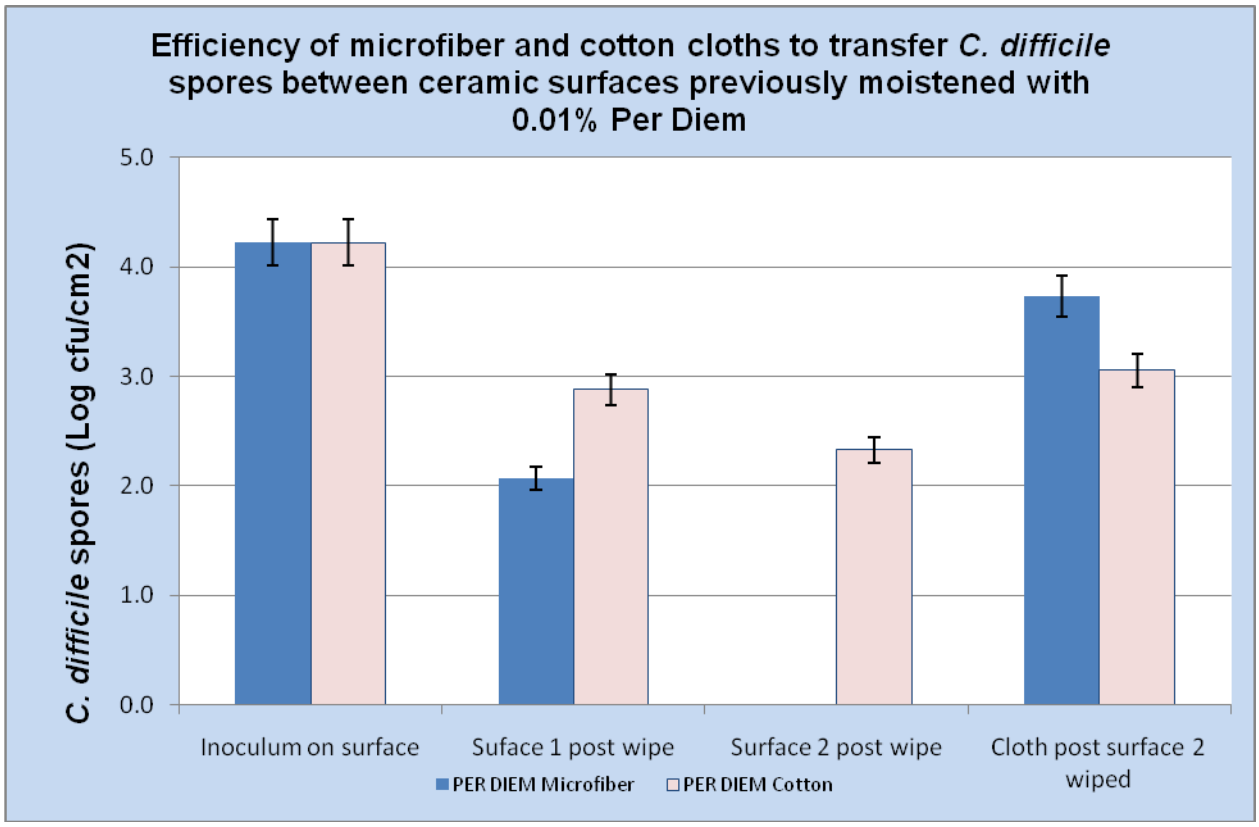


Figure 20: Efficiency of microfiber and cotton cloths to transfer *C. difficile* spores between ceramic surfaces previously moistened with 0.01% Per Diem

The *C. difficile* spore inoculum on the first surface was 4.220 ± 0.09 Log_{10}/cm^2 . Per Diem was used at a 1:64 dilution for a final AHP concentration of 0.016%.

We tested the carryover of bacteria using test cloths directly inoculated with *C. difficile* spores. Microfiber and cotton cloths were inoculated with a previously known concentration of *C. difficile* spores. The transfer was performed under the same conditions as the one described before, with the only difference that spores were not collected from a surface and transported by the cloths to a new wet ceramic surface rather than the inoculum was placed directly onto the test cloth. Microfiber released fewer spores onto the test surfaces compared to cotton test cloths (Figure 21).

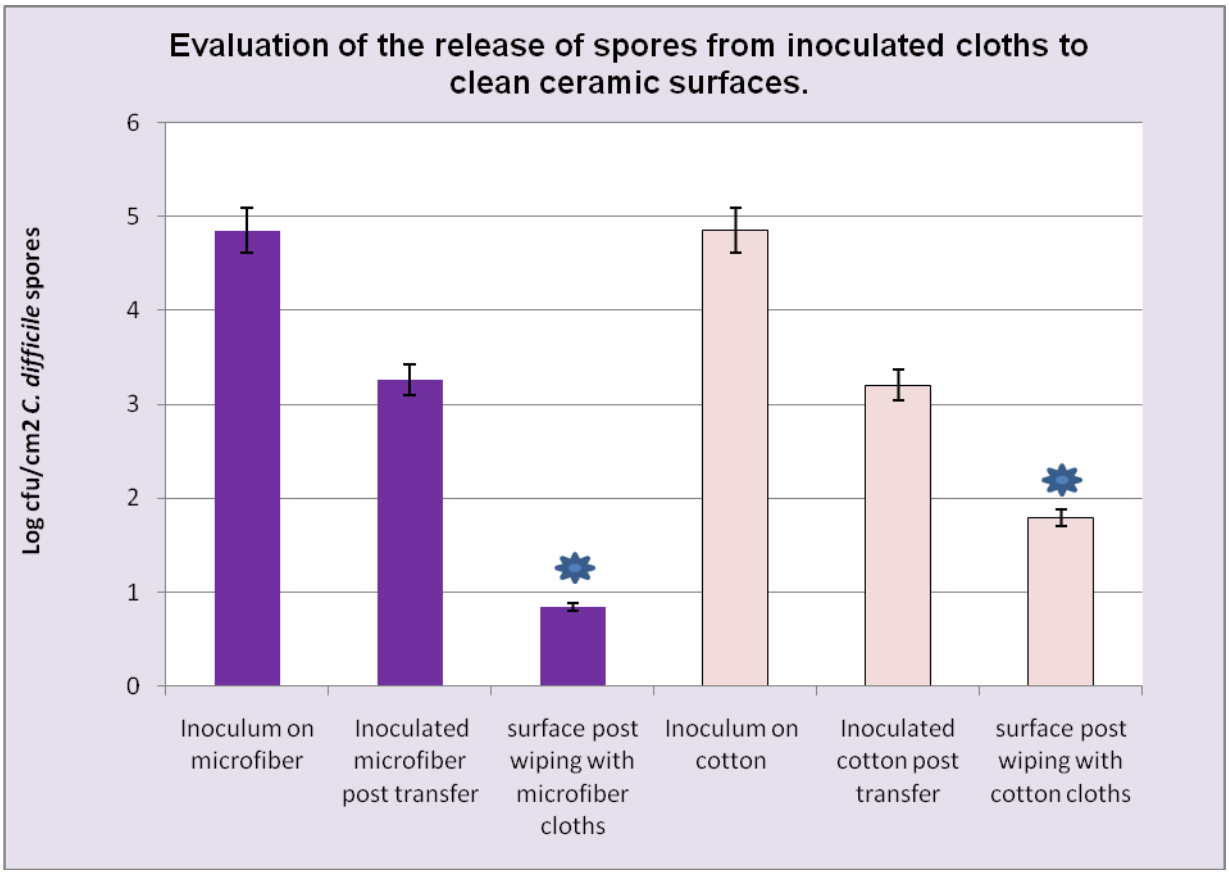


Figure 21: Efficiency of inoculated microfiber and cotton cloths to release *C. difficile* spores to clean ceramic surface previously moistened with PBS

Inoculated microfiber and cotton cloths were used to evaluate the transfer of spores from wipes to ceramic surfaces using the drill apparatus.
Cloths and surfaces were processed after the transfer was completed and viable counts were performed on the elutents.
This experiment allowed us to compare the ability of previously inoculated cotton cloths to release spores on wetted ceramic surfaces compared to microfiber cloths, under the experimental conditions.

Significantly different ($p < 0.001$)

- Laundry process ability to remove spores from microfiber and cotton cloths

Microfiber and cotton cloths were inoculated with a known concentration of *C. difficile* spores after being laundered a spore count was performed on the cloths.

The negative control yielded 0.863 ± 0.0.95 Log_{10}/ cm^2 *C.difficile* spores on microfiber and 1.634 ± 1.85 Log_{10}/ cm^2 *C. difficile* spores on cotton cloths, after the laundry process. This means that the cloths picked up organisms from the laundering process.

Ward use cloths were evaluated before and after being exposed to the laundry process, they were tested as per protocol and cultured for aerobic and anaerobic bacteria. The overall count of aerobic bacteria grown on blood agar plates cultured in triplicate yielded 3.157 ± 1.8 Log_{10}/ cm^2 on microfiber cloths and 3.215 ± 1.8 Log_{10}/ cm^2 for cotton cloths. Anaerobic cultures of the cloths resulted in a count of 0.464 ± 0.6 Log_{10}/ cm^2 on microfiber cloths after being laundered and no growth on the eluate from cotton cloths was detected. Further studies are currently being conducted in our Lab to elucidate this finding. No spores were found on the ward use cloths up until the submission of this Thesis after the laundering process.

Negative controls contained 0.863 ± 018 Log_{10}/ cm^2 for microfiber and 1.634 ± 0.75 Log_{10}/ cm^2 of *C. difficile* spores for cotton cloths after laundry. The colonies grown on CDMN were tested for fluorescence under the UV light, Gram stained and a positive Proline test was performed to confirm the identification of *C. difficile* isolates.

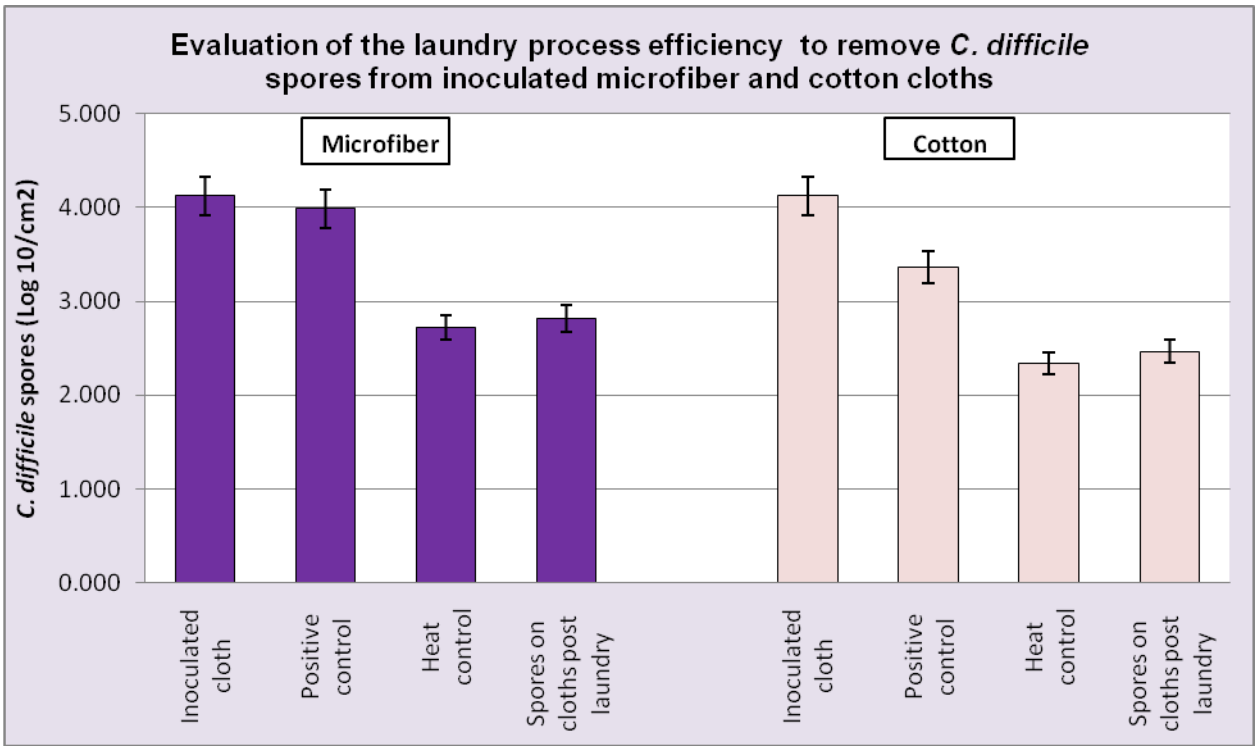


Figure 22: Evaluation of the laundry process efficiency to remove *C. difficile* from microfiber and cotton cloths.

Inoculated microfiber and cotton cloths were placed in mesh bags in the housekeeping washing machine to test the efficiency of the laundering process.
Inoculated cloths , used for heat controls, experienced the same thermal conditions inside small sealed cryovials tubes. These controls allowed us to check whether the heat applied to the process was high enough to kill *C. difficile* spores or not, without the help of fluid detergents or disinfectants.
Positive controls of inoculated cloths were not exposed to the washing process.
All the cloths were processed after the exposure to the laundry process and viable counts were performed on the elutents.

5. Discussion

5.1. Cleaning audit: Clinical study

The results of our study contributed to better understanding of the UVM as a useful audit methodology to assess cleaning compliance. There is a lack of national written principles for the practice of cleaning in Canada (PIDAC, 2009). The level of cleaning compliance in health-care settings is not regulated. It is commonly based on visual audit. This method is not objective and usually overvalues cleanliness (Sherlock et al., 2009).

Recent studies by Sherlock et al. (2009) compared visual assessment with microbiology testing such as total aerobic colony count (ACC), and MRSA detection to establish cleaning efficiency. Although the cost of ACC swab is low, the processing of the samples requires 48 hours incubation and microbiology lab personnel need to be available to perform the testing. Lewis et al. (2008) suggested that ACC may be used under specific circumstances such as outbreak investigations. This study also tested adenosine triphosphate (ATP) bioluminescence monitoring system. ATP audit is a sensitive test; however, it does not correlate with cfu/ml values shown by ACC testing, as reported by Sherlock et al. (2009); Lewis *et al.*(2008). ATP reflects the contamination with organic material (i.e.: milk, urine, blood). These findings do not necessarily show a relationship with the presence of pathogens in the healthcare environment.

We chose UVM as a tool to monitor cleaning compliance. The UVM can be used in a broad range of health-care facilities. Sustained cleaning compliance can be easily assessed by

housekeeping supervisors and housekeeping staff may perform self assessment on a daily basis. The purpose of cleaning is to physically remove foreign material (i.e. dust, soil) and organic material (i.e. blood, body excretions and fluids, microorganisms). It is crucial to use friction in order to remove microorganisms and debris (PIDAC, 2009). Therefore, the complete removal of the UVM from the chosen surfaces proved that the compliance with cleaning protocols was optimal.

A previous publication showed the important role that performance feedback provided to housekeeping personnel plays in improving environmental cleaning. (Carling *et al.*, 2008b). They evaluated the terminal cleaning compliance on a range of high risk surfaces on patients' rooms and bathrooms before and after an intervention. The results were presented to the environmental services personnel and hospital directors for evaluation. Educational soft wares were distributed to show the results obtained during the intervention, emphasizing on the consequence of a higher level of cleaning compliance on the improvement of patients' safety in the hospital setting. After this intervention, they assessed the performance of the employees for a second time and evaluated the positive impact of cleaning feedback on the environmental services personnel performance.

In terms of patient safety, we focused on testing the surfaces that are most likely to be in contact with the patients and heath care personnel in general. Therefore, the toilet seat, the sink, the washroom door knob and the soap dispenser were the sites chosen in the patients'

washrooms to assess compliance with housekeeping protocols. These are high touch environmental surfaces which pose a risk to the entire hospital community. As a consequence of the temporary stay of the staff, patients and visitors within the health care setting, there is an increasing opportunity of contact with contaminated surfaces, either directly or indirectly. The toilet seat and the sink are by far the sites most exposed to excretions and secretions of patients. Health care workers use them to discard dirty solutions and dirty water after cleaning bedpans (PIDAC, 2009). These regular practices may increase the chance of contaminating surrounding areas. AROs could be disseminated to other surfaces which are also in contact with patients, such as faucet handles, commodes and walls, among others. (PIDAC, 2009). These are the main reasons why we chose the door knob in the washroom and the soap dispenser to perform our research study, as examples of high touch surfaces.

Broadly speaking, the 3 Arms followed the same pattern of scoring for cleaning compliance for the 4 sites. Our findings are consistent with other studies by Carling *et al.* (2007). The two best cleaned sites were the sinks and the toilet seats. In contrast, the overall cleaning compliance for the bathroom doorknobs and for the soap dispensers was lower.

Our research study represents the first report that shows the impact of daily performance feedback of permanent and casual housekeeping employees' behavior for a 24 weeks period of time. The posting of the graphs on the wards and housekeeping office on a weekly basis,

contributed in expanding our results to different members of the hospital community, such as patients, visitors, nurses, doctors and volunteers. Peer pressure exerted on performance improvement played a crucial role in achieving the highest score.

The design of our study allowed us to demonstrate the sustainability of cleaning feedback by 3 different groups of employees. One acted as a positive control, the second showed the influence of the UVM in improving cleaning compliance even before the start of the feedback phase of the study and the third one demonstrated that cleaning compliance could be sustained, even though feedback was discontinued. Consequently, we demonstrated that for some groups feedback is useful for sustaining compliance, whereas for other groups UVM is a powerful tool to encourage the staff to achieve their best level of cleaning compliance.

The staff members' individual behavior was never examined before this report using the UVM as an audit tool. We found that cleaning feedback improved cleaning compliance of both casual and permanent staff.

Even more interesting is the influence that the trainer may exert on causal and new employees on the job training. Our data is the first to show that there is a correlation in cleaning compliance scores reached by 'the trainer' and 'the trainees".

The pre-study level of cleaning compliance using the UV Marker, when supervisors provided verbal feedback to the staff, was 55%.The sites that were tested were the toilet seat, the sink, the washroom door knob and the soap dispenser. We applied our methodology for 9 weeks without providing any feedback; surprisingly, the percentage of cleaning compliance reached 66.7% for the three Arms, on average. This improvement in the staff performance likely occurred because the staff were aware that a study on cleaning was to be implemented.

Each Arm of the study consisted of 2 wards, and the results were reported to the staff and supervisors as an average of the cleaning compliance scores obtained by all staff on the two wards combined. Arm 1 was the control group, as they received feedback for the whole study period. Arm 2 did not receive feedback for the first 12 weeks of the study, and then feedback was provided to this group for the last 12 weeks of the study. Arm 3 was given feedback from week 1 to week 12; feedback was discontinued from week 13 to 24.

A meeting with housekeeping staff was held and there was a discussion regarding the level of cleaning compliance that they felt was a reasonable target. Based on the meeting and the verbal survey, 90% was set as a target cleaning compliance to be reached after the implementation of the UVM audit methodology.

Each HKS member was given a code to keep their identities anonymous. Casual employees for each ward were considered as a group and they were included in the same unique "casual" code.

Arm 1: after 5 weeks from the study start date, they reached the study target of 90%. Although the 90% compliance target was not maintained they were able to sustain over 80% cleaning compliance over 80% of the time. This is the only Arm that reached 100% cleaning compliance as a group, in 12.5% of the time during the first 12 weeks. The overall cleaning compliance during the first 12 weeks was 88.6% and this percentage dropped to an overall average of 85.6% during the second 12 weeks ($P<0.05$).

We analysed the individual behaviour of the HKS members in order to investigate the factors involved in cleaning compliance. The personal performance analysis showed that the overall result could be extremely influenced by the individual behavior. We examined the score obtained by two HKS members, HKS 2, who achieved the highest score in Arm 1 and HKS 7, who obtained the lowest score. HKS 2 reached 95.0% for the first 12 weeks of the study, whereas HKS 7 only achieved 77.1%. For the second 12 weeks of the study HKS 2 sustained cleaning compliance level over 90%, obtaining 91.5% on average, whereas HKS 7 showed a significant drop in cleaning compliance reaching only 58.9%, with respect to the score obtained in the first phase of the study.

It should be noted that HKS 7 represents the group of casual employees for one of the 2 wards included in Arm 1. When the group of casual employees working on the other ward in the same Arm was tested (HKS 4), the results obtained were surprisingly different. HKS 5, the employee who trained HKS 7 (casual employees group) obtained the best score on the ward where HKS 7 worked. However, HSK 5 never accomplished a score as high as the one

achieved by HKS 2, the employee who trained HKS 4 (casual employees group) on the other ward that was part of Arm 1. Despite the fact that the employees HKS 2 and HKS 5 (both trainers) worked at a level above 80% of cleaning compliance for the 24 weeks, only HKS 2 sustained the score above 90% all the time. Conclusions drawn from testing the casual group working on both wards (HKS 4 trained by HKS 2 and HKS 7, trained by HKS 5), led us to conclude that the casual group who worked with HKS 2 simply received better training than the one who was trained by HKS 5. The influence of the initial "trainer", especially for new employees could be a key factor in the accomplishment of a better level of cleaning.

The choice of cleaning compliance as a UVM of 0 or a UVM of < 3 (i.e. some cleaning), did not affect Arm 1 results very significantly during the first 12 weeks of the study. ($P>0.05$). The overall cleaning compliance result was 88.6% using the < 3 UVM score for Arm 1, whereas only a small reduction to 77.8% compliance occurred when the UVM score was set to 0 (i.e. total cleaning). Contrasting with the first phase of the study, for the second 12 weeks using the UVM score of 0 as the indicator of "clean", Arm 1 only reached 58.8% compliance which is a significant drop compared to cleaning compliance of 85.6% achieved when the UVM scale of < 3 was utilized.($P<0.05$). The reason of this discordant outcome could be the fact that 100% compliance was reached less frequently during the second phase of the study; therefore UVM scores representing some cleaning compliance rather than UVM score 0, predominated and the percentage of compliance decreased.

Arm 2: they reached 90% cleaning compliance on week 4 and compliance never went back to the pre-study level of 55%, nor the control without feedback level of 66.7%, even though feedback was not given to this group for the first 12 weeks of the study. The overall cleaning compliance for weeks 1 to 12 was 76.6% and 80.4% for the last 12 weeks of the study. No significant difference was found in the overall cleaning compliance for both phases of the study. ($P>0.05$). The performance of Arm 2 does not seem to be affected by the feedback provided to them on the second phase of the study. However, the fact that the other 2 Arms of the study were receiving feedback while Arm 2 was not informed of their cleaning performance could strongly influence their behavior. The staff members were willing to know their level of compliance, as they declared to the study researcher.

HKS 24 achieved the highest score for Arm 2. This HKS worked in 38 rooms (50% of the 24 weeks) and reached 91.7 % cleaning compliance for the first 12 weeks of the study.
HKS 30 achieved the lowest score in Arm 2 and provided service to 16 rooms (29% of the 24 weeks) and only achieved 51.5% cleaning compliance. For the second 12 weeks of the study, when feedback was provided, HKS 24 sustained a cleaning compliance level over 90%, obtaining 92.0% on average, whereas HKS 30 showed an increase in cleaning compliance reaching 58.3%.

Interestingly, the same phenomenon, as seen for casual employees in Arm 1, was observed for Arm 2. HKS 30 represents the group of casual employees which obtained the lowest result of the overall cleaning compliance for Arm 2. They were trained by HKS 26, the

employee who achieved the highest score on the same ward. HKS 24 trained HKS 23 (casual employees working on the other ward that was part of Arm 2). When HKS 23 was evaluated the results obtained were surprisingly higher than the performance scores obtained by HKS 30. The explanation for such a difference between the casual employees' performance working in the two wards which formed Arm 2, is that HKS 26 (trainer of HKS 30) never accomplished a score as high as the one achieved by HKS 24 (trainer of HKS 23). In addition, HKS 24 accomplished a score over 90% in 66.7% of the study period, while HKS 26 score over 90% in 50% of the time.

These additional findings support the idea that the compliance of the trainer plays a significant role in the compliance of the staff they train. Moreover, our results showed that when the contribution of shifts filled with casual employees is high compared to the shifts staffed by permanent personnel, the overall cleaning compliance score decreases. The same analysis could be extracted from the 3 Arms that were involved in our study. Important conclusions that could be drawn from this interesting evidence, is that the training protocols of casual employees should be reviewed and improved in order to provide new and casual staff with the same high quality of instruction as the one received by permanent and senior staff members. Standardizing the training and appointing a qualified and skill employee as 'the trainer' with demonstrated compliance could play a major role in improving cleaning provided by casual staff.

A decrease in cleaning compliance results was observed when we used a UVM of 0 (i.e. clean) and a UVM of < 3 (i.e. some cleaning) to monitor the staff in Arm 2. The overall cleaning compliance result for the first 12 weeks of the study was 76.6% using the < 3 UVM score, whereas a reduction to 61.9% compliance was reached when the UVM score was set to 0 (i.e. total cleaning). (P<0.05).

When the UVM score <3 was implemented for the second 12 weeks, Arm 2 reached 80.4% cleaning compliance. The use of the UVM score of 0, showed a significant drop in cleaning compliance as Arm 2 only reached 44.6% compliance. (P<0.05). This drop in cleaning compliance reflects the predominance of UVM scores that represent some cleaning compliance over those that correspond to 100% cleaning compliance. (UVM score of 0).

Arm 2 reached 92.0% cleaning compliance for the sink and 87.7% for the toilet seat, 64.3% and 56.0% for the door knob and the soap dispenser respectively while they were not receiving feedback. When feedback was given to them, the results for the sink and the soap dispenser decreased by 6.7%. However, cleaning compliance for the door knob and the soap dispenser improved by 15.3%.

Remarkably, HKS 24 reached scores over 85% for the sink, the toilet seat and the door knob, and 81% for the soap dispenser when this group was not receiving feedback; Moreover, this staff member sustained the cleaning level over 90% for the 4 sites when feedback was given after monitoring the wards.

This data demonstrated the value of the UVM audit tool. It was not only successful in identifying low compliance employees but it also identified those who achieved good compliance all the time regardless of the feedback provided. By reporting these results anonymously to the whole group of employees, supervisors could show how the job could be complete at the highest level of performance.

Arm 3 was represented by 9 HKS and 2 casual groups, 11 HKS in total. These HKS never achieved the target of 90% cleaning compliance as a group during the first phase of the study when they were receiving feedback. In the second twelve weeks when feedback was discontinued they only achieved the target of 90% cleaning compliance on 8.3% of the time.
The overall cleaning compliance for the first 12 weeks was 74.0% and 78.0% for the last 12 weeks of the study ($P>0.05$). The highest score was obtained by HKS 16, who worked in 48 rooms for the whole length of the study (100% of the time) and had a cleaning compliance score of 84.9%. HKS 16 increased the level of cleaning compliance by 6.7% when feedback was discontinued in the final twelve weeks of the study.

HKS 15, who achieved the lowest score of Arm 3 (72.5 %), cleaned fewer rooms than HKS 16. This HKS performance showed how feedback could impact on individual behavior.
In the second twelve weeks when feedback was not received, HKS 15 showed a dramatic drop in cleaning compliance, reaching 0% on one week. HKS 16, on the contrary, showed a cleaning compliance score of 91.6% which is even higher than achieved while receiving feedback.

Generally speaking, this Arm followed the same cleaning compliance pattern for the four sites examined as the other two Arms; the toilet seats were the best cleaned site and the soap dispenser the least cleaned. When the individual conduct was examined, the discrepancies between individual HKS behavior allowed us to verify the important role that the UVM audit plays when supervisors need to follow up the performance level of trainees and casual staff separately from permanent or experienced staff.

The number of rooms assigned to each HKS might have influenced the score achieved by each staff member. It could be considered that an employee, who cleans a higher number of rooms in a given period of time, might reach a lower score if the time spent per room was not enough to meet the terms of the cleaning protocols. It should be noted that employees who cleaned less than 10 rooms throughout the study were not included in this analysis.

However, this study revealed that the HKS who obtained the highest score for each Arm were the employees who were assigned a higher number of rooms on their working schedule. The difference in work load is based on the working shifts. Part-time employees will clean less number of rooms than full-time staff members. This fact does not prevent the HKSs from achieving a higher score. Moreover, some staff members devote part of their time working on the wards, and part working on different locations, such as hallways, out-patients area, and waiting rooms within the health-care facility. We demonstrated that the level of cleaning compliance is not dependent on the work load.

Interestingly, HKS 16, the employee who achieved the highest score in Arm 3, belongs to the group of staff members who cleaned over 40 rooms throughout the study period. The scores obtained for the different sites when feedback was discontinued for this Arm, were higher than the scores obtained when feedback was provided. HKS 16 scored over 90% of cleaning compliance for the toilet seat and the door knob, while receiving feedback. The score for the sink, the toilet seat and the door knob reached by this staff member were sustained over 90% of cleaning compliance and improved when feedback was discontinued in comparison to the results obtained when receiving feedback.

Definitely, the UV marker can be implemented for accurate individual feedback. The UV marker will help identify the staff members within a team who are responsible for sustaining a high level of cleaning compliance. This will reduce the error in supervisor ratings.

In some cases, this monitoring tool will reveal the identity of the employees whose performances are inadequate to help maintain a desired level of cleanliness in the health-care environment. These results strongly support our hypothesis. In the case that the team did not achieve the target level, individual performance demonstrated that 90% of cleaning compliance represents a score that could be achieved by implementing the UV marker methodology along with the introduction of performance feedback.

General considerations

The wards included in each Arm were chosen with no particular preference for which wards were used. We chose the 6 wards included in this study based on the fact that they were not ICU units, but regular internal medicine care facilities. The six wards had in common the same case scenario: they are general medicine wards where the patients may be hospitalized for long periods of time and the rooms may become 'isolation rooms' at any time.

However, the wards involved in this study differ in the nature of the patients that they can accommodate. Arm 1 included two wards that take care of patients who had different types of surgery, while Arm 2 comprised 2 wards that provide accommodation for elderly and dialysis patients. In Arm 3 we tested long term patients' wards, including cancer and obese patients.

Many factors may influence the level of cleaning compliance accomplished by housekeeping employees. The average cleaning time is calculated based on the normal time required by a skilled worker to comply with regulations in place. The normal cleaning time depends on education and training. Generally, new workers perform their job at a lower pace compared to experienced employees (PIDAC, 2009).

Staffing is an important aspect to be taken into consideration. The appropriate number of staff members allocated to a particular ward should be carefully considered in order to meet the needs of each department in a health care setting.

A good distribution of the staff will contribute to the success of the environmental cleanliness. The number of personnel assigned to a particular ward should be increased in the case of outbreaks (PIDAC, 2009.

It is plausible that differences in patient acuity, mobility and in-room equipment may affect the easiness with which cleaning can be performed. Older facilities pose more difficulties to be cleaned in a proper manner, such as the design (i.e. shared rooms and bathrooms), type of floors, number of surfaces present in the patient environment (PIDAC, 2009). The size of the rooms and space available per patient should be taken into consideration when planning the renovation of an old health care institution or building a brand new facility. The removal of avoidable furniture could provide patients and housekeeper with more space to move around and to prevent any possible accident.

The occupancy rate of the facility, including volume of patients assisted by the health care institution, and rapid turnover of clients (i.e. frequent new admissions/discharges), would determine the regularity of cleaning required (PIDAC, 2009). When patients are discharged the rooms need a thorough terminal cleaning, which definitely determines a priority in the environmental services schedule. All these dynamic scenarios require a rapid adaptation of the housekeeping staff to these new situations. The requirement to use PPE, could be an additional factor for an increase in the cleaning time spent by the housekeeping staff on each room (PIDAC, 2009).

It should be noted that in our facility the cleaning of the patients' regular rooms is done once a day, unless the room becomes an isolation room. The incidence rate of AROs and outbreaks in a particular health care facility may determine the need of isolation rooms by an increased number of patients at the same time; consequently, the daily schedule may change with very short notice.

The presence of healthcare personnel (i.e. doctors, nurses, etc) and visitors in the patients rooms at the moment when cleaning should be performed may interfere with the ability of cleaning personnel to complete the housekeeping work . Especially, in the long term care units, where visitors may stay overnight, introducing an additional load of work on the housekeeper duties.

5.2. Cleaning tools: Comparison of microfiber to cotton cloths

Recently, microfiber cloths were offered on the market as an innovative cleaning tool. The manufacturers claimed that this new textile is able to remove microorganisms from the environment more efficiently than cotton cloths. This difference in the quality of cleaning may be due to the nature of the internal structure of the microfiber wipe (Norwex, 2009, Tergo, 2009, Blue wonder, 2009).

There have been no published studies to determine if removal and/or transfer of *C. difficile* spores from surfaces are altered by using microfiber cloths instead of cotton cloths.
We chose to examine this issue and, in addition, to assess the efficacy of laundering or eradicating *C. difficile* spores from cleaning cloths. The equipment apparatus used in this study was an adaptation of that described by Williams *et al.* (2007).

This report demonstrates the essential role that the nature of the surfaces may play in the interaction with the cleaning cloth. Two surfaces, considered the most common ones present in the health care environment were tested: ceramic and arborite. Ceramic surface seems to absorb the inoculums easier than arborite; the internal structure of this material may leave pores inside the matrix where eventually bacteria and particles would remain. Once the spore suspension is inoculated on ceramic surfaces, the drying process begins. The liquid runs through the porous surface. As a consequence, the solid material receives a gradient of pressure on different directions inducing deformation of the surface and dilatation of the pores.

Evaporation of the liquid/vapour interface (meniscus) present on the surface may occur while the fluid is still on the exterior of the pore. When the radius of the meniscus is small enough, the fluid can remain inside the pore. The last step in the drying process is the deep penetration of the fluid inside the pore which creates a saturated region. Within this region the spore suspension might be more compressed than the fluid remaining near the outside region of the ceramic surface (Chotard *et al.*, 2007).

Microfiber cloths are more efficient at removing spores from ceramic than at collecting them from arborite surface. Cotton and microfiber cloths picked up equal amount of spores from ceramic. However, when we numbered the spores left on arborite after the surface was wiped with cotton cloths using the drill apparatus, no colonies were grown on the plates. Arborite is not a porous surface; therefore no absorption of the inoculums could have occurred as in the case of ceramic surface. We implied that cotton cloths might have reached a closer contact with the arborite surface than microfiber, when the pressure was exerted on the surface by the drill apparatus. The reason for a lower interaction between microfiber cloths and the arborite surface might have been the irregular matrix of the microfiber cloths compared to the regular internal structure of the cotton cloths. Consequently the level of spores left on the surface was higher when microfiber was used. The concentration of spores on the arborite surface when cotton cloth was used to remove spores from it, was under the limit of detection of the methodology that we used to numbered *C. difficile* 765 spores.

Interestingly, no relevant discrepancy was found on the viable count done on microfiber cloths and cotton cloths eluate after the transfer experiment using PBS as the moistening agent was performed ($P>0.05$, CI: 95%). Despite this evidence, the presence of spores removed from surface 1 by microfiber cloth was greater than the one for cotton cloths. ($P<0.05$). The ability of cotton cloths to release spores on a clean surface was higher compared to microfiber cloths. Taken together, these findings clearly explain that microfiber can remove bacteria more efficiently than cotton cloths and, even more interesting, that they can better retain microorganisms without releasing them onto a new surface compared to cotton cloths.

The release of spores onto a wet ceramic surface from inoculated cotton cloths was significantly greater than the release from inoculated microfiber cloths. Only 0.05% of the original inoculum was found on the surface when microfiber was tested.

In particular, we focused on the daily activities of housekeeping staff in the health care facilities. With this purpose in mind, the transfer study was repeated with 0.01% Per Diem as the moistening agent. The outcome of this experiment was predicted; however, the fact that Per Diem could reduce the bacterial population in the bioburden, had not been tested in previous studies with spores on microfiber cloths.

The amount of spores retained by cotton cloths was smaller than the one retained by microfiber, whereas the spore population on surface 1 when cotton was tested was greater compared to microfiber ($P<0.05$). Furthermore, no growth was seen on the eluate from surface 2 when microfiber was used for the transportation of spores.

When the surface was moistened with 0.01% Per Diem, microfiber cloth did not release spores as readily as when the surface was sprayed with PBS. An interpretation of this event could be that the addition of 0.01% Per Diem to moisten the microfiber cloths killed part of the spore population present inside the microfiber matrix.

It is plausible that the combination of the killing actions of 0.01% Per Diem and the interaction between hydrogen peroxide and the static charges present in the microfiber matrix, resulted in an increased ability of microfiber to retain spores inside the textile.

Other means of environmental hygiene were proposed such as steam disinfection. There are some disadvantages in implementing this methodology. Some of the contaminated surfaces in the patients' rooms may be electrical devices and appliances. (i.e. buttons, switches on computers and electrical equipment). They need to be cleaned very frequently and the exposure time of the microorganisms to the steam is crucial. The wetness of the environment may encourage survival of certain pathogens and biofilm formation. In addition, inhalation of steam may aggravate breathing symptoms in predisposed patients (Griffith & Garret, 2009).

Washing laundry is a crucial part in the process of re-using cloths in the hospital setting, as they may carry infectious agents such as bacteria, fungi and virus. (Fijan *et al.*, 2005).

Therefore, the laundry procedure must have an effective action against these microorganisms. Hospital cloths are utilized and re-used by patients with a weak immune system; proper hygiene of textiles is essential to prevent survival of germs and spread to other clean area within the laundry room (Fijan *et al.*, 2005). Specification on composition and concentration of cleaning

agents, temperature, mechanical operation procedures and adequate length of washing, disinfecting and drying times must be taken into consideration.

Microfiber manufacturers recommend laundering of their product with warm water and/or a soft detergent before reuse the cloths. (Norwex microfiber, 2009). This recommendation is only applicable to some settings (i.e. household, office) where the presence of microorganisms is lower than the bacterial and virus populations usually found in the health care environment.

Since microfiber does not have a killing effect on bacteria, the assumption that the cleaning laundry will disinfect the cloths properly could not be affirmed unless the laundry conditions are controlled in-depth, are evaluated periodically and biological indicators are included in every load.

Considering the increased number of resistant bacteria that are present in the hospital environment nowadays, it would be recommended to run washing loads more frequently in order to leave enough space inside the machine for the cloths to get in contact with detergents and disinfectants.

When we assessed the laundry process, it was accomplished 1.308 Log reduction on the spore population inoculated to microfiber cloths and 1.655 Log reduction on the inoculated cotton cloths. Patients' fecal material may contain up to 10^4 spores/g feces (Alfa *et al*, 2008). It should be noted that in our simulated study we inoculated the microfiber and cotton cloths with 4 logs of *C. difficile* spores per cm^2.

After laundry, our experiments with ward use wipes showed that before laundry the most common microorganisms present on the cloths were Gram positive rods and Gram positive cocci from the environment. *C. difficile* spores count on microfiber cloths after laundry was 0.464 ± 0.6 Log_{10}/ cm^2, while no growth on the eluate from cotton cloths was detected.

Further studies are being conducted in our lab in order to investigate more in detail the reasons why the laundry process was not efficient enough to bring the concentration down to an acceptable level. No spores were found on the ward use cloths up until the submission of this Thesis after the laundering process. We concluded that under the real life situation the level of spores in the environment is lower than the one we used for our simulated study.

However, if the concentration of spores was increased due to a frequent scenario in the health care setting (i.e. outbreak, sudden patient's episode of diarrhea), as we demonstrated in our simulated study, the current conditions of the laundry process would not be adequate to reduce the spore load.

The washing process appears to be insufficient to disinfect ward use and experimental cloths. It is not feasible to re use either microfiber or cotton cloths after being washed under the current conditions. It would be recommendable to through the cloth after direct use on the wards if it looks visibly contaminated with fecal material after cleaning the patients' washrooms.

The positive controls for heat killing demonstrated that the heat is not consistent inside the laundry machine and that some microorganisms could be more exposed than others to the killing

effect of the heat. Another interpretation would be that the heat reached by the machine, although consistent, is not sufficiently high in order to kill bacteria in the spore form.

The presence of spores on negative controls placed inside the washing machine could be understood as the consequence of the exposure of microfiber and cotton cloths to the spores present on other pieces of cloths, including our testing cloths inoculated with *C. difficile* spores. This finding raises the concern that in the case of an outbreak, clean linen could be contaminated with spores unless the laundry process and conditions are improved to reach the standards.

Although both cotton cloth and microfiber cloth can remove comparable amounts of spores from the surfaces, the tremendous difference found in the release of spores when 0.01% Per Diem was the cleaning agent, provides a convincing evidence that microfiber cloths use should be implemented, even when the spores collected by the textiles could not be released from the wipe during the laundry process and a new cloth needs to be used per patient's room.

No economic effort to prevent the transmission of AROs within the health care environment is sufficient, compared to the cost of a drug treatment against a resistant pathogen. An additional factor to be considered is the impact of prolonged length of stay of inpatients on the hospital beds availability and, overall, the patient's priceless safety and well being.

6. Conclusion

The use of the novel UVM as an audit mechanism to monitor housekeeping staff performance resulted in a better tool than the visual audit to assess cleaning compliance with the established protocols. The introduction of the UVM as a novel monitoring tool and the feedback provided to the housekeeping staff helped to enhance and sustain ongoing compliance of housekeeping personnel with established protocols in some groups of environmental services staff members.

The implementation of this methodology will contribute to assure a better performance of the housekeeping staff as a team and individually, while reducing the inaccuracy in supervisors' observations on their employees' performances. Moreover, the application of the UVM method along with performance feedback will influence casual and new employees' effective training, as it was demonstrated to be crucial in achieving a high overall cleaning compliance score.

The use of microfiber cloths in the daily cleaning in the hospital setting as an alternative for cotton cloths may decrease the number of microorganisms on environmental surfaces. They are more efficient at removing spores from the surfaces tested than regular cotton cloths. Furthermore, they do not release spores onto a new surface as easily as cotton cloths do.

The transfer of *C. difficile* spores between surfaces may be prevented by implementing a proper washing protocol post utilization of these wipes on the hospital wards. However, the laundry

process to be implemented for disinfection of the cloths should be thoroughly controlled, considering key components, such as composition and concentration of cleaning agents, temperature used during the process, mechanical operation procedures and adequate length of washing, disinfecting and drying times.

Further studies on the efficiency of washing and drying machines will contribute in the implementation of updated standards for laundry processes in health care settings.

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