

The persistence of *Staphylococcus aureus* on hospital privacy curtains

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May 1, 2017

Abstract

While healthcare professionals are working in hospitals, they have a tendency of manipulating the curtains during the care of their patients. Current studies have shown that the transfer of bacteria from hands to the curtains and vice versa is possible. Despite the possibility of hospital curtains being a mode of infection transmission, a study by DeAngelis and Phakoo (2013) showed that 53% of hospitals surveyed did not have a policy for cleaning or changing their curtains. Therefore, the question that this study focused on was whether curtain material affects the persistence of *Staphylococcus aureus* (*S. aureus*). In this study, five different curtain types were inoculated with overnight, diluted, and finger imprint cultures of *S. aureus*. Then they were swabbed using a sterile cotton swab and streaked onto Mannitol Salt Agar (MSA) plates. The colonies were counted, and One-Way ANOVA statistical analysis was completed on the data. The statistical analysis showed that persistence of liquid cultures of *S. aureus* on the curtains was not dependent upon initial concentration. In addition, the finger imprints for curtains ABC, abc, 123, and def had statistically significant longer persistence times than the liquid cultures. Curtain 456 (100% antimicrobial polyester with water repellent) had significantly lower persistence times for the finger imprint culture than the other four curtains. The results suggest that the 100% inherently FR antimicrobial polyester curtain material reduces *S. aureus* persistence times and that it may benefit hospitals to use this type of curtain.

Introduction

The environment of the hospital has an important role in the transmission of health-care associated pathogens which cause nosocomial infections. Studies have found that hospital privacy curtains are quickly contaminated by microorganisms that can be transferred to healthcare workers' hands and the patient or from the patient and the environment (Ohl et al., 2012; Trillis, Eckstein, Budavich, Pultz, & Donskey, 2008). In 1988, there was an outbreak of multiple-antibiotic-resistant *Acintebacter baumannii* in the Queen Elizabeth Hospital in Birmingham, UK. This outbreak was investigated by Das et al. (2002), and the Carbapenem-resistant Acintebacter was isolated from surfaces of equipment, bed surfaces, mops, and curtains. It was determined that the curtains were the main source of the outbreak because they had the highest number of the organism present on them (Das et al., 2002).

In addition to the curtains being easily contaminated with pathogens that can be transferred via the hands to people or other surfaces most bacteria can persist on the curtains for weeks and even months. A study by DeAngelis and Khakoo (2013) indicated that these lengthy persistence times are problematic. Their study included surveys completed by hospitals on curtain cleaning policies. Over half of the hospitals surveyed (53%) said they do not have a policy for cleaning the hospital curtains, 29.8% said they only clean their curtains when visibly soiled, 10.6% clean the curtains every year, 10.6% clean their curtains every three months, and only 10.6% clean their curtains every month. In other words, the most frequently the hospitals change their curtains is every month. On top of that, only 10.6% of the total hospitals surveyed clean their curtains that often, which means that most of the hospitals either do not have a cleaning policy or change the curtains every three months or greater. This three month cleaning interval is not frequent enough because, according to Kramer et al. (2006), there are many

pathogens that can last on hospital surfaces for up to four months and some can last much longer than that. This fact is an indication that there needs to either be better cleaning or changing policies or the type of curtain or curtain material used needs to be considered (e.g. 100% inherently flame resistant polyester, antimicrobial, etc.).

So far, not much research has been completed on the topic of hospital curtains and bacteria or bacterial infections. Only nine research articles were found during a broad literature search of databases including CINAHL, MEDLINE, EBSCO, Ovid, ScienceDirect, and Google Scholar. In addition, the research is varied on the topic, the types of curtain used, and the methods for carrying out the research.

Seven of the studies found swabbed or took finger imprints from a specified area of the hospital curtains actively hanging in a hospital. One of the studies that used finger imprints (Larocque et al., 2016), took finger imprints from hospital staff before hand hygiene (HH) with 72% ethyl alcohol hand sanitizer, after HH, and then after opening and closing the curtains. The other six of seven studies swabbed rather than did finger imprints of the curtains. The area of the curtains that was swabbed ranged from 25cm² to 800 cm², with one study using 25cm² (Rutala et al., 2014), one using 300cm² (Kotsanas et al., 2014), one using 100cm² near the head of the hospital bed (Kurashige, Oie, & Furukawa, 2016), and two using 800 cm² (Ohl et al., 2012; Schweizer et al., 2012). One study by Butt et al. (2016) did not specify the area of the curtains, bed sheets, utensils, floors, tables, apparatus, doors, and staff's hands that it swabbed. Two of the other studies had similar interventions. Both inoculated various bacteria onto specified areas of curtain swatches (Kotsanas et al., 2012; Sood et al., 2012). One difference between these studies was Sood et al. (2014) used two by two centimeter swatches, whereas Kotsanas et al. (2012) used larger curtain swatches at five by five centimeters. Also, Kotsanas et

al. (2012) used two different types of curtains in their study, while Sood et al. (2012) used two different types of chemicals to treat the curtains, including activated hydrogen peroxide and 3.1% hydrogen peroxide. In a study by Shek et al. (2017), the curtains were pressed directly against the growth media rather than being swabbed or using a finger imprint. The remaining study completed an analysis of articles found in Medline on how long various types of bacteria can persist on hospital surfaces (Karmer, Schewbke, & Kampf, 2006). Because this study had no experimental intervention, it was very different than the other eight studies.

Eight of the studies specified their duration. The durations were varied and ranged from 7 days to six months. One study lasted 7 days (Larocque et al., 2016), one three weeks (Ohl et al., 2012), one four weeks (Schweizer et al., 2012), one a month (Kurashige, Oie, & Furukawa, 2016), one two months (Kotsanas et al., 2012), and three lasted six months (Butt et al., 2016; Kotsanas et al., 2014; Shek et al., 2017). The studies completed by Ohl et al. (2012) and Schweizer et al. (2012) were not only similar in duration, but they also implemented their interventions two times a week throughout the duration. Two other studies, Kotsanas et al. (2014) and Butt et al. (2016), were also very similar in that they both implemented their interventions continuously over a six month period. Additionally, Larocque et al. (2016) and Shek et al. (2017) took the samples twice at the beginning and end of the duration.

Although there were some variations in the bacteria involved in these studies, eight out of the 13 studies included *Staphylococcus aureus* (or some form of it including Methicillin-resistant *Staphylococcus aureus* [MRSA]), *Clostridium difficile* (*C. difficile*), and *Enterococcus faecalis* (or some form of it including Vancomycin-resistant *Enterococcus*). The four newer studies (Butt et al., 2016; Kurashige, Oie, & Furukawa, 2016; Larocque et al., 2016; Shek et al., 2017) focused mainly on *S. aureus* and MRSA, but also included *Micrococcus luteus* and *Streptococcus*

pneumoniae in the study by Larocque et al. (2016) and *Escherichia coli* (*E. coli*), *Pseudomonas*, *Bacillus*, and *Acinetobacter* in the study by Butt et al. (2016). All of these studies involved interventions where those bacteria were already present on the hospital curtains. On the other hand, Kotsanas et al. (2012) and Sood et al. (2014) directly inoculated those specific bacteria plus some others, including *E. coli* and *Pseudomonas aeruginosa*, onto curtain swatches.

Twelve studies used growth media (agar plates) in their interventions, but the media types varied. Some of the media types were chosen to select for particular bacterial isolates, while others were used to grow up all of the bacteria and count total colony forming units (CFUs). Two studies used tryptic soy agar with 5% sheep blood (Ohl et al., 2012; Schweizer et al., 2012); one study used Columbia blood agar with 5% sheep blood plate (Laroque et al., 2016); one study used Rodac agar plates (Rutala et al., 2014); one study used Dey/Engley Neutralizing agar (DNA) Rodac Contact plates, Mannitol Salt Agar (MSA), and MSA-Oxacillin agar (Shek et al., 2017); one study used sheep blood agar (Sood et al., 2014); two studies used horse blood agar (Kotsanas et al., 2012; Kotsanas et al., 2014); one study used Staph110 agar, Pseudomonas agar, blood agar, and MacConkey's agar (Butt et al. 2016); one study used salt egg yolk agar plates (Kurashige, Oie, & Furukawa, 2016); and two studies used selective media including ChromID agar (Trillis et al., 2008; Vickery et al., 2012).

Of the 13 studies that involved hospital curtains as part of their intervention, seven mentioned the type of curtain or curtain material that was used. Almost all of the studies involved different types of curtains. One study used vinyl curtains (Ohl et al., 2012), one used 100% flame retardant curtains (Rutala et al., 2014), one used cotton/polyester blend curtains (Sood et al., 2014), one used propylene curtains (Kotsanas et al., 2012), one used disposable sporicidal curtains (Kotsanas et al., 2014), and one used both complex element compound (CEC)

and 100% polyester curtains (Schweizer et al., 2012). Similarly, Kurashige, Oie, and Furukawa (2016) also used 100% polyester curtains in their study. Schweizer et al. (2012) was the only study that compared two different types of curtains.

Because all of these studies had different interventional focuses, their results were different. Seven of the 13 studies calculated the colony forming units (CFUs) to determine how much bacteria was present after the intervention. Rutala et al. (2014) found a 96.9% reduction in bacteria after treatment of curtains with 1.4% improved hydrogen peroxide solution (IHP). Sood et al. (2014) demonstrated that there was no bacterial growth after the application of either activated hydrogen peroxide or 3.1% hydrogen peroxide to curtains. In another study involving CFUs, Kotsanas et al. (2012) showed a reduction in both types of curtains used within one day and a complete eradication of bacteria within two months, with the exception of *C. difficile* which had 10 to 50 CFUs after two months. Kotsanas et al. (2014) showed a complete eradication of bacterial cells and a significant reduction in *C. difficile* spores. This same study also measured the zone of inhibition to determine the effectiveness of the sporicidal curtains against various bacteria. Twelve out of the 14 organisms had detectable zones of inhibition and they ranged from 0.5 millimeters to five millimeters, which indicates that these curtains are completely effective in preventing the growth of 12 of the 14 organisms tested.

Two other studies used a similar measure, which included examining growth on agar plates. Ohl et al. (2012) used this method to determine how long bacteria take to contaminate the hospital privacy curtains. Ninety-two percent of curtains placed during the study showed contamination within a week and 95% of the curtains already present at the beginning of the study demonstrated contamination on at least 1 occasion, including 21% with MRSA and 42% with VRE. The study demonstrated that it generally takes only one week for contamination to

occur because twelve of the thirteen curtains showed contamination of one or more organisms within one week. Trillis et al. (2008) used this measure to see if bacteria could be transferred from the curtains to hands. The presence of bacterial growth on the agar plates demonstrated that bacteria could be transferred from the curtains to hands. Shek et al. (2017) used this measure to see how many curtains within a burn unit were contaminated with MRSA. This study found that 22% (5/23) of curtains had MRSA from the first sample and 31% (8/26) had MRSA in the second sample. Kurashige, Oie, and Furukawa (2016) was similar to the last study in that it also looked for the presence of MRSA on curtains, but it also looked at the overbed tables and bedside rails. In addition, this study only checked for the contamination of these objects in patients' rooms from whom MRSA was isolated via a clinical specimen. This study found that 25% of overbed tables (6/24), 31.6% of bedside rails (6/19), and 0% (0/24) of curtains were contaminated with MRSA. Butt et al. (2016) used this measure to see which pathogenic bacteria and how much of each bacteria were present on the curtains, bed sheets, utensils, floor, curtains, tables, apparatus, door, and staff's hands. The results showed that *E. coli* and *Bacillus* were isolated in a statistically significant high number from the utensils and *Pseudomonas* was isolated in statistically significant low numbers from the curtains and doors.

The study by Larocque et al. (2016) also looked at growth on media, but it looked at the growth from finger imprints at multiple points in time rather than directly from the curtains. These finger imprints were taken before HH, after HH with hand sanitizer, and after opening and closing the curtains. The results showed that the median colony counts per plate were 58.5 at baseline, 6 after HH, and 9.5 after opening and closing the curtains. In other words, there was not a significant increase in colony counts after handling the curtains. However, the results indicated an increase in the number of distinct bacterial morphotypes post-curtain.

Only three studies used statistical tests. One study used the Wilcoxon rank-sum test, the Kaplan-Meier survival analysis, and Poisson regression (Schweizer et al., 2012). The Wilcoxon rank-sum test and the Kaplan-Meier survival analysis were used to determine the amount of time it took to contaminate both the CEC and the 100% polyester curtains. The Poisson regression was used to compare the incidence rates of contamination between the two types of curtains. These measures showed that the CEC curtains took seven times longer to become contaminated and had a significantly lower incidence of contamination than the 100% polyester curtains (Schweizer et al., 2012). Additionally, the study by Butt et al. (2016) used the Poisson regression and the study by Larocque et al. (2016) used the Wilcoxon rank-sum test and a 95% confidence interval estimated using Hodges-Lehmann methods.

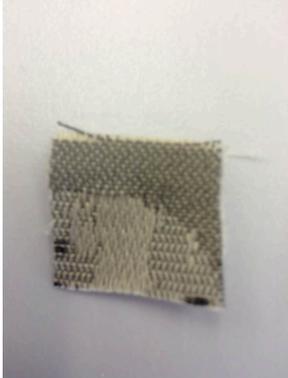
In conclusion, Trillis et al. (2008) tested 50 curtains in a hospital and found that 42% had VRE on them and 22% had MRSA. This study also demonstrated that VRE, MRSA, and *C. difficile* can be acquired on the hands by touching the curtains. Therefore, this study indicated that antibiotic resistant bacteria are present on hospitals curtains and healthcare workers, patients, and the patient's family can get that bacteria on their hands from touching the curtains. The study by Larocque et al. (2016) had somewhat contradictory evidence by having a minimal increase in colony counts post-curtain from finger imprints. Although, this contradiction may be explained by the difference between gloved and nongloved hands and because the curtains had been changed four weeks before the study. Kramer, Schwebke, and Kampf (2006) found that bacteria can persist on hospital surfaces for weeks or even months. Specifically, *Enterococcus* (including VRE) can persist on hospital surfaces for up to four months and *S. aureus* (including MRSA) can persist for up to seven months. In addition, Ohl et al. (2012) showed that most hospital curtains become contaminated within a week. Also, measures in the Schweizer et al. (2012) study

demonstrated that the CEC curtains take seven times longer to become contaminated and have much lower rates of contamination than 100% polyester curtains. This shows that hospital curtain material can have a great effect on the presence of bacteria on the curtains. The different types of curtains used in these studies include vinyl, 100% flame retardant, cotton/polyester blend, propylene, disposable sporicidal, CEC, and 100% polyester.

The main problems with these studies are that only one of them compares more than one type of curtain, so it cannot be determined if the curtain type would have had an effect on the results. The results of the study by Kurashige, Oie, and Furukawa (2016) completely contradicted previous studies that showed a high rate of MRSA contamination on curtains (Ohl et al., 2012). Therefore, Kurashige et al. (2016) mentioned that curtain material may have an effect and should be studied further. Another limit to the available studies is that the persistence times mentioned in Kramer, Schwebke, and Kampf (2006) are only for hospital surfaces in general. It does not mention hospital curtains specifically.

This study will serve to fill in some of the gaps of the existing research. The focus of this study will be on *S. aureus*, which are the bacteria responsible for the antibiotic resistant strain of MRSA. This study will build on the findings of Kramer, Schwebke, and Kampf (2006) and Schweizer et al. (2012) by comparing the persistence times of *S. aureus* on several different curtain types including: 100% inherently flame retardant (FR) polyester, 46% FR polyester, 27% post-consumed recycled polyester, and 27% post-industrial recycled polyester, 87% polyester and 13% Avora FR polyester, 52% post-consumer recycled FR polyester and 47% FR polyester, 56.6% Amy antimicrobial polyester and 43.4% recycled FR polyester, and 100% inherently FR antimicrobial polyester (water repellent).

Methods and Materials

Curtain Code	Curtain Material	Picture
ABC	46% FR polyester, 27% post-consumer recycled polyester, and 27% post-industrial recycled polyester	
abc	87% polyester, 13% Avora FR polyester	
123	52% post-consumer recycled FR polyester, 48% FR polyester	
def	56.6% Amy antimicrobial polyester, 43.4% recycled FR polyester	

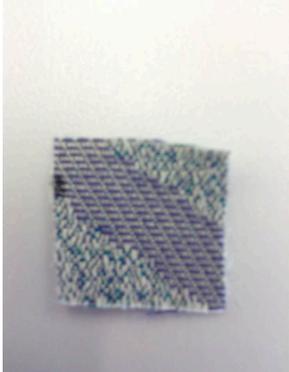
456	100% inherently FR antimicrobial polyester with water repellent	
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Table 1. Curtain type codes, materials, and pictures.

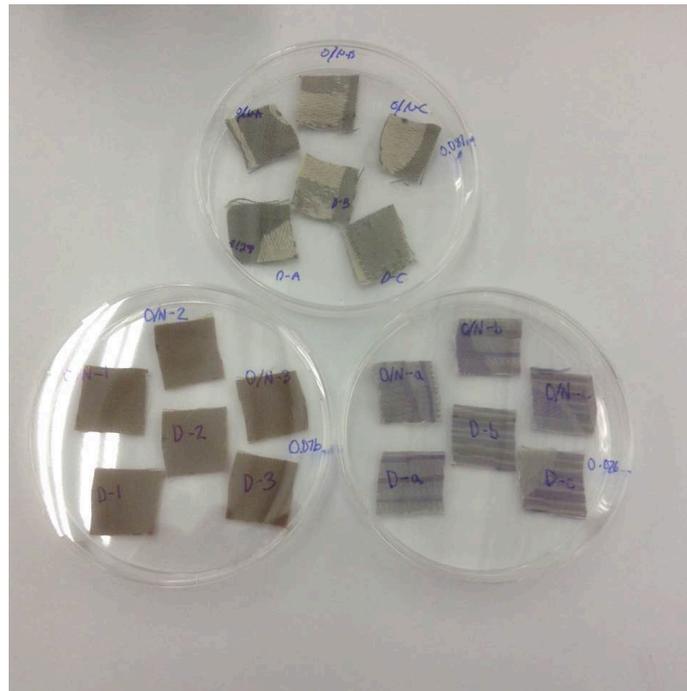


Figure 1. The sterile petri dishes for the overnight and diluted cultures of curtains ABC, 123, and abc.

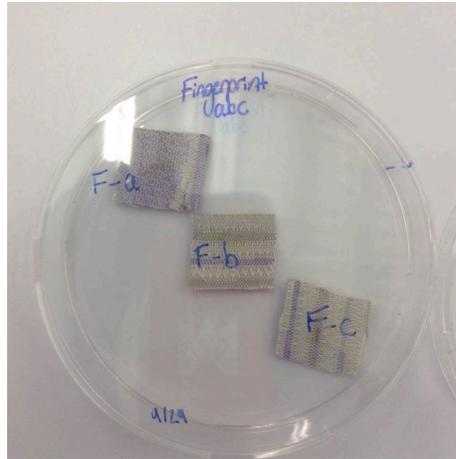


Figure 2. The sterile petri dish for the finger imprint culture of curtain abc.

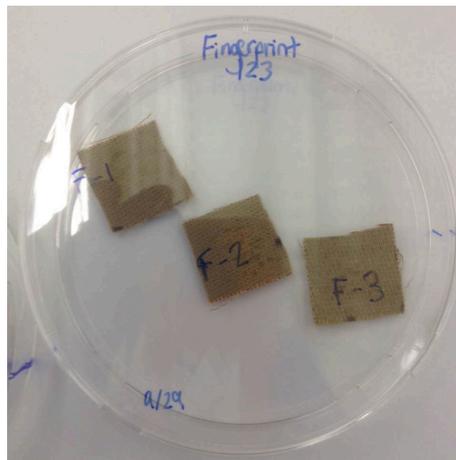


Figure 3. The sterile petri dish for the finger imprint culture of curtain 123.

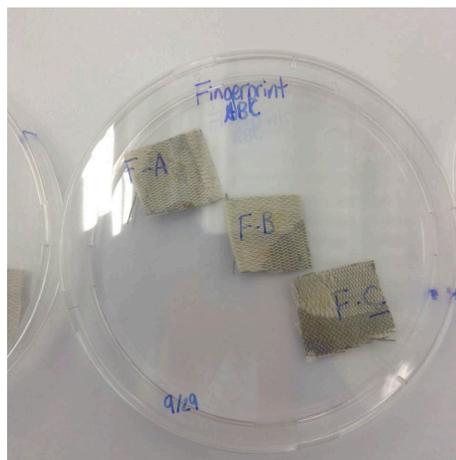


Figure 4. The sterile petri dish for the finger imprint culture of curtain ABC.

The curtains used in this study include a 46% flame resistant (FR) polyester, 27% post-consumer recycled polyester, and 27% post-industrial recycled polyester; 56.6% Amy antimicrobial polyester with 43.4% recycled FR polyester; and 100% inherently FR antimicrobial polyester from the Covov corporation curtain company. From the InPro corporation curtain company, 87% polyester with 13% Avora FR polyester and 52% post-consumer recycled FR polyester with 48% flame retardant polyester curtain samples were used. These curtain materials with their codes and pictures are listed in Table 1. The codes for the curtains were created and used to prevent bias on the part of the experimenter when counting colonies and persistence times.

This experiment had two trials, and for each trial, these curtains were cut into 2x2cm pieces. Nine of those pieces of each curtain type were set aside and autoclaved to remove all bacteria initially present. Three of those curtain pieces were inoculated with 20 microliters of the liquid overnight culture of *S. aureus* in tryptic soy broth (TSB) that had been incubated in a 37 degree Celsius water bath for 24 hours. Three of the other pieces were inoculated with 20 microliters of the same liquid overnight culture that was diluted with sterile 0.9% sodium chloride to a measurement of 0.08 optical density (OD₆₀₀) via the spectrophotometer. In order to ensure the sterility of the 0.9% sodium chloride, the solution was continuously streaked onto a tryptic soy agar (TSA) plate using a sterile cotton swab and placed in the 37 degree incubator to make sure there was no bacterial growth. The final three pieces of each curtain material were inoculated with a colony of *S. aureus* by touching the colony with a gloved finger and pressing it onto the curtain piece. The colonies of *S. aureus* used for this step were obtained from a quadrant streaked mannitol salt agar (MSA) plate that was incubated at 37 degrees Celsius for 48 hours. Curtain 456 was the only curtain where the overnight and diluted cultures were not inoculated

onto the curtain. Only the finger imprint culture was inoculated onto to this curtain because this curtain is water repellent and, consequently, the liquid cultures ran off the curtain. After the nine curtain pieces were inoculated—three pieces with curtain 456—they were left to dry in separate sterile petri dishes for 20 minutes. The three overnight and three diluted culture pieces of each curtain type were placed in one petri dish and the finger imprint culture pieces were placed in another (shown in figures 1-4). Then, each piece of curtain was held down with a pair of tweezers— that were sanitized with 90% ethanol and the Bunsen burner—while swabbing. Each piece was swabbed in 10 strokes with five strokes down and five strokes up using a sterile cotton swab dipped in sterile 0.9% sodium chloride. This cotton swab was then continuous streaked onto a MSA plate that was then wrapped in parafilm and placed in the 37 degree Celsius incubator for 48 hours. During the first trial, the curtains were swabbed, streaked onto MSA, and placed in the 37 degree incubator for 48 hours every three days until there were no colonies growing on the incubated plates for two consecutive days. For the second trial, the curtains were swabbed, streaked, and placed in the incubator every day until there were no colonies growing on the plates for two consecutive days. After the 48 hours of incubation, the number of colonies on each plate was counted and recorded. If the plate was completely covered in colonies of *S. aureus* or had more than 300 colonies on it, it was recorded to have “too numerous to count” (TNTC) colonies. If the plate had less than 300 colonies, the exact number was recorded.

Once all of the data was collected, the number of days that the *S. aureus* persisted on each sample of each curtain type was counted for both trials. The day that the curtain pieces were inoculated with the overnight, diluted, and finger imprint cultures and swabbed initially was considered day zero. Additionally, when counting the number of days *S. aureus* persisted on each curtain type, the count was cut off after two consecutive days where there were there were

five or less colonies on that particular MSA plate. All of this data, including both experimental trials, was compiled in excel and then One-Way ANOVA statistics with the Tukey HSD test were completed on it. Using One-Way ANOVA, the overnight, diluted, finger imprint cultures within each curtain type were compared. After that, the overnight cultures for all of the curtain types were compared; all of the diluted were compared; and all of the finger imprint cultures were compared.

Results

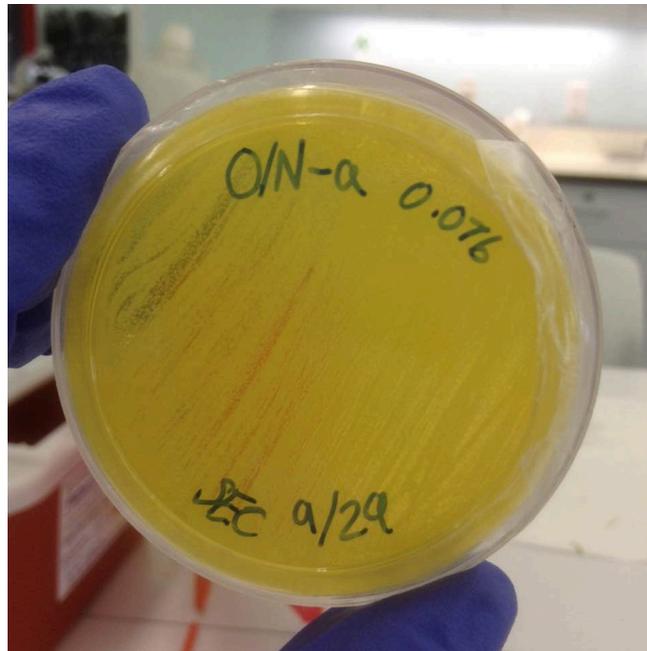


Figure 5. Overnight culture for curtain piece "a" of curtain abc on day 0. There were TNTC colonies.

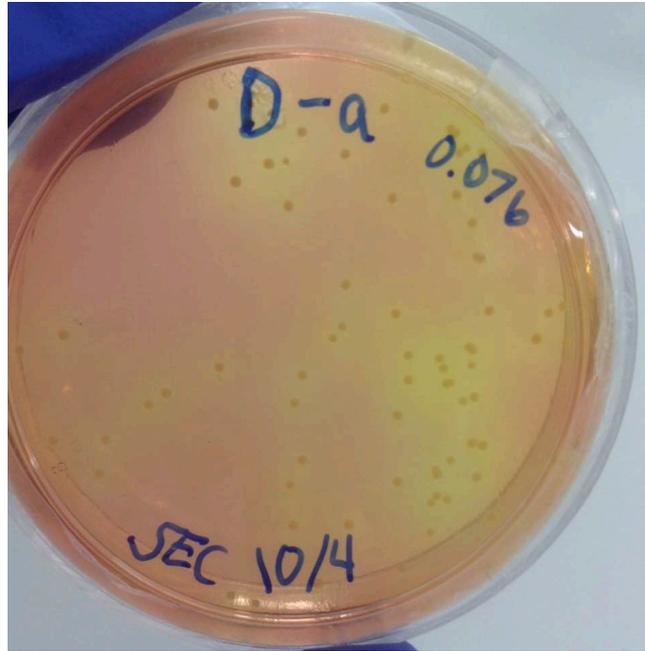


Figure 7. Diluted culture for curtain piece “a” of curtain abc on day 5. There are 82 colonies.

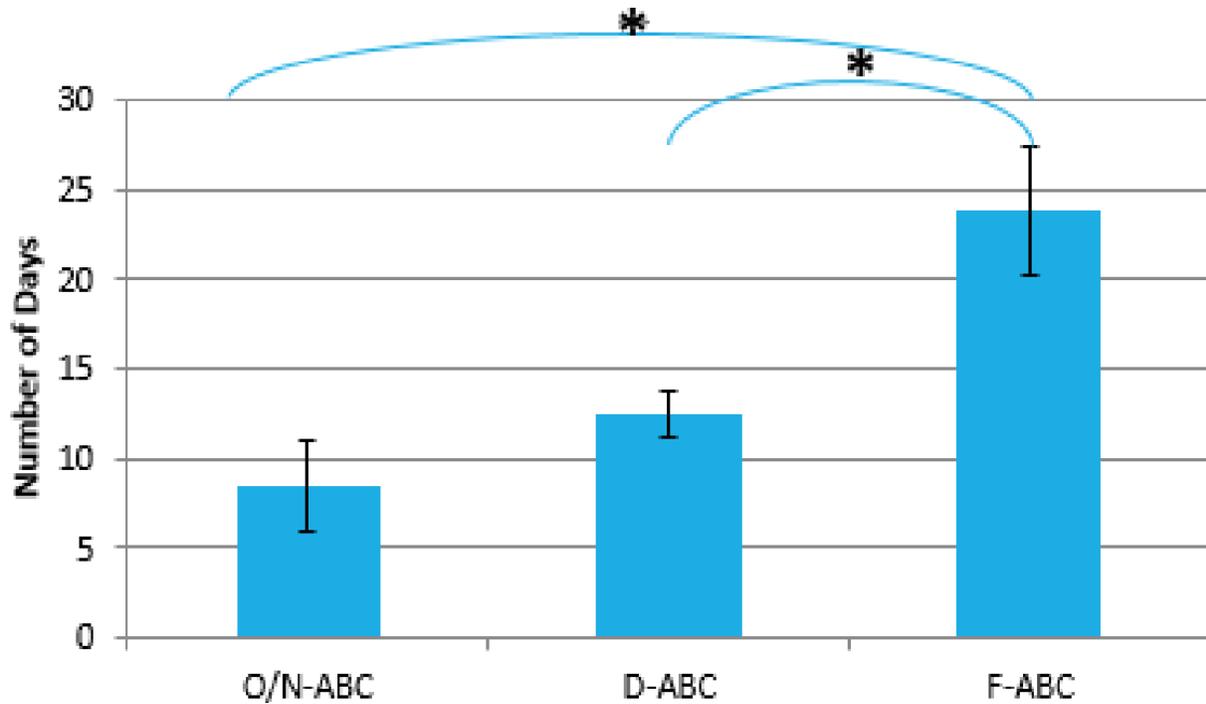


Figure 8. Bar graph comparison of the overnight, diluted, and finger imprint cultures of curtain ABC with error bars and statistical significance illustrated with asterisks.

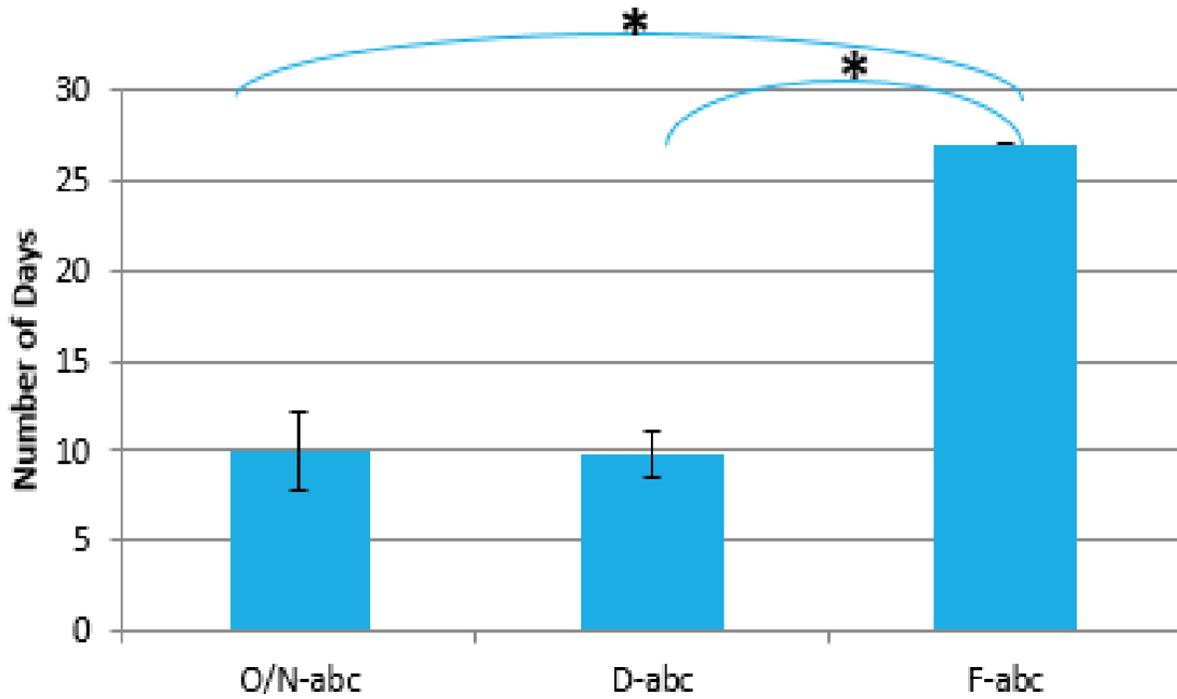


Figure 9. Bar graph comparison of the overnight, diluted, and finger imprint cultures of curtain abc with error bars and statistical significance illustrated with asterisks.

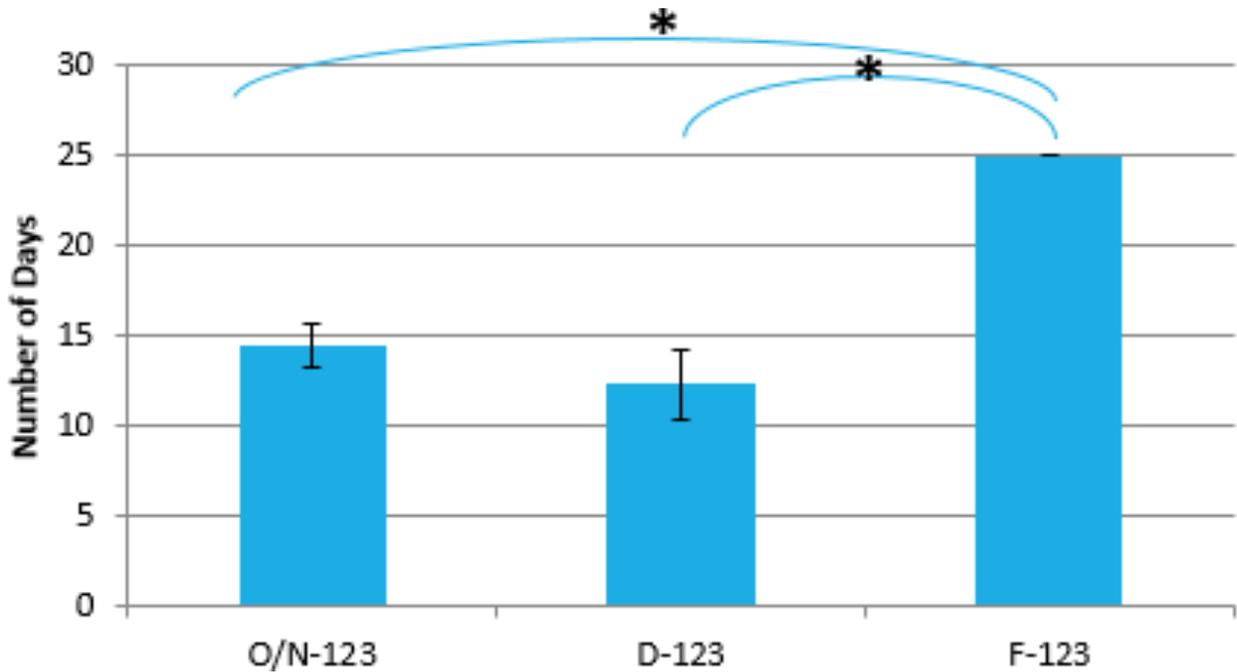


Figure 10. Bar graph comparison of the overnight, diluted, and finger imprint cultures of curtain 123 with error bars and statistical significance illustrated with asterisks.

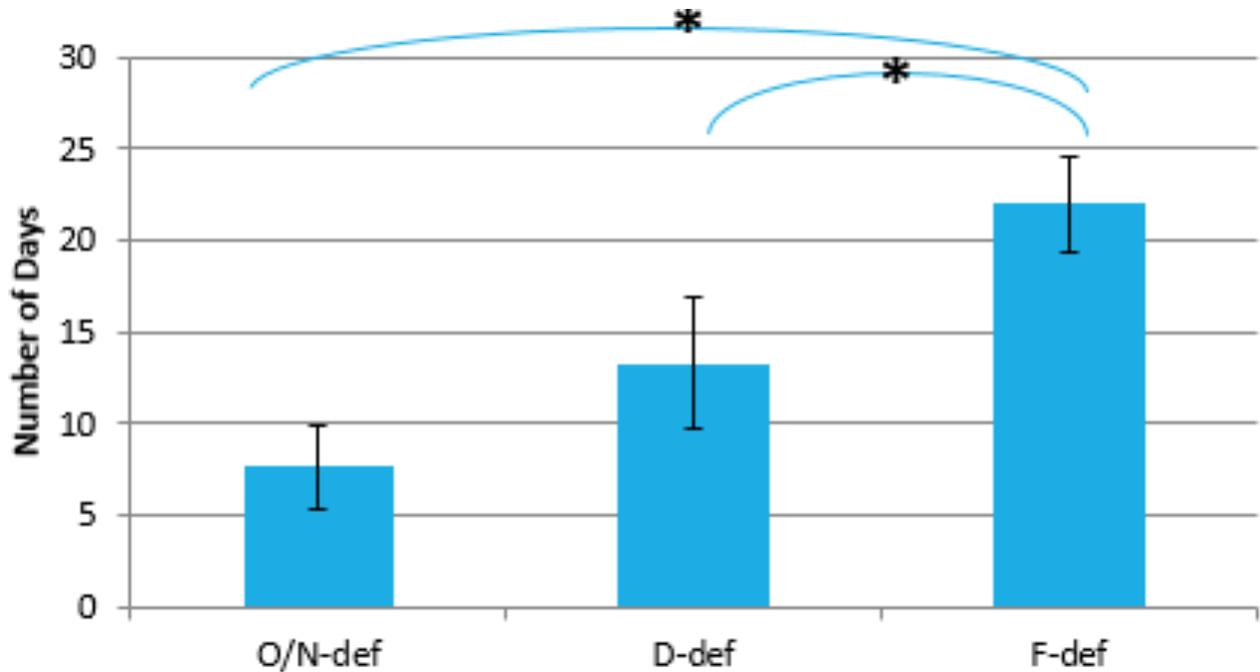


Figure 11. Bar graph comparison of the overnight, diluted, and finger imprint cultures of curtain def with error bars and statistical significance illustrated with asterisks.

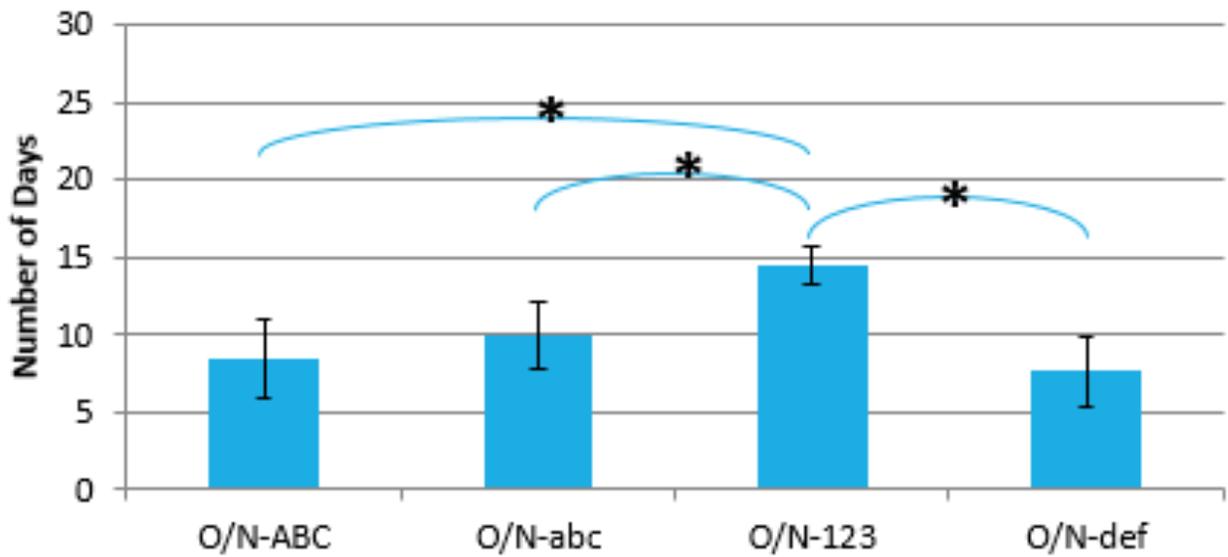


Figure 12. Bar graph comparison of the overnight cultures for all curtain types with error bars and statistical significance illustrated with asterisks. O/N means overnight culture.

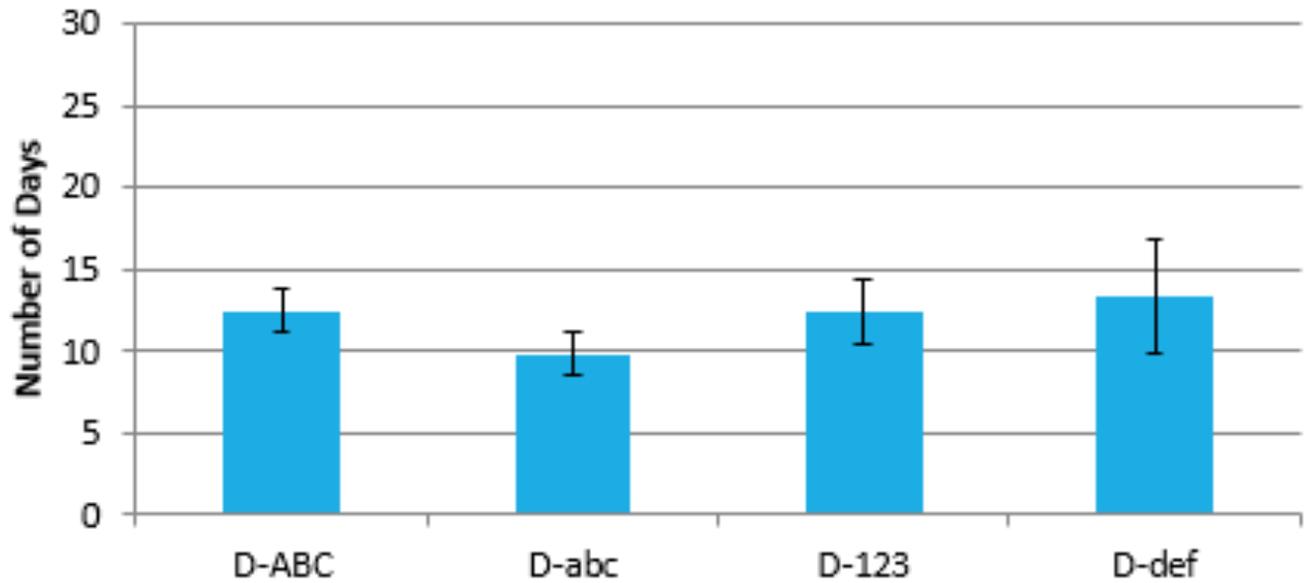


Figure 13. Bar graph comparison of the diluted cultures for all curtain types with error bars and statistical significance illustrated with asterisks. D means diluted culture.

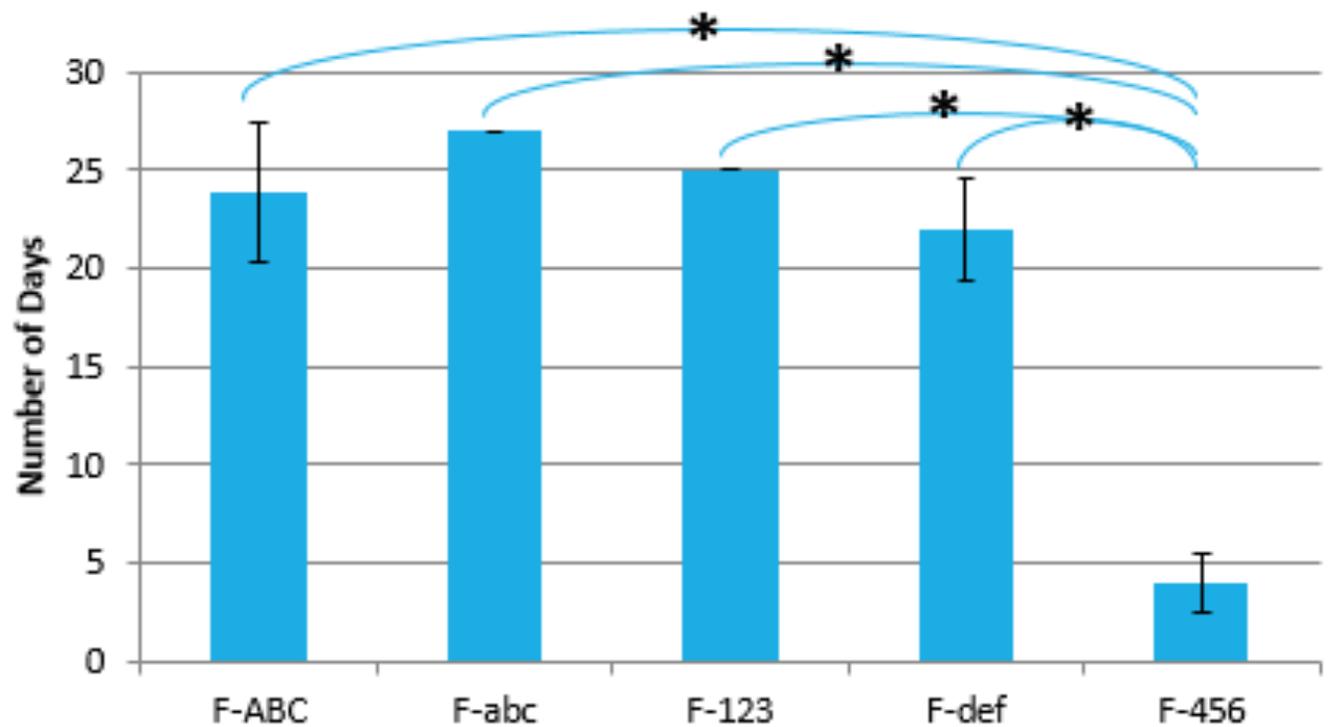


Figure 14. Bar graph comparison of the finger imprint cultures for all curtain types with error bars and statistical significance illustrated with asterisks. F means finger imprint culture.

For curtain ABC, the mean and standard deviation for the overnight cultures was 8.5 days and 2.51 respectively, the diluted was 12.5 days and 1.67, and the finger imprint culture was 23.83 days and 3.54. The F ratio between the cultures for curtain ABC was 48.79 and the $P < 0.0001$. Between the overnight and diluted cultures, there was no statistical significance. On the other hand, there was statistical significance between the overnight culture and the finger imprint culture and the diluted and finger imprint culture with a $P < 0.01$ for both, which is illustrated with the blue arches and asterisks in the bar graph in Figure 8. In addition, this figure compares the means of the samples.

With curtain abc, the mean and standard deviation for the overnight cultures was 10 days and 2.19 respectively, the diluted was 9.83 days and 1.33 respectively, and the finger imprint culture was 27 days and 0 respectively. The F ratio between the cultures for curtain abc was 128.01 and the $P < 0.0001$. Between the overnight and diluted cultures, there was no statistical significance. On the other hand, there was statistical significance between the overnight culture and the finger imprint culture and the diluted and finger imprint culture with a $P < 0.01$ for both, which is illustrated with the blue arches and asterisks in the bar graph in Figure 9. In addition, this figure compares the means of the samples.

The mean and standard deviation for the overnight cultures of curtain 123 was 14.5 days and 1.22 respectively, the diluted was 12.33 days and 1.97 respectively, and the finger imprint culture was 25 days and 0 respectively. The F ratio between the cultures for curtain 123 was 75.15 and the $P < 0.0001$. Between the overnight and diluted cultures, there was no statistical significance. On the other hand, there was statistical significance between the overnight culture and the finger imprint culture and the diluted and finger imprint culture with a $P < 0.01$ for both,

which is illustrated with the blue arches and asterisks in the bar graph in Figure 10. In addition, this figure compares the means of the samples.

Finally, the mean and standard deviation for curtain def was 7.67 days and 2.25 respectively, the diluted was 13.33 days and 3.51 respectively, and the finger imprint culture was 22 days and 2.65 respectively. The F ratio between the cultures for curtain def was 29.02 and the $P=0.000119$. Between the overnight and diluted cultures, there was statistical significance with $P<0.05$. There was also statistical significance between the overnight and the finger imprint culture and the diluted and finger imprint culture with a $P<0.01$ for both. The statistical significance between these different cultures is illustrated with the blue arches and asterisks in the bar graph in Figure 11. In addition, this figure compares the means of the samples.

Figure 12 shows the comparison of the mean days for the overnight cultures for all of the curtains, except for curtain 456. The F ratio was 12.6 and the $P<0.0001$ for this data. There was no statistical significance between curtain ABC and abc, curtain ABC and def, and curtain abc and def. On the other hand, there was statistical significance between curtain ABC and 123, curtain abc and 123, and curtain 123 and def with a $P<0.01$ for each. The blue arches and asterisks demonstrate this statistical significance.

Figure 13 shows the comparison of the mean days for the diluted cultures for all of the curtains, except for curtain 456. The F ratio was 2.93 and the $P=0.068$ for this data. As a result of this low F ratio and the high P value, the Tukey HSD was unable to be performed. The bar graph has no blue arches and asterisks to indicate the lack of statistical significance.

Figure 14 shows the comparison of the mean days for the finger imprint cultures for all of the curtains. The F ratio was 38.25 and the $P<0.0001$ for this data. There was no statistical significance between curtain ABC and abc, curtain ABC and 123, curtain ABC and def, curtain

abc and 123, curtain abc and def, and curtain 123 and def. On the other hand, there was significance between curtains ABC and 456, curtains abc and 456, curtains 123 and 456, and curtains def and 456. The blue arches and asterisks illustrate the statistical significance in Figure 14.

Discussion

The first step in collecting the results was to count the number of colonies of each MSA plate after the 48 hours of incubation. Additionally, each curtain was swabbed and streaked onto the MSA until there were two consecutive days of no colony growth on the plates. Originally, the first of those two consecutive days of no growth was used as the date to determine the number of days of persistence of *S. aureus* on that particular curtain material. This method for determining persistence ended up not being an accurate measure because there were many curtains that would have colony counts of five or less for several days in a row. Also, there were some curtains that would have no growth on the MSA one day and then the next time that they were swabbed there were some colonies present. Similarly, there were curtains that would have a few days of less than 10 colonies and then the colony count would increase significantly the next time it was swabbed. These issues could be explained by the inability to swab the curtains with the 10 strokes the same exact way each time and the possibility of not streaking the MSA plate completely, while ensuring that the surface area of the cotton swab that touched the curtain was streaked all the way down the plate. Another possible explanation for these results is the programmed cell death hypothesis (Willey, Sherwood, & Woolverton, 2014). This hypothesis states that a portion of the microbial population is genetically programmed to die after growth stops so that its nutrients can be released. Therefore, the surrounding bacteria that did not undergo programmed cell death can use these nutrients to continue to grow (Willey et al., 2014).

In order to help resolve the discrepancies in persistence times caused by the colony count anomalies, the end date was deemed as the second consecutive day that there were five or less colonies present on the MSA plate. This new end date was then used to determine the persistence times for each curtain material.

Once the persistence times were compiled and statistical analysis was completed on them via One-Way ANOVA with the Tukey HSD test, they were compared using the bar graphs portrayed in Figures 8 through 14. When comparing the overnight and diluted cultures of each of the curtains ABC, abc, and 123, there was no difference between the overnight and diluted cultures as indicated by the lack of statistical significance. In other words, the persistence following liquid inoculation was not dependent on initial concentration. On the other hand, there was a statistically significant difference between the both the overnight and diluted cultures and the finger imprint culture for all of these curtains as indicated by the $P < 0.01$. In addition, the longer length of the bars for the finger imprint cultures in Figures 8-10 demonstrates that the finger imprint lasted much longer than the other cultures for all three curtains. Further demonstrating the longer persistence times of the finger imprint, the averages for the finger imprint was 23.8 days for curtain ABC, 27 days for curtain abc, and 25 days for curtain 123, whereas the average for the overnight cultures was 8.5 days, 10 days, and 14.5 days respectively. In other words, the finger imprint did have an effect on persistence times and lasted on average 10 or more days longer than the overnight cultures.

Curtain def had some similar results to the other three curtains, but it had some differences. Unlike the other curtains, the overnight and diluted cultures for this curtain had a difference that was statistically significant with a $P < 0.05$. This means that the concentration of the liquid inoculation did have an effect on persistence times for this curtain—with the diluted

culture of *S. aureus* persisting longer than the more concentrated overnight culture. Additionally, there was a statistically significant difference between the both the overnight and diluted cultures and the finger imprint culture with a $P < 0.01$. This statistical significance indicates that the finger imprint did have an effect on the persistence times. Additionally, the bar graph in Figure 10 shows that the finger imprint culture had the longest persistence times with an average of 22 days compared to the averages of 7.67 and 13.33 days for the overnight and diluted cultures respectively. In other words, these results suggest that the finger imprint had an effect on the persistence times of curtain def by increasing it by about 9 days or more.

With the comparison of the overnight cultures of curtains ABC, abc, 123, and def, there was statistical significance between ABC, abc, and def and curtain 123 at $P < 0.01$. This statistical significance suggests that the curtain material of 123 had an effect on the persistence of the *S. aureus* overnight culture. In addition, 123 had the longest persistence time of all of the overnight cultures with an average of 14.5 days as opposed to the averages of 8.5, 10, and 7.67 days for curtains ABC, abc, and def respectively. The main distinction in curtain material between this curtain and the others is that it had the highest percentage of post-consumer recycled FR polyester at 52%, which could contribute to the increased persistence time.

The diluted cultures for curtains ABC, abc, 123, and def were also compared using One-Way ANOVA. For this data, the $P = 0.068$ and the F ratio was 2.93, so the persistence times were not varied enough to undergo a Tukey HSD test. In other words, the persistence times for the diluted cultures were not statistically significant. Therefore, the curtain material did not have an effect on the persistence times of the diluted cultures.

Finally, the finger imprint cultures for all of the curtains, including curtain 456, underwent statistical comparison. As already mentioned, the finger imprint cultures persisted

much longer on curtains ABC, abc, 123, and def than the overnight and diluted cultures.

However, the Tukey HSD test calculated that the persistence times between these curtains was not statistically significant, revealing that these curtain materials had no effect on persistent times for the finger imprint culture. On the other hand, curtain 456 was statistically significant with $P < 0.01$, which means that this curtain material did have an effect on the persistence times for the finger imprint. In addition, as illustrated in Figure 14, this curtain had significantly lower persistence times with an average of only four days, which is over 15 days lower than the averages of the other four curtains.

Overall, the results showed that the finger imprint cultures lasted significantly longer—9 or more days—than the liquid cultures on every curtain except for curtain 456. These results have an important implication in the hospital setting because the finger imprint cultures are probably more similar to the conditions present in the hospital. For example, in the hospital, healthcare professionals might touch the source of infection with their gloved hands and then touch the curtain. The results also showed that curtain 456 had the lowest persistence times of *S. aureus* finger imprint cultures. *S. aureus* persisted on this curtain an average of only four days, which was over two weeks less than the other curtains. Therefore, these results suggest that the 100% inherently FR antimicrobial polyester (curtain 456) curtain material reduces *S. aureus* persistence times and that it may benefit hospitals to use this type of curtain, especially in areas like the Emergency Department where contamination can occur quickly and frequently with high patient turnover rates. In addition, the results suggest that getting a curtain with a higher percentage of antimicrobial polyester may decrease persistence times. For example, in this experiment, curtain def—which had 56.6% antimicrobial polyester—had similar persistence times to the other curtain materials that did not contain antimicrobial polyester, whereas curtain

456—which had 100% antimicrobial polyester—had considerably lower persistence times than the other curtains. The results also suggest that the use of a water repellent curtain may be helpful in reducing persistence times within hospitals.

Limitations and Suggestions for Future Research

The main issue with curtain 456 was that it was water repellent, which may have had an undetermined effect on the persistence times of the finger imprint culture, and it also prevented the completion of the inoculation of the liquid overnight and diluted cultures. In turn, this prevented the determination of how this curtain material may have affected the persistence times of those particular cultures. In order to determine how the water repellent affected the finger imprint, another experiment would have to be completed comparing this 100% inherently FR antimicrobial polyester with water repellent to the same curtain material without the water repellent. In addition, to determine how this curtain material affects the liquid cultures, another experiment would have to be completed comparing the persistence times of curtains ABC, abc, 123, and def to the 100% inherently FR antimicrobial polyester without water repellent.

During the first trial, the persistence times were limited by the swabbing being completed every 3 days. Consequently, it was impossible to determine if the *S. aureus* had completely died off from that particular curtain on the last day that it was swabbed or if it had died off on the days in between where it had not been swabbed. Therefore, the results from the first trial may not be completely accurate, which is why the swabbing was switched to every day for the second trial. Despite this change, the results overall may have been skewed somewhat by the data obtained during the first trial. As a result, it is recommended that in future studies that the curtains should be swabbed every day in both trials.

Another limitation to this study is that only the persistence times of *S. aureus* was tested on these curtain materials. While *S. aureus* is an important bacteria to study as it is responsible for MRSA, there are other important nosocomial infection-causing bacteria to study, including *Enterococcus* and *C. diff*. These other bacteria may have different persistence times on these curtains than *S. aureus* and may be affected differently by the curtain materials. Therefore, in future studies, the persistence times of various bacteria should be measured to determine if there is a difference in persistence times of a variety of bacteria.

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