

Microbial Contamination and Cleaning Efficacy of Lead Aprons Used by Orthopaedic Surgeons in the Operating Room

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Background: Radiation Personal Protective Equipment (RPPE) is crucial for shielding against radiation exposure in medical settings, particularly in orthopedics. Typically stored on open racks outside operating rooms, these items are shared among users without designated ownership.

Objective: This study aims to evaluate contamination rates and levels in lead aprons used in orthopedic surgery, as well as assess the efficacy of cleaning procedures in reducing microbial growth.

Methods: A cross-sectional study was conducted at major tertiary hospital in Eastern Saudi Arabia. Twenty aprons out of thirty in the hospital's orthopedic operating rooms were sampled over two months, both before and after cleaning. Microbiological analysis was performed at Imam Abdulrahman bin Faisal University's microbiology laboratory.

Results: Out of 120 swabs, 62 tested positive for microorganisms including *micrococcus*, *Coagulase-negative staphylococci*, *Methicillin-sensitive Staphylococcus aureus*, *Pseudomonas Stutzeri*, *yeast*, *Haemophilus spp*, *Corynebacterium diphtheriae*, and *Klebsiella*. Pre-cleaning contamination was significantly reduced from 37% to 25% post-cleaning ($P = 0.023$). Highest contamination levels were found inside the aprons ($P < 0.001$).

Conclusion: While cleaning processes reduced contamination levels, detection of concerning organisms post-cleaning highlights the need for enhanced cleaning protocols in orthopedic surgery settings to mitigate contamination risks effectively.

Keywords: lead aprons, swabs, microorganisms, contamination, cleaning

Introduction

Surgical site infections (SSIs) continue to pose a significant public health challenge, despite the availability of infection control guidelines. SSIs are defined as infections that develop within 30 days following surgery and are responsible for approximately 40% of all healthcare-associated infections (HAIs).¹ While most SSIs can be treated with antibiotics, they remain a leading cause of morbidity, mortality, and prolonged hospital stays, significantly increasing healthcare costs. The risk factors contributing to SSIs are multifactorial and can be categorized into patient-specific factors, such as age, comorbidities, and immune status, as well as surgical factors, including the surgical site, duration of the procedure, surgical technique, and the use of prophylactic measures.²

One commonly used form of personal protective equipment (PPE) in surgical settings is radiation personal protective equipment (RPPE), designed to shield healthcare workers from radiation exposure. However, RPPE may be shared among multiple users or worn by a single individual. In many healthcare institutions, these garments are typically stored on open racks

in hallways or operating rooms and returned to the racks after use without a designated cleaning protocol. This lack of standardized cleaning practices raises concerns about the potential for RPPE to become a source of microbial contamination.

Several studies have highlighted the risk of contamination on RPPE. For instance, a clinical study conducted in 2021 found that 50.8% of RPPE garments tested positive for microbial contamination, despite being periodically cleaned with hypochlorite or alcohol-based wipes.³ Another study, conducted in 2016, tested 109 RPPE garments and discovered that 80.7% were contaminated, even though 83.3% of the garments were worn with disposable lab coats to provide an additional layer of protection.⁴ These studies underscore the prevalence of contamination and the inadequacy of current cleaning protocols.

Although existing research has demonstrated the high levels of contamination found on RPPE and the inconsistencies in cleaning practices, there remains a significant gap in the literature regarding the development of effective cleaning guidelines. More research is needed to identify the most common pathogens associated with RPPE contamination and pinpoint the areas of the equipment most susceptible to microbial growth. This knowledge is crucial for developing targeted cleaning protocols that can reduce the risk of SSIs and improve overall infection control in surgical environments.

This study aims to further explore the risk of contamination associated with lead aprons, specifically evaluating whether they serve as a source of infection and assessing the effectiveness of the current cleaning protocol at a teaching hospital in Eastern Saudi Arabia.

Methods

Study Design

This study followed a descriptive cross-sectional design to evaluate the microbial contamination of lead aprons used in the operating rooms of King Fahad University Hospital, located in the Eastern Province of Saudi Arabia. The primary aim was to investigate the contamination levels before and after cleaning procedures and to assess the effectiveness of the current cleaning protocol in reducing microbial load on the aprons.

Setting

The study was conducted at King Fahad University Hospital, a tertiary healthcare facility in the Eastern Province of Saudi Arabia, known for its advanced medical practices and operating rooms. The operating room environment, where radiation personal protective equipment (RPPE) is used, is considered to have a higher risk for contamination due to the nature of surgical procedures and exposure to various pathogens.

Participants

The participants in this study were lead aprons used by healthcare workers in the operating rooms (Figure 1). These aprons are critical for protection against radiation exposure but may pose a risk of microbial contamination when not properly cleaned. Ethical approval for the study was obtained from the Institutional Review Board (IRB) at Imam Abdulrahman bin Faisal University, with IRB number: IRB-UGS-2022-01-421. The study focused on the contamination of these aprons as a potential source of infection in surgical settings.



Figure 1 Showing one of the aprons that was collected. (A) shows the outside of the apron with the arrow pointing towards the neck area. (B) shows the inside of the apron.

Variables

The independent variable in this study was the cleaning of aprons using alcohol-based wipes according to hospital protocol. The dependent variable was the level of contamination, measured through microbial growth on agar plates after swabbing different apron areas.

Several controlled variables were maintained for consistency. The same aprons were tested before and after cleaning, and swabs were taken from three predefined locations: the neck area, outside surface, and inside surface. A sterile environment was maintained throughout, and alcohol-based wipes were used consistently for cleaning to ensure uniformity and accurate assessment of cleaning effectiveness.

Measurement

Twenty lead aprons were randomly selected from the operating rooms; each assigned a unique ID for tracking. The aprons were divided into three regions: the neck area (margin of the neck and 2 cm below), the outside surface (front surface excluding the neck area), and the inside surface (inner surface excluding the neck). Swabs were collected from each region before and after cleaning, resulting in 6 swabs per apron, labeled for pre- and post-cleaning comparison.

The aprons were cleaned daily by the operating room staff using alcohol-based disinfectant wipes. Swab samples were cultured on three types of agar media: 5% sheep blood agar, MacConkey agar, and Sabouraud agar (SAB). After incubation at 37°C for 24 hours, the plates were visually inspected for microbial growth, noting colony characteristics such as shape, size, color, and hemolysis patterns.

Colonies were then Gram-stained and observed under the microscope for further classification. Biochemical tests, including catalase and coagulase tests, were performed to confirm the species of the microorganisms. Any *Staphylococcus aureus* isolates were sent for antibiotic sensitivity testing. All results, including microbial growth, species identification, and cleaning efficacy, were recorded in an Excel 2016 spreadsheet (v16.0) for data analysis and comparison.

Study Size

A total of 20 lead aprons were randomly selected from the racks in front of the operating rooms. These aprons were collected in a sterile environment to prevent contamination during the sampling process. The study focused on both the pre- and post-cleaning contamination levels of these aprons.

Statistical Method

The data collected from the swab samples were organized in an Excel sheet, categorizing aprons by their identification number, the location of swabs, cleaning status, and the organisms detected.

Bivariate analysis was conducted using McNemar's test, which is appropriate for paired data, to assess any significant differences in contamination levels before and after cleaning the same aprons. A p-value of less than 0.05 was considered statistically significant.

The data analysis was performed using both Microsoft Excel and the Statistical Package for Social Science (SPSS) version 27 (IBM Corp, 2017). This approach ensured that any significant changes in contamination levels were properly identified and evaluated.

Results

The samples collected are equal to 120 from 20 different aprons from three different predetermined locations in the apron (inside, outside, and neck), each location was assessed once before cleaning and once after cleaning. Regardless of their cleaning time, more than half of the swabs showed positive microorganism growth ($n = 62$, 51.7%).

Moreover, eight different organisms were found with a majority being normal flora. More than third of the samples grew micrococcus ($n = 37$, 30.8%), almost third of the samples grew Coagulase-negative staphylococci ($n = 28$, 23.3%), less than 10% of the samples grew staphylococcus aureus that Methicillin-sensitive *Staphylococcus aureus* (MSSA) ($n = 9$, 7.5%), while less than 5% samples grew *Pseudomonas stutzeri* ($n = 5$, 4.2%), and only two samples grew yeast (1.7%).

However, *Haemophilus* spp, *Corynebacterium diphtheriae*, and *Klebsiella* were only detected in one sample each with a frequency of (0.8%). No Methicillin-resistant *Staphylococcus aureus* (MRSA) was detected.

The total number of the positive samples before cleaning is 37 (61.7%) and after is 25 (41.7%). The most prevalent organisms that were detected before cleaning were micrococcus (37.7%), Coagulase-negative staphylococci (27.9%) staphylococcus aureus (MSSA) (4.9%). Similarly, the most prevalent organisms after cleaning were micrococcus (23.7%), staphylococcus spp (18.6%), staphylococcus aureus (MSSA) (10.2%).

The difference between the positive and negative samples before and after cleaning is statistically significant ($\chi^2 = 3.725$, $P = 0.023$). However, there was no significant difference between the organisms detected before and after cleaning when it comes to the growths of specific microorganisms, such as: micrococcus (37.7% vs 23.7%, respectively, $P = 0.078$), Coagulase-negative staphylococci (27.9% vs 18.6%, respectively, $P = 0.286$), staphylococcus aureus (MSSA) (4.9% vs 10.2%, respectively, $P = 0.453$). The remaining detected organisms are further displayed in Table 1 and Figure 2.

Table 1 The Number of Growths for Each Organism Detected Pre and Post Cleaning

Variable	Before Cleaning	After Cleaning		Total Frequency	McNemar's Test (P-value)
		Negative	Positive		
Sample	Negative	17	6	23	3.725 (0.023)*
	Positive	18	19	37	
	Total	35	25	60	
Micrococcus	Negative	31	6	37	2.733 (0.078)
	Positive	15	8	23	
	Total	46	14	60	
Yeast	Negative	58	0	58	1.967 (0.500)
	Positive	2	0	2	
	Total	60	0	60	
Coagulase negative staphylococcus	Negative	35	8	43	0.007 (0.286)
	Positive	14	3	17	
	Total	49	11	60	
Staphylococcus aureus (MSSA)	Negative	52	5	57	1.910 (0.453)
	Positive	2	1	3	
	Total	54	6	60	
<i>Pseudomonas stutzeri</i>	Negative	56	2	58	8.820 (1.000)
	Positive	1	1	2	
	Total	57	3	60	
<i>Corynebacterium diphtheriae</i>	Negative	59	0	59	0.975 (1.000)
	Positive	1	0	1	
	Total	60	0	60	
<i>Haemophilus</i> spp	Negative	59	1	60	1.043 (1.000)
	Positive	0	0	0	
	Total	59	1	60	
<i>Klebsiella</i>	Negative	59	0	59	0.975 (1.000)
	Positive	1	0	1	
	Total	60	0	60	

Note: *Significant associations ($P < 0.05$).

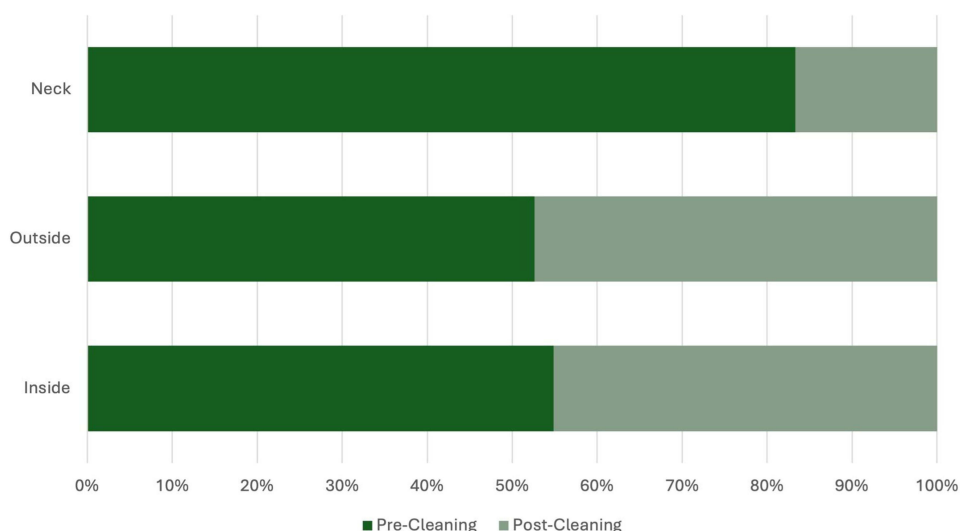


Figure 2 Distribution of Organisms Based on Location Pre- and Post-Cleaning.

Moreover, in accordance with the predetermined locations, the locations that had the most growth in descending order regardless of the cleaning process, were inside, outside then neck (75.6% Vs 43.6% Vs 35.0%, respectively, $P < 0.001$), Which showed that the growth inside the apron was statistically significant compared to the other locations as shown in Table 2 and Figure 3. Furthermore, micrococcus was grown significantly more inside the apron as compared to other predetermined locations tested ($\chi^2 = 14.145$, $P < 0.001$). The rest of the microorganism did not show any significant difference between the locations in the study, ie, microorganisms are grown similarly across the different locations in the study.

Table 2 The Distribution of the Organisms Depending on the Location of the Sample

Variable	Location of Swab			χ^2 Test (<i>P</i> -value)
	Inside n = 41 (%)	Outside n = 39 (%)	Neck n = 40 (%)	
Sample				
Negative	9 (22.5)	21 (52.5)	28 (70.0)	18.487 (<0.001)*
Positive	31 (77.5)	19 (47.5)	12 (30.0)	
Micrococcus				
Negative	19 (47.5)	30 (75.0)	34 (85.0)	14.145 (<0.001)*
Positive	21 (52.5)	10 (25.0)	5 (15.0)	
Yeast				
Negative	38 (95.0)	40 (100)	40 (100)	4.068 (0.131) ^a
Positive	2 (5.0)	0 (0)	0 (0)	
Coagulase negative staphylococcus				
Negative	26 (65.0)	33 (82.5)	33 (82.5)	4.565 (0.102)
Positive	14 (35.0)	7 (17.5)	7 (17.5)	
Staphylococcus aureus (MSSA)				
Negative	37 (92.5)	35 (87.5)	39 (97.5)	2.883 (0.237) ^a
Positive	3 (7.5)	5 (12.5)	1 (2.5)	
Pseudomonas stutzeri				
Negative	35 (87.5)	40 (100)	40 (100)	10.435 (0.005) ^a
Positive	5 (12.5)	0 (0)	0 (0)	

(Continued)

Table 2 (Continued).

Variable	Location of Swab			χ^2 Test (P-value)
	Inside n = 41 (%)	Outside n = 39 (%)	Neck n = 40 (%)	
Corynebacterium diphtheriae				
Negative	40 (100)	40 (100)	39 (97.5)	2.017 (0.365) ^a
Positive	0 (0)	0 (0)	1 (2.5)	
Haemophilus spp				
Negative	39 (97.5)	40 (100)	40 (100)	2.017 (0.365) ^a
Positive	1 (2.5)	0 (0)	0 (0)	
Klebsiella				
Negative	39 (97.5)	40 (100)	40 (100)	2.017 (0.365) ^a
Positive	1 (2.5)	0 (0)	0 (0)	

Notes: *Significant associations ($P < 0.05$). ^a3 cells with expected counts less than 5.

As for the microorganism that grew inside the aprons, micrococcus was the most predominant with a total of 21 positive samples out of 40. Followed by coagulase negative staphylococcus with a total of 14 positive samples. In addition, the only 2 positive samples for yeast and the 5 positive samples for *Pseudomonas stutzeri*, and 1 sample for both *klebsiella* and *haemophilus* were strictly detected inside the aprons. Lastly, there was no growth of *staphylococcus aureus* (MSSA) inside the apron as shown in Table 3. The cleaning process did not show any statistical significance with a p-value of (0.453).

As for the outside of the aprons, there were 19 positive samples in total with only 3 organisms being detected which are: 10 micrococcus, 7 coagulase negative staphylococcus and 5 staphylococcus aureus. The cleaning process did not show any statistical significance with a p-value of (1.000) as shown in Table 3. Lastly, as for the neck region, the total positive samples were 12, with coagulase negative staphylococcus being the most predominant amounting to 7 positive samples followed by micrococcus 6 samples and one sample of staphylococcus aureus grew. The cleaning process showed significant reduction in bacterial contamination with a p-value of (0.021) as shown in Table 3.

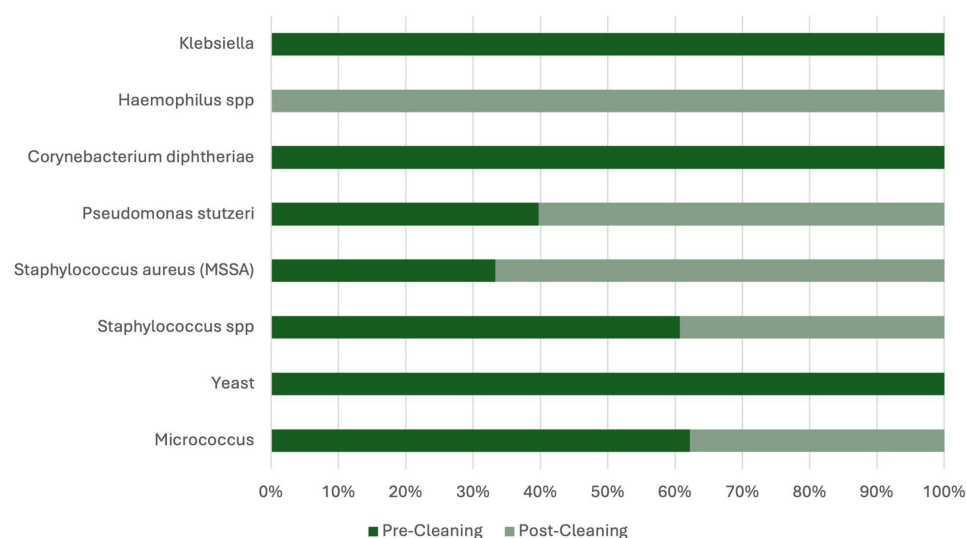
**Figure 3** Distribution of Types of Organisms Pre-and Post-Cleaning.

Table 3 The Different Organisms That Grow on the Different Locations of the Aprons Both Pre- and Post-Cleaning: McNemar's Test

Variable	Before Cleaning	Inside				Outside				Neck			
		After Cleaning		Total	Test (P-value)	After Cleaning		Total	Test (P-value)	After Cleaning		Total	Test (P-value)
		–	+			–	+			–	+		
Sample	–	1	2	3	0.019	7	3	10	1.818	9	1	10	0.000
	+	5	12	17	(0.453)	4	6	10	(1.000)	9	1	10	(0.021)*
	Total	6	14	20		11	9	20		18	2	20	
Micrococcus	–	4	4	8	0.135	12	2	14	0.952	15	0	15	3.158
	+	7	5	12	(0.549)	4	2	6	(0.687)	4	1	5	(0.125)
	Total	11	9	20		16	4	20		19	1	20	
Yeast	–	18	0	18	^a	20	0	20	^a	20	0	20	^a
	+	2	0	2		0	0	0		0	0	0	
	Total	20	0	20		20	0	20		20	0	20	
Staphylococcus spp	–	8	4	12	0.159	13	3	16	0.882	14	1	15	0.741
	+	6	2	8	(0.754)	4	0	4	(1.000)	4	1	5	(0.375)
	Total	14	6	20		17	3	20		18	2	20	
Staphylococcus aureus (MSSA)	–	17	3	20	^b	16	2	18	2.135	19	0	19	^a
	+	0	0	0		1	1	2	(1.000)	1	0	1	
	Total	17	3	20		17	3	20		20	0	20	
Pseudomonas stutzeri	–	16	2	18	2.135	20	0	20	^a	20	0	20	^a
	+	1	1	2	(1.000)	0	0	0		0	0	0	
	Total	17	3	20		20	0	20		20	0	20	
Corynebacterium diphtheriae	–	20	0	20	^{a,b}	20	0	20	^a	19	0	19	^a
	+	0	0	0		0	0	0		1	0	1	
	Total	20	0	20		20	0	20		20	0	20	
Haemophilus spp	–	19	1	20	^b	20	0	20	^a	20	0	20	^a
	+	0	0	0		0	0	0		0	0	0	
	Total	19	1	20		20	0	20		20	0	20	
Klebsiella	–	19	0	19	^a	20	0	20	^a	20	0	20	^a
	+	1	0	1		0	0	0		0	0	0	
	Total	20	0	20		20	0	20		20	0	20	

Notes: *Significant associations ($P < 0.05$). ^aNo statistics are computed because there are no positive cases before or after cleaning. ^bNo statistics are computed because there are no positive cases before cleaning.

Discussion

In this study, we investigated whether lead aprons worn by healthcare workers in the OR theatre carry a potential risk of infection and whether the cleaning protocol of the hospital is effective in reducing the number of microorganisms. It was shown in a similar study that was published in 2020 that 87.80% of the aprons were contaminated.⁵ Compared to our study which showed growth of 51.6%.

In regard to the contamination level pre- and post-cleaning 61.7% of the pre-cleaning samples showed positive growth while 41.7% of the post-cleaning samples had positive growth which indicates that the cleaning process led to

a statistical significance in reducing the level of bacterial contamination, and this supports the original hypothesis that lead aprons are a source of contamination in the operating room. This is similar to the conclusion of the study published in 2010 that involved the swabbing of a sample of 15 lead aprons with predetermined locations. All aprons were significantly reduced after the cleaning in both predetermined locations.⁶

The same study found bacterial contamination in all aprons, those identified were Coagulase-negative staphylococci, staphylococcus aureus, Bacillus, diphtheroid, and some fungal spores. While most of the microorganisms that were identified are part of the normal flora. They still carry the potential to be pathogenic. In our study, we found microorganisms similar to those discovered in the previous study. Showcasing that this is a crucial issue to investigate.⁶

One of the organisms detected was Staphylococcus aureus which is a coagulase-positive staphylococci that can be detected in one-third of people's skin, nose, or throat.⁶ Staphylococcus aureus is a highly prevalent pyogenic pathogen in both community-acquired and hospital-acquired settings.⁷ It can cause a range of superficial skin infections as well as more serious infections such as osteomyelitis, septicaemia, and pneumonia.⁶ Treatment of Staphylococcus aureus infections remains challenging due to the emergence of multi-drug-resistant bacteria like MRSA (Methicillin-Resistant Staphylococcus aureus).⁷

According to other research, inpatients with S. aureus infections had significantly 3 times longer average LOS, greater than 3 times the total charges, and nearly 5-fold higher in-hospital mortality rates than inpatients with other types of hospital infections.⁸ In this research, Staphylococcus aureus colonies were identified on 9 (7.5%) samples, all the 9 samples were Methicillin sensitive, and no MRSA was detected. The positive samples were found pre- and post-cleaning (4.9% vs 10.2%, respectively) this shows that the cleaning process did not significantly affect the growth of this organism.

Furthermore, Coagulase-negative staphylococci (CoNS) was also detected. Which is a common normal skin flora.⁹ However, it's the most common cause of hospital acquired bloodstream infection with Staphylococcus epidermidis and Staphylococcus Haemolyticus being the most significant species.¹⁰ Some patients are at more risk than others, especially patients who are immunocompromised, neonates or have invasive devices like orthopaedic joints, pacemaker, prosthetic valves or intravascular devices.¹¹ CoNS were identified on 28 (23.3%) samples. Of those samples 17 were pre-cleaning and 11 was post cleaning (27.9% vs 18.6%, respectively). This indicates that the cleaning process did not significantly affect the growth of this organism.

Lastly, gram negative bacilli (klebsiella, pseudomonas) are bacteria that are commonly found in the gut as part of the normal flora, and they can be a serious source of nosocomial infection.¹² Hospitalised patients are usually vulnerable and immunocompromised, thus, the vast majority of Pseudomonas species, are a cause of nosocomial infections, causing a wide variety of manifestations from UTI to ventilation associated pneumonia as the most common cause for it.¹³ For this reason, it's imperative to evaluate the hospital equipment as a reservoir for their spread. As for klebsiella spp, the majority of infections occurred in the hospital setting, with urinary tract infections (UTI) being the most common manifestation.¹⁴ In our study, pseudomonas of the stutzeri species was detected in a total of 5 samples pre- and post-cleaning (3.3% vs 5.1%, respectively) meaning the cleaning process did not significantly affect the growth of this organism. Whereas klebsiella pneumonia was detected in one sample which was collected only before cleaning the apron.

Regarding the growth distribution based on the location, the most significant growth was detected inside the apron (75.6%) with pseudomonas stutzeri, klebsiella, yeast and haemophilus spp being only detected on the inside. These results might suggest that the cleaning process inside the apron was the least adequate out of all other locations. But interestingly, staphylococcus aureus was not detected inside, which might be due to the outside surface being in contact with the hands prior to hand sensitization.

The inside was followed by the outside with the neck showing the least number of positive samples. In contrast, the neck was the second common location for microorganisms' growth in a similar study that was published in 2021. Moreover, in our study, the neck was the only location that showed a significant reduction in the organism growth post cleaning. Indicating that the cleaning process was most adequate on the neck area.

Conclusion

Lead aprons are a potential source of infection. Most of the samples taken were positive for contamination. We concluded, the cleaning method used by the hospital showed a significant difference in the number of microorganisms

that grew on the apron, but it did not fully eliminate concerning organisms indicating the need for a more standardized cleaning process. Moreover, the most significant location for growth was inside the apron indicating that the cleaning inside the apron might be subpar.

Even though surgical site infections remain a huge cause of morbidity and mortality,² the number of studies highlighting the contamination of lead aprons is very limited worldwide, and there is no literature about this topic in Saudi Arabia which indicates the need for further research. In our hospital, specifically, there is no standardised cleaning protocol, so to be able to achieve an effective protocol for cleaning aprons there needs to be more studies on the organisms most commonly affecting aprons and effectiveness of the current cleaning method.

Like any other study, this study has some limitations. First being that it was only conducted in King Fahad University Hospital which limited the sample size for aprons. Another being the limited time to get all enough samples and identify all of them. Lastly, even though the process of identification for the organisms was supervised all the way through it was still done by university medical students in the university laboratory. For future research, we would recommend more areas on the aprons be swabbed for identifications of organisms and expanding the study into a multicentre study to increase the sample size. There also needs to be more literature comparing different cleaning methods to develop the most effective cleaning protocol and to set a standard based on patterns of organism growth.

Abbreviations

PPE, Personal protective equipment; RPPE, radiation personal protective equipment; SSI, Surgical site infection; HAIs, healthcare-associated infections.

Data Sharing Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

IRB for the study was obtained from the Ethic Committee at Imam Abdulrahman bin Faisal University, Saudi Arabia (IRB-UGS-2022-01-421). The study has been conducted in accordance with the ethical standards noted in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Consent for Publication

The corresponding author on behalf of the coauthors in the study would like to provide the journal their consent to publish the manuscript.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Disclosure

The authors have no conflicts of interest to disclose for this work.

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