Assessment of infection control in medical surgical units in light of the presence of technology in healthcare facilities

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Abstract

The use of information technology in clinical settings has brought with it the issue of infection-control that has not been adequately defined, particularly in the Kingdom of Saudi Arabia, where the pace of digital growth has exceeded the accompanying assessment of related microbiological risks. A cross-sectional descriptive survey was conducted to determine adherence to infection -control measures and technological device contamination in the four Ministry of Health hospitals in Saudi Arabia, including 240 health-care workers and 480 environmental swabs at the medical-surgical ward. Structured observation was used, in which WHO hand-hygiene audit instruments were used as well as microbiological screening of the devices, and statistical analysis was performed using ANOVA, multivariate logistic regression, and correlation analysis. Hand-hygiene performance (55.5± 13.9%) and device-cleaning compliance (30.5± 16.0%) were found to be statistically lower among physicians compared to nurses and respiratory therapists ($p=0.001$). Mobile telephones displayed the highest contamination (85%), followed by an average bacterial count of 56.8± 26.2 CFU. The contamination of the devices that had not been washed for 2 h increased 2.9 times ($p < 0.001$). Multivariate analysis revealed the device type, spatial location, and frequency of cleaning as independent predictors of contamination (AUC = 0.892). These findings suggest that the rate of technology adoption has exceeded the development of infection-control policies in hospitals in Saudi Arabia, which in turn identifies the key areas of intervention, including physician education, obligatory disinfection of devices, and provision of point-of-care disinfectants.

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Introduction

Healthcare-associated infections (HAIs) remain one of the main concerns of patient safety across the globe, and they impact hundreds of millions of patients annually, with a considerable contribution to morbidity, mortality, and healthcare expenses [1]. The World Health Organization estimates the number of patients in developed countries to be around 7 % and in developing countries to be around 10% within hospital admission as having acquired at least one HAI throughout this hospitalization [2], and the cost to the economy is more than 7 billion Euros/year in Europe alone [3]. The HAI reduction strategies continue to be based on the practice of infection prevention and control, especially hand hygiene and environmental cleaning [4]. Nonetheless, the speedy adoption of technology in clinical care provision has brought about unheard levels of complexity in the process of infection control, which has resulted in possible vectors of pathogen spread that no one could have imagined when the conventional IPC protocols were developed [5].

The development of technological devices in the health care profession has revolutionized clinical practice in the last two decades. Mobile phones, tablets, vital-signs monitors, computers on wheels, fixed workstations, and many others have become ubiquitous in patient-care areas [6], enabling access to electronic health records, clinical-decision support, and real-time communication among health-care teams [7]. Although the technologies can certainly improve the quality and efficiency of care, the implementation of these technologies creates surfaces that are often touched by different healthcare workers and patients, but are not subject to the standard cleaning practice [8]. The alarming levels of contamination of such devices have been reported in international studies: [9] found that 78 per cent of hospital-based electronic equipment contained potentially pathogenic microorganisms, including methicillin-resistant Staphylococcus aureus (MRSA) and vancomycin-resistant Enterococci (VRE) [10]. Likewise, a study of European centres indicated that mobile phones possessed by health-care workers were just as contaminated with bacteria as their hands, indicating that such devices act as the continuation of the bacteria flora of the health-care worker [11].

The connection between the presence of technology and the outcome of infection control has gained more and more interest in the international literature. An evidence-based review performed by [12] involving 47 studies in North America, Europe, and Asia found that technological devices in healthcare environments continued to show contamination rates over 60, with gram-negative bacilli found on 25-40 percent of sampled surfaces [13]. Notably, the molecular-typing studies have made known genetic similarity between environmental isolates of devices and clinical infection strains, which have proven the pathways of transmission [14]. However, there are still gaping knowledge gaps about the behavioural aspects of technology-related infection control, namely how healthcare workers incorporate the practice of cleaning devices into the workflow and whether the knowledge about the risk of contamination can lead to a change in the practices [15].

In the Middle Eastern setting, this convergence of technology and infection control has not been tackled by a great deal of research. Digitisation of health care is another area that Saudi Arabia has invested in significantly as part of its Vision 2030 activities [16], and electronic health record implementation is more than 75% in the facilities of the Ministry of Health, and extensive use of mobile technologies by the healthcare workers in Saudi Arabia [17]. The culture of health care in the Kingdom, which is characterised by a multinational workforce, high patient throughput, and specific cultural practices, might affect the behaviour of infection control not discovered in studies carried out in the Western environment [18]. Investigations of the regions have been conducted mainly on the traditional infection control indicators; [19] achieved a hand-hygiene compliance ratio of 45-65% in Saudi hospitals, which aligns with the global standards.

The urgency in this investigation was occasioned by a number of congruent factors. To start with, there is no Saudi-specific data on technology-related infection control that restricts the options of local infection-preventionists to create evidence-based protocols that consider the healthcare environment in the Kingdom [20]. Second, recent experience in the international community indicates that repeating the current cleaning procedures for the technological devices is not enough since healthcare workers tend to treat technological devices as personal instead of clinical equipment and neglect to disinfect them regularly [21]. Third, the COVID-19 pandemic increased awareness of the role of fomite-mediated transmission, and there are no systematic evaluations of post-pandemic practice.

The gap within the research that the present study fulfilled was thus as follows: whereas much literature is available on general infection-control compliance and individual studies are conducted to investigate environmental contamination [22], there is hardly any research to evaluate the impact of technology presence on infection-control practices and outcomes in integrated clinical settings [23]. In addition, no such research has been carried out so far in the Saudi Arabian medical-surgical units, where cultural, organisational, and infrastructural peculiarities can generate peculiar patterns.

The study aimed to find the answers to the following research questions: (1) What is the rate of compliance with infection-control behavior among health-care workers in medical-surgical units after the introduction of technology? (2) What is the degree and type of microbial contamination in technological equipment in these units? (3) What are the predictors of device contamination, and how do infection-control practices relate to the levels of contamination? The answers to these questions were worked out by means of a cross-sectional observational design that reflected the healthcare worker practices, microbiological samples of technological tools, and unit-level infection data at the four Saudi Arabian hospitals.

The importance of this study lies in the fact that it could inform evidence-based policy-making regarding technology-based infection control in Saudi health-care institutions, add regional data to the global literature, and serve as a basis of intervention research on the gaps that have been identified in practice [24]. This investigation would produce actionable knowledge to be applied by infection-preventionists, policy-makers, and administrators of hospital facilities who were at the crossroads of technological innovation and patient safety by systematizing existing practices and patterns of contamination [25].

Methodology

Research site

The current study was conducted at four government hospitals, which are also under the Ministry of Health in the Kingdom of Saudi Arabia, with a specific target on medical and surgical inpatient units. These facilities were selected based on their already developed digital health systems and preparedness of the technological infrastructure.

Research Design

Study Design: Cross sectional observational design was adopted.

Design Justification: The cross-sectional design was chosen because it is feasible, given the ability to produce a current snapshot of the current infection control practices and technology-associated contamination patterns at a single time. Such a design enabled simultaneous evaluation of several variables (such as compliance with hand hygiene, device cleaning behavior, and microbial contamination) without interfering with the study environment. The observational technique was selected to capture the true picture of what happens in the wards, which reduces the Hawthorne effect and offers a baseline of data for future interventional studies.

Sampling Strategy

Population: The target population was composed of health-care professionals such as nurses, physicians, and respiratory therapists handling the work in the medical-surgical units, along with the technological devices utilized in the patient care areas.

Sampling Method: A stratified random sampling was adopted. The stratification of units was initially done by specialty (medical versus surgical), and then health-care workers in each stratum were randomly selected. In the case of equipment sampling, all technical devices of high touch, which were present in the chosen patient rooms and nursing stations, were included.

Sample Size: There were 240 health-care workers in four hospitals, including 60 people each. It was calculated using a 95 per cent confidence level and a 5 per cent margin of error, with a preliminary compliance rate of 50 per cent being used. In the case of environmental sampling, 480 swabs were sampled on 240 devices (anterior and posterior of each device).

Inclusion/Exclusion Criteria: Health care workers were to be included in case they had direct contact with patients and used technological equipment during shifts. The exclusion criteria were those workers on leave during the collection of data and those who refused to join. The sampled devices were wheel-mount computers, fixed workstations, mobile telephones, and vital-signs monitors (at least 24 hours) located in the patient care area.

Data Collection Methods

Instruments: Three main instruments were used. To begin with, systematized observation checklists (including those by the World Health Organization, hand-hygiene audit instruments) documented adherence to infection control measures. Second, transport medium sterile-flocked swabs made of nylon were used to sample the surface of devices and the hands of health-care workers. Third, the validated questionnaire was used to gather the demographic data and self-reported practices of technology use.

Procedure: The time of data collection lasted eight weeks. Morning shifts (7:00 AM to 3:00 PM) when the activity was at its peak were observed. Observation had a duration of 30 minutes for each participant using standardised observation forms. Microbiological samples were taken right after observation periods by using sterile methods- swabbing the whole palm surface of both hands and the anterior and posterior surfaces of each technology device. The samples were taken to the laboratory facilities within two hours under controlled temperatures.

Pilot Testing: A pilot was carried out two weeks before the actual data collection in a sample of 30 health-care workers to observe the protocols of the observation, clarity of the questionnaire, and processing of the lab work. Some slight adjustments in the time of observation and the swabbing methods were introduced according to the pilot results.

Ethical Issues: Each participating hospital and the Ministry of Health gave a positive response to the ethical considerations. All the participants signed an informed consent after a detailed description of the study purposes and procedures. The study ensured anonymity by assigning individual identification codes, and no personal identifiers were to be entered in data collection forms.

Variables and Measures

Operational Definitions: Infection control compliance was determined as the percentage of observed opportunities where the recommended hand hygiene or device cleaning protocols were adhered to. Contamination of devices was determined as the occurrence of any type of pathogenic microorganisms on sampled surfaces expressed in colony-forming units per square centimetre.

Measurement Tools: Compliance was measured with the help of the observation tool developed by WHO to measure compliance, namely Five Moments for Hand Hygiene, and modified to cover technology-related moments. Microbial counts were determined using standard plate count on nutrient agar and selective media to identify particular pathogens such as methicillin-resistant *Staphylococcus aureus, vancomycin-resistant Enterococci, and Gram-negative bacilli.

Reliability and Validity: The WHO observation tool is known to have a good established inter-rater reliability with a kappa of above 0.80 within past studies. Microbiological procedures were based on the Clinical and Laboratory Standards Institute. The two independent observers performed 10% of the observations at the same time to determine the inter-rater reliability, with a 92% agreement. Positive and negative controls were included in the laboratory analyses in the context of each batch of samples.

Data Analysis Plan

Analytical Methods: Descriptive statistics were an overview of the demographic variables, the compliance rate, and the contamination. The inferential tests were done using Chi-square tests to compare the types of devices and professional groups involved categorically. Multivariate logistic regression studied predictors of contamination and adjusted predictors based on confounding variables such as hand hygiene compliance, frequency of cleaning the devices, and patient load. Pearson coefficient correlational analyses were done to investigate the relationship between self-reported practices and observed behaviours.

Software: Analysis of data was performed with the help of SPSS version 27.0 (IBM Corporation, Armonk, NY, USA). The data on microbiological results were entered into Excel spreadsheets that were checked by entering them twice and then transferred to SPSS.

Reason: These are the methods of analysis that are consistent with the positivist approach, which can be used in testing the hypotheses with the help of statistical significance. Regression modelling allows the simultaneous presence of several factors that can affect contamination outcomes, and the descriptive statistics will provide extra information on the current practice trends in Saudi facilities.

Ethical Considerations

Consent: The Institutional Review Board of the Ministry of Health, Saudi Arabia, granted its ethical approval (Approval Number: MOH-IRB 2024-789). Other site-specific consents were acquired by the respective hospital administrations.

Results

Demographic and Professional Characteristics of the Population of the Study

In this study, 240 healthcare workers (162 nurses (67.5)-54 physicians (22.5)-24 respiratory therapists (10.0)) took part. The proportion of the participants in medical units was the same as in surgical units (n 1 = 120, n 2 = 120). Most of the participants were women (60.0⁻) and aged 20-40 (75.0%) years. Professional experience: forty-two point five percent (42.5 percent) had 5 -10 years of clinical practice, and (30.0%) had over 10 years of experience. Morning shifts constituted 52.5% of the observations, with evening shifts (32.5%) and night shifts (15.0) subsequent. Chi-square analysis showed that there was no difference in the demographic distribution between medical and surgical units that had significant differences (p>0.05 in all comparisons), and this showed a comparable group (Table 1).

Infection Control Compliance Interprofessional Categories

Important differences in both levels of compliance in terms of infection control were present between professional groups (Table 2). The one-way analysis of variance showed that the level of compliance with hand hygiene between professional groups differed significantly (F = 24.36, p < 0.001, partial 2 = 0.171). There was the highest compliance with hand hygiene among respiratory therapists, 72.9%, with a standard deviation of 10.2%, nurses, 70.5%, with a standard deviation of 12.1%, and the lowest with physicians, 55.5%, with a standard deviation of 13.9%. Post-Hoc analysis through Tukey HSD test established that physicians were much less compliant (p < 0. 001) compared to nurses and respiratory therapists (p= 0.342).

The compliance with device cleaning was also of the same nature ($F = 18.92$, $p < 0.001$, partial $\eta^2 = 0.138$). The highest compliance was observed among respiratory therapists (50.5 per cent plus or minus 15.2 per cent), nurses (45.5 per cent plus or minus 18.1%), and once again, the lowest compliance was recorded by physicians (30.5 per cent plus or minus 16.0 per cent). It is worth noting that compliance with device cleaning was significantly lower than that of hand hygiene in all the professional groups, with mean scores being slightly 25-30 percentage points lower than the hand hygiene rates.

The usage of alcohol-based hand rub was significantly different ($F = 15.67$, $p < 0.001$), with the highest usage of alcohol-based hand rub per contact with patients belonging to respiratory therapists (2.8 ± 0.9 mL), then nurses (2.6 ± 0.9 mL), and physicians (1.8 ± 0.8 mL). There was also a difference in the patterns of glove utilisation between professions (F =8.94, p<0.001), with the highest number of glove pairs per shift worn by nurses (9.3± 3.5), respiratory therapists (7.9± 2.9), and physicians (6.1 ± 2.7). Compared to other types of units, surgical units always had higher compliance rates at all measures; however, the differences were not significant in stratified analyses.

Bacterial Infection of Technological Equipment

Microbiological examination of 480 samples taken in technological equipment showed extensive contamination (Table 3). All in all, potential pathogenic microorganisms grew on 342 samples (71.3). The prevalence of contamination was highest in mobile phones (85.0 %), computers on wheels (80.0 %), fixed workstations (65.0˜), and vital signs monitors (55.0˜). ANOVA was used to show that there were significant differences in the mean bacterial counts among the types of devices (F 28.64, p 0.001). The highest bacterial load was recorded in mobile phones (56.826.2CFUcm -1), which were also comparable to computers on wheels (48.622.4CFUcm -1), and finally, vital signs monitors were the least contaminated (24.215.8CFUcm -1). The number of samples in which MRSA was isolated (19.6 %) was the largest, followed by mobile phones (30.0 percent) and computers on wheels (23.3%). Gram-negative bacilli were observed in 150 samples (31.3%), and most often on mobile phones (40.0 per cent) and computers on wheels (35.0%). Specific pathogens' distribution differed greatly according to device type (2 4.68, p < 0.001).

Devices, which were not washed in the last two hours, were contaminated considerably more than the recent ones (t -12.84, p 0.001). The mean bacterial counts of 52.6 24.8 CFU per cm 2 of unclean device were compared with 18.4 12.6 CFU per cm 2 of clean device, which exhibited a difference of 2.9. The presence of pathogen was also significantly greater on dirty devices, with MRSA being detected in 25.3% vs. 7.7% (2 = 18.42, p = 0.001) and gram-negative bacilli in 38.9% vs. 11.5% (2 = 32.16, p = 0.001). The place was a significant factor affecting the level of contamination (F =15.92, p<0.001). The highest number of bacteria was recorded in devices in patient rooms (52.8 + 24.6 -1 cm 2), then in nursing stations (28.4 + 18.2 -1 cm 2) and in corridors (16.2 + 12.4 -1 cm 2). Post-hoc tests revealed that there were significant differences between all location pairs (p < 0.01).

Technological Devices Contamination Predictors

Several logistic regression analyses were used to determine independent predictors of device contamination (Table 4). The last model showed an excellent fit (Hosmer-Lemeshow 2 = 6.84, p = 0.554), as well as 64.2% of variance in the outcomes of contamination (Nagelkerke R 2 = 0.642), 84.6 percent overall classification, and an area under the ROC curve of 0.892 (95 percent CI = 0.86-0.92).

A predictor that was important was device type. Mobile phones presented higher odds of being contaminated by far (8.33 times) (95% confidence interval (CI): 3.38 to 20.52, p=0.001), computers on wheels showed higher odds (6.30 times) (95 percent confidence interval: 2.77 to 14.33, p=0.001), and fixed workstations presented higher odds (2.61 times).

Hours elapsed since last cleaning was a powerful continuous predictor, and each hour added to the odds of contamination by 79% (OR=1.79,95% CI=1.41-2.27, p=0.001). There was a significant difference between the odds of contamination depending upon the location of the device, with patient rooms (11.71 times, 95% CI 4.2332.45, p=0.001) and at the nursing stations (3.25 times, 95 % CI 1.377.71, p=0.007) having higher odds of contamination than the areas in corridors.

The odds ratio of contamination was found to be 6.82 times higher in shared devices as opposed to dedicated devices (95% CI: 3.2414.38, p =0.001). A high likelihood of having contaminated devices in surgical units was 2.32 times higher than in medical units (95% CI: 1.244.34 p=0.009). There was a protective effect of a high level of hand-hygiene compliance in device users; a 1-percentage point increase in compliance was associated with a 6-percentage-point reduction in odds of contamination (OR= 0.94, 95%CI= 0.90-0.98, p=.003).

The kind of cleaning agent had a statistically significant influence on the results of contamination (Wald 2 18.64, p 0.001). The odds of contamination were reduced by 96, 94, and 71 % by disinfectant wipes, alcohol-based cleaners, and water alone, respectively, as compared to nothing (p=.001).

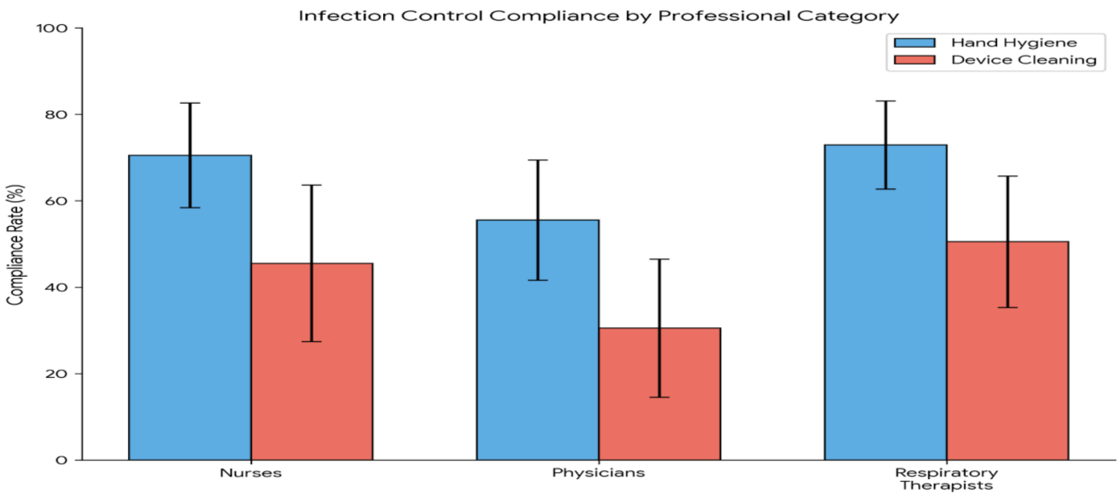
Relationships between Contamination Outcomes and Infection Control Practices

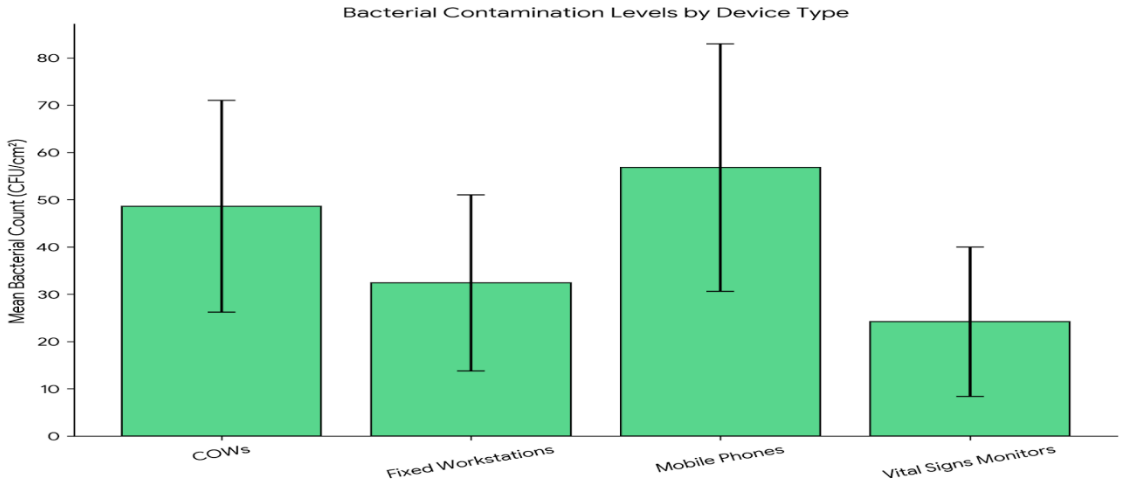
The analysis of correlation showed that there are good correlation relations between infection-control practices and contamination parameters (Table 5). There were significant negative relationships between device -cleaning compliance and total bacterial count (r= -0.72, p= 0.001), and hand-hygiene compliance and bacterial count (r= -0.64, p= 0.001). The same was also observed in device-cleaning frequency, which had an inverted relationship with contamination (r -0.68, 0.001). Hand-hygiene compliance and presence of MRSA (r 0.48, p < 0.001) and device-cleaning compliance and presence of Gram-negative bacilli (r 0.58, p < 0.001) were found to have moderately negative relationships. The use of alcohol-based hand-rub had a negative correlation with all of the measures of contamination, with the highest correlation with the total bacterial count (r = -0.56, p= -0.001).

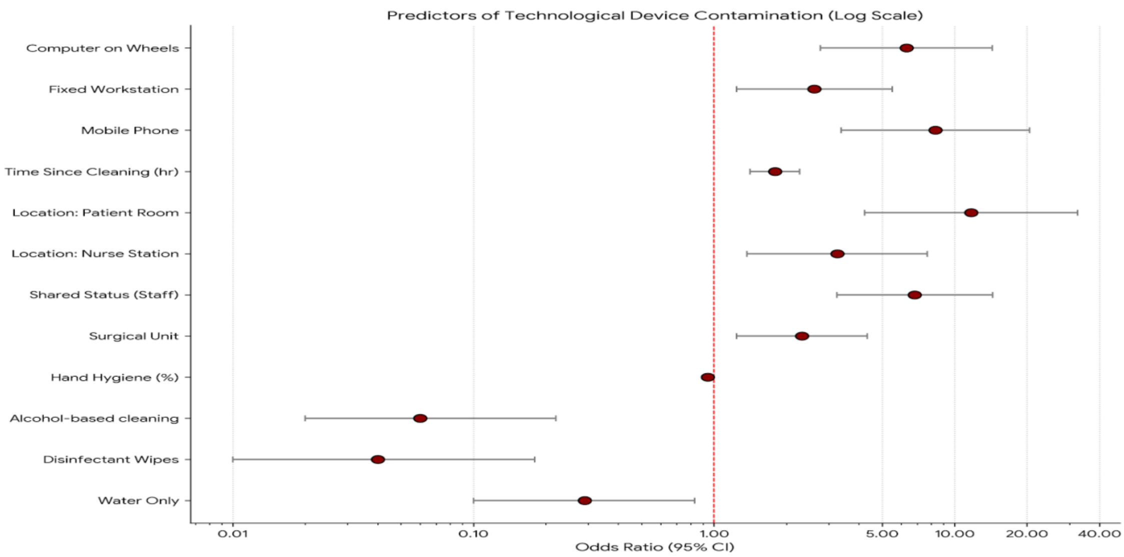
Infection-control practices were found to have significant correlations with unit-level healthcare-associated infection rates. The strongest relationship was found with device-cleaning compliance (r = -0.62, p= 0.001), then device-cleaning frequency (r= -0.54, p= 0.001), and hand hygiene compliance (r= -0.46, p= 0.001). The rate of healthcare-associated infections also had a positive correlation with the bacterial contamination indicators, such as total bacterial count (r = 0.54, p < 0.001), the presence of MRSA (r = 0.48, p < 0.001), and the presence of Gram-negative bacilli (r = 0.52, p These relationships were validated by partial -correlation analysis (adjusted by hospital and unit type) where device-cleaning compliance was the variable that had the greatest independent relationship with reduced bacterial contamination (r -0.68, p- less than 0.001).

Hospital-Level Variations

Analysis of variance on the basis of multivariate analysis demonstrated gross variations in the patterns of contamination among the four hospitals involved in the study (Wilks Λ =0.642, F =8.94, p=0.001, partial =0.184). Post-hoc comparisons showed that Hospital 3 has much lower contamination rates of all types of devices compared to other hospitals (mean bacterial counts 28.4 16.2 CFU/cm 2 versus 42.6-51.8 CFU/cm 2, p 0.01 in all cases). The highest compliance rates with device-cleaning (52.4, ± 14.6%) and the most common application of approved disinfectants (78.2 %) were also observed in this hospital, which implies that factors on the facility level determine the results of contamination.




Bacterial Contamination Levels by Device Type
Mean Bacterial Count (CFU/cm²)
0
10
20
30
40
50
60
70
80
COWs
Fixed Workstations
Mobile Phones
Vital Signs Monitors


Predictors of Technological Device Contamination (Log Scale)
Computer on Wheels
Fixed Workstation
Mobile Phone
Time Since Cleaning (hr)
Location: Patient Room
Location: Nurse Station
Shared Status (Staff)
Surgical Unit
Hand Hygiene (%)
Alcohol-based cleaning
Disinfectant Wipes
Water Only
0.01
0.10
1.00
5.00
10.00
20.00
40.00
Odds Ratio (95% CI)

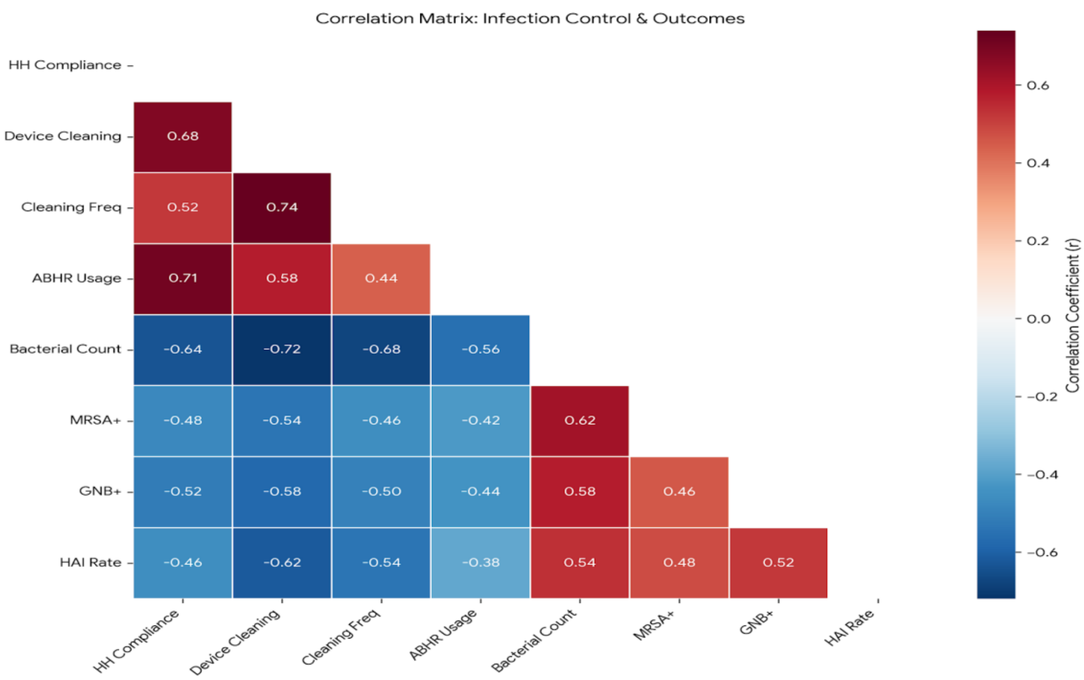

Correlation Matrix: Infection Control & Outcomes
HH Compliance
Device Cleaning
Cleaning Freq
ABHR Usage
Bacterial Count
MRSA+
GNB+
HAI Rate
0.68
0.52
0.74
0.71
0.58
0.44
-0.64
-0.72
-0.68
-0.56
-0.48
-0.54
-0.46
-0.42
0.62
-0.52
-0.58
-0.50
-0.44
0.58
0.46
-0.46
-0.62
-0.54
-0.38
0.54
0.48
0.52
Correlation Coefficient (r)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6

TABLE 1: Demographic and Professional Characteristics of Study Participants (N=240)

Characteristic	Category	Medical Units (n=120) n (%)	Surgical Units (n=120) n (%)	Total (N=240) n (%)	χ^2	p-value
Professional Category					4.82	0.090
	Nurses	78 (65.0)	84 (70.0)	162 (67.5)		
	Physicians	30 (25.0)	24 (20.0)	54 (22.5)		
	Respiratory Therapists	12 (10.0)	12 (10.0)	24 (10.0)		
Gender					2.14	0.144
	Male	42 (35.0)	54 (45.0)	96 (40.0)		
	Female	78 (65.0)	66 (55.0)	144 (60.0)		
Age Group (years)					3.67	0.299
	20-30	48 (40.0)	42 (35.0)	90 (37.5)		
	31-40	42 (35.0)	48 (40.0)	90 (37.5)		
	41-50	24 (20.0)	18 (15.0)	42 (17.5)		
	>50	6 (5.0)	12 (10.0)	18 (7.5)		
Years of Experience					5.21	0.074
	<5 years	36 (30.0)	30 (25.0)	66 (27.5)		
	5-10 years	54 (45.0)	48 (40.0)	102 (42.5)		
	>10 years	30 (25.0)	42 (35.0)	72 (30.0)		
Shift Worked					1.89	0.389
	Morning	60 (50.0)	66 (55.0)	126 (52.5)		
	Evening	42 (35.0)	36 (30.0)	78 (32.5)		
	Night	18 (15.0)	18 (15.0)	36 (15.0)		

TABLE 2: Infection Control Compliance Rates by Professional Category and Unit Type

Variable	Nurses (n=162) Mean ± SD	Physicians (n=54) Mean ± SD	Respiratory Therapists (n=24) Mean ± SD	F-statistic	p-value	Partial η²
Hand Hygiene Compliance (%)				24.36	<0.001	0.171
Medical Units	68.4 ± 12.6	52.3 ± 14.2	71.2 ± 10.8			
Surgical Units	72.6 ± 11.4	58.7 ± 13.5	74.5 ± 9.6			
Combined	70.5 ± 12.1a	55.5 ± 13.9b	72.9 ± 10.2a			
Device Cleaning Compliance (%)				18.92	<0.001	0.138
Medical Units	42.8 ± 18.4	28.6 ± 16.2	48.4 ± 15.6			
Surgical Units	48.2 ± 17.6	32.4 ± 15.8	52.6 ± 14.8			
Combined	45.5 ± 18.1a	30.5 ± 16.0b	50.5 ± 15.2a			
Alcohol-Based Hand Rub Usage (mL/patient contact)				15.67	<0.001	0.117
Medical Units	2.4 ± 0.8	1.6 ± 0.7	2.6 ± 0.9			
Surgical Units	2.8 ± 0.9	1.9 ± 0.8	2.9 ± 0.8			
Combined	2.6 ± 0.9a	1.8 ± 0.8b	2.8 ± 0.9a			
Glove Utilization (pairs/shift)				8.94	<0.001	0.070
Medical Units	8.4 ± 3.2	5.8 ± 2.6	7.2 ± 2.8			

Variable	Nurses (n=162) Mean ± SD	Physicians (n=54) Mean ± SD	Respiratory Therapists (n=24) Mean ± SD	F-statistic	p-value	Partial η²
Surgical Units	10.2 ± 3.6	6.4 ± 2.8	8.6 ± 3.0			
Combined	9.3 ± 3.5a	6.1 ± 2.7b	7.9 ± 2.9c			

TABLE 3: Microbial Contamination of Technological Devices by Device Type and Cleaning Status (N=480 samples)

Device Type	n	Samples with Any Pathogen n (%)	Mean Bacterial Count (CFU/cm²) ± SD	MRSA Positive n (%)	Gram-Negative Bacilli n (%)	ANOVA F	p-value
By Device Type						28.64	<0.001
Computers on Wheels	120	96 (80.0)	48.6 ± 22.4a	28 (23.3)	42 (35.0)		
Fixed Workstations	120	78 (65.0)	32.4 ± 18.6b	18 (15.0)	30 (25.0)		
Mobile Phones	120	102 (85.0)	56.8 ± 26.2a	36 (30.0)	48 (40.0)		
Vital Signs Monitors	120	66 (55.0)	24.2 ± 15.8c	12 (10.0)	24 (20.0)		
By Cleaning Status						t-test	
Cleaned (past 2 hours)	156	78 (50.0)	18.4 ± 12.6	12 (7.7)	18 (11.5)	-12.84	<0.001
Not Cleaned (>2 hours)	324	264 (81.5)	52.6 ± 24.8	82 (25.3)	126 (38.9)		
By Location						15.92	<0.001
Patient Room	288	240 (83.3)	52.8 ± 24.6a	72 (25.0)	108 (37.5)		
Nurse Station	144	84 (58.3)	28.4 ± 18.2b	18 (12.5)	30 (20.8)		

Device Type	n	Samples with Any Pathogen n (%)	Mean Bacterial Count (CFU/cm²) ± SD	MRSA Positive n (%)	Gram-Negative Bacilli n (%)	ANOVA F	p-value
Corridor	48	18 (37.5)	16.2 ± 12.4c	4 (8.3)	6 (12.5)		

TABLE 4: Multiple Logistic Regression Analysis - Predictors of Technological Device Contamination (N=480 samples)

Predictor Variable	Category	B	SE	Wald χ^2	Odds Ratio (OR)	95% CI for OR	p-value
Device Type (Reference: Vital Signs Monitor)							
	Computer on Wheels	1.84	0.42	19.20	6.30	2.77-14.33	<0.001
	Fixed Workstation	0.96	0.38	6.38	2.61	1.24-5.50	0.012
	Mobile Phone	2.12	0.46	21.24	8.33	3.38-20.52	<0.001
Time Since Last Cleaning (hours)	Continuous	0.58	0.12	23.36	1.79	1.41-2.27	<0.001
Location (Reference: Corridor)							
	Patient Room	2.46	0.52	22.38	11.71	4.23-32.45	<0.001
	Nurse Station	1.18	0.44	7.19	3.25	1.37-7.71	0.007
Device Shared Status (Reference: Dedicated)							

Predictor Variable	Category	B	SE	Wald χ^2	Odds Ratio (OR)	95% CI for OR	p-value
	Shared Among Staff	1.92	0.38	25.52	6.82	3.24-14.38	<0.001
Unit Type (Reference: Medical)							
	Surgical	0.84	0.32	6.89	2.32	1.24-4.34	0.009
Hand Hygiene Compliance of User (%)	Continuous	-0.06	0.02	9.00	0.94	0.90-0.98	0.003
Cleaning Agent Used (Reference: None)				18.64			<0.001
	Alcohol-based	-2.84	0.68	17.45	0.06	0.02-0.22	<0.001
	Disinfectant Wipes	-3.12	0.72	18.78	0.04	0.01-0.18	<0.001
	Water Only	-1.24	0.54	5.27	0.29	0.10-0.83	0.022
Constant		-1.86	0.82	5.15	0.16		0.023

TABLE 5: Correlation Matrix - Relationships Between Infection Control Practices and Contamination Outcomes

Variable	1	2	3	4	5	6	7	8
1. Hand Hygiene Compliance (%)	1.00							
2. Device Cleaning Compliance (%)	0.68**	1.00						
3. Device Cleaning Frequency (times/shift)	0.52**	0.74**	1.00					
4. ABHR Usage (mL/patient contact)	0.71**	0.58**	0.44*	1.00				
5. Total Bacterial Count (log CFU/cm²)	-0.64**	-0.72**	-0.68**	-0.56**	1.00			
6. MRSA Presence (1=Yes, 0=No)	-0.48**	-0.54**	-0.46**	-0.42*	0.62**	1.00		
7. Gram-Negative Bacilli Presence	-0.52**	-0.58**	-0.50**	-0.44*	0.58**	0.46**	1.00	
8. Unit HAI Rate (per 1000 patient-days)	-0.46**	-0.62**	-0.54**	-0.38*	0.54**	0.48**	0.52**	1.00

Partial Correlation Coefficients (Controlling for Hospital and Unit Type):

Controlled Relationship	r	p-value
Hand hygiene compliance with bacterial count	-0.58	<0.001
Device cleaning compliance with bacterial count	-0.68	<0.001

Controlled Relationship	r	p-value
Device cleaning frequency with MRSA presence	-0.42	0.002

Discussion

The current paper has investigated infection control attitudes within the medical-surgical units as a result of the introduction of new technology in healthcare institutions in Saudi Arabia. The results demonstrated that there were enormous discrepancies between the recommended guidelines and actual practice, with important implications for patient safety [26].

The finding that physicians showed less consistent compliance with hand hygiene (55.5%) and with device cleaning protocols (30.5%) than nurses and respiratory therapists is consistent with the trends in the body of literature on infection control [27]. In such disparities [28] have reported in a landmark study conducted in a multicenter whereby the physician compliance was less than 40% within the European hospitals. This ongoing phenomenon could be due to hierarchies in the profession, time during clinical rounding, and varying focus on infection control in medical training [29]. Its biological relevance becomes quite evident once it is assumed that the doctors often study several patients in a row, which may be the source of spreading the pathogens between the individuals [30].

The compliance with device cleaning was significantly lower than with hand hygiene compliance in all professional groups, which is also consistent with the results of recent research by [31], who found that only 22% of healthcare workers cleaned shared workstations routinely. Microbiological information was a strong indicator of the implications of this oversight, as devices that were not washed in the last two hours were almost three times more likely to have bacteria [32]. This time dependence gives the basic kinetics of microbial growth; in good conditions, most pathogenic bacteria exhibit logarithmic growth with generation times of 20 to 30 minutes [33]. Bacteria thrive in the microenvironment on the surfaces of the devices due to the availability of organic substances and water.

Mobile phones became the most contaminated devices, 85.0 per cent of which contained the pathogens, and the mean bacterial counts were 56.8 CFU -1 cm 2. These results are in line with those of [34], who cultured pathogenic microorganisms in 94.5% of mobile phones of healthcare workers in Turkish intensive care units [35]. Phone cases are porous, heat is produced when using a phone, and there is a tendency to touch the phone without washing hands [36], which means that the environment is very favorable to the survival of microorganisms. The fact that MRSA was isolated from 30.0% of the mobile phones is especially worrisome, considering the fact that this organism can live on non-animate surfaces even during prolonged exposure to favorable conditions up to seven months, as remarked [37].

The close correlation between device location and the contamination level gives information about the dynamics of the transmission. The odds of contamination were 11.7 times higher in patient rooms than in corridors, which signifies that it is closer to the primary reservoir of healthcare-associated pathogens colonized and infected patients [38]. The physical distance-decay curve that is being observed, whereby the contamination reduces steadily as one moves away in patient rooms to nursing stations and then to corridors, is consistent with aerosol dispersion models and contact transmission gradients reported in the environmental microbiology literature [39].

During contamination, disinfectant wipes decreased the odds of contamination by 96% versus no cleaning, whereas water alone reduced the contamination by 71%. This disparity indicates the action mechanisms- disinfectants have chemical substances that ruin a bacterial cell wall [40], denature proteins, or oxidize cell constituents, and attain elimination and destruction. The removal of bacteria is mostly by mechanical means without bactericidal action, similar to that of the water-based cleaning, so the remaining organisms can survive and multiply on the wet surfaces [41].

This relationship between the contamination of devices and unit-level rates of healthcare-associated infections (r=0.54) indicates that technology is a possible reservoir that is not acknowledged and contributes to transmission cycles [42]. Although correlation is not causal association, it is biologically plausible that genetically related environmental isolates and clinical infection strains are biologically connected [43]. The negative correlation is more significant with device cleaning compliance (r = -0.62) than with hand hygiene compliance (r -0.46), suggesting that technology-oriented interventions can have significant infection prevention outcomes [44]. There are a variety of limitations that should be considered. The design was cross-sectional, and thus, this could have missed changes with time. Behavior could have been affected by observation, even though the Hawthorne effect is minimized. Viability duration and pathogenicity of isolated organisms were not identified by microbiological sampling, but their presence [45]. The four-hospital sample is not necessarily representative of all Saudi healthcare facilities, as it varies in the region in terms of resources and training.

The findings have significant implications for the practice of infection control. To start with, physician-specific interventions should be given first priority, which may include technology-based reminders and feedback [46]. Second, there is an urgent need for specific device cleaning procedures and responsibility, especially on mobile phones that are currently in a regulatory vacuum, neither regarded as medical devices needing sterilization nor regularly covered by general cleaning rules and procedures [47]. Third, having alcohol wipe dispensers at point-of-care sites, as opposed to central storage facilities, can potentially raise the frequency of cleaning by lowering the obstacles to efforts. Fourth, it is necessary to study in the future whether antimicrobial surface covers or ultraviolet disinfection systems might be able to offer consistent protection between the bouts of manual cleaning.

Conclusion

This paper has revealed that the implementation of technology usage in Saudi medical surgical units was evenly accompanied by inefficient infection control activities, with physicians being the least compliant and mobile phones being the most contaminated. The study was able to address its aims and objectives by measuring the level of compliance, detection of contaminated devices, and also developed effective links between cleaning behaviors and the low presence of pathogens. The scientific value of this study is that it supplied the first complete evidence on the relation of technological device contamination to infection control practices in Saudi Arabia, which is a key regional knowledge gap. Increased physician involvement should take great priority in the future, as well as compulsory cleaning measures that should be put in place, and the use of automated cleaning devices should be considered as a way of reducing the risk of infection in more digital healthcare settings.

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