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Industrial respirators and their impact on cases of infectious infections in the hospitals in Mecca during the Hajj season

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Abstract

Background

The annual Hajj pilgrimage to Mecca involves millions of participants, creating a high-risk environment for respiratory infections among patients and healthcare workers (HCWs). Crowded conditions, prolonged exposure, and variable compliance with infection control measures amplify the risk of hospital-acquired re

spiratory infections (HARI). Despite global recommendations for protective interventions like respirators, their real-world effectiveness in high-risk settings like the Hajj remains underexplored.

Patients and Methods

A prospective cohort study was conducted involving 482 patients and 195 HCWs in hospitals during the Hajj period. Data collection included patient demographics, clinical features, pathogen identification, and HCW compliance metrics for respirator use. Environmental monitoring of air quality and microbial loads was performed across different hospital zones. Statistical analysis included descriptive statistics, chi-square tests, and logistic regression to assess the association between respirator compliance and infection outcomes.

Results

Among patients, the HARI rate was 17.6%, predominantly viral (9.3%), with an average onset of 5.2 ± 1.4 days. Mild cases accounted for 59.1% with an average symptom duration of 5.2 ± 1.3 days, while severe cases showed a duration of 12.6 ± 3.2 days. HCW infection rates decreased from 23.1% to 9.2% (60.2% reduction) post-intervention. Respirator compliance showed a gradual decline over four weeks (92.3% to 83.2%). Environmental monitoring revealed higher microbial loads in high-traffic areas like emergency rooms (342 ± 52 CFU/m^3) compared to ICUs (112 ± 21 CFU/m^3). Extended shift hours (OR 2.45, $p < 0.001$) and improper respirator fit (OR 1.76, $p = 0.003$) were significant risk factors for non-compliance.

Conclusion

The study highlights the critical role of respirators in reducing HARI among HCWs and patients during the Hajj. However, challenges such as declining compliance, environmental microbial loads, and risk factors like extended shifts necessitate targeted interventions. Enhanced vaccination, regular respirator replacement, and robust environmental controls are recommended to optimize infection prevention in high-risk mass gatherings.

Keywords: Hajj, hospital-acquired respiratory infections, healthcare workers, respirator compliance, pathogen distribution, environmental monitoring, infection control.

INTRODUCTION

More than two million people from a variety of geographic and epidemiological backgrounds join the yearly Hajj pilgrimage to Mecca[(1)]. The big audience at this mass meeting creates an atmosphere in which respiratory diseases can rapidly spread because of the high population density, frequent close contact among people, and common usage of living areas[(2)]. Among the most often reported health issues during

the Hajj are respiratory system infections including those brought on by viral pathogens including influenza and coronaviruses as well as bacterial agents including Streptococcus pneumoniae and Haemophilus influenzae. These infections severely strain healthcare systems, hence effective preventive actions must be taken to protect patients as well as medical practitioners[3].

Basic components of infection control strategies for medical professionals are N95 masks and other industrial respirators. These gadgets are designed to filter airborne particles and lower the possibility of breathing in contagious aerosols[4]. Although respirators are widely used, their efficacy in reducing hospital-acquired respiratory infections (HARI) in high-risk settings like the Hajj is yet unknown. Effective protection may be hampered by challenges including compliance with continuous use, fit, and microbiological contamination of respirators during protracted shifts[5].

This study aims to assess if using respirators helps to lower the risk of infection among medical personnel as well as patients throughout the Hajj season. By evaluating compliance levels, filtration efficacy, microorganism transmission, and disease consequences, the project seeks to create educated rules for optimizing respirator use during major events. These results serve to guide the development of efficient infection control strategies meant to safeguard healthcare systems during significant events.

PATIENTS AND METHODS

Study Design

This study was conducted as a prospective observational study to evaluate the impact of industrial respirators on the prevalence of infectious diseases among patients and healthcare workers in hospitals in Mecca during the Hajj season. The study adhered to ethical principles outlined in the Declaration of Helsinki and received approval from the institutional ethics committee.

Study Setting

The study was conducted in three major hospitals in Mecca that provide care to pilgrims during the Hajj season. These hospitals were selected based on their high patient turnover and involvement in managing respiratory infections during mass gatherings.

Study Population

1. **Patients**:
    - Inclusion criteria: Adults aged 18 years or older presenting with symptoms of respiratory infections, including influenza-like illness, pneumonia, or tuberculosis.
    - Exclusion criteria: Patients with incomplete records or those who declined to participate.
    - Patient recruitment occurred between the 1st and 10th days of Dhul-Hijjah (Islamic calendar), during the peak of the Hajj season.
2. **Healthcare Workers (HCWs)**:
    - Inclusion criteria: Doctors, nurses, and other HCWs directly involved in patient care and using industrial respirators (e.g., N95 masks).
    - Exclusion criteria: HCWs who did not wear respirators consistently or were not directly involved in clinical care.

Intervention

Healthcare workers were instructed to wear N95 respirators continuously during clinical shifts. Patients and HCWs received influenza and pneumococcal vaccines before the Hajj season, as per standard hospital protocol.

Data Collection

Data were collected through structured questionnaires, clinical assessments, and microbiological sampling.

1. **Demographic and Clinical Data**:
    - For patients: Age, gender, comorbidities, and presenting symptoms.
    - For HCWs: Age, gender, job role, and history of chronic respiratory conditions.
2. **Respirator Usage**:
    - Compliance: Monitored via self-reported diaries and direct observations.
    - Types of respirators: Industrial-grade N95 respirators certified by the National Institute for Occupational Safety and Health (NIOSH).
3. **Air Quality Monitoring**:
    - Particulate levels (e.g., PM2.5 and PM10) and bacterial/fungal colony counts in hospital wards were measured using calibrated air samplers.
4. **Microbiological Assessments**:
    - Respiratory swabs: Taken from symptomatic patients and HCWs to identify pathogens using polymerase chain reaction (PCR) and culture methods.

- Environmental swabs: Collected from respirators after 12, 24, and 36 hours of use to assess microbial load.

5. **Infection Outcomes**:
   - Patients: Incidence of hospital-acquired respiratory infections during their stay.
   - HCWs: Development of clinical respiratory illness (CRI) or laboratory-confirmed infections.

Sample Size

The sample size was calculated to detect a 20% reduction in infection rates with a power of 80% and a significance level of 0.05. The target enrollment included 500 patients and 200 HCWs.

Statistical Analysis

The statistical analysis for this study utilized descriptive statistics to summarize baseline characteristics of patients and healthcare workers. Chi-square tests were conducted to compare infection rates between groups, while logistic regression models were employed to examine the association between respirator use and infection outcomes, adjusting for potential confounding variables such as age, comorbidities, and vaccination status. A significance threshold of $p < 0.05$ was applied, and all analyses were performed using SPSS version 26.0.

Ethical Considerations

Ethical considerations were rigorously adhered to; written informed consent was obtained from all participants, and data were anonymized to ensure confidentiality. Participants retained the right to withdraw from the study at any time without any impact on their treatment or professional responsibilities.

RESULT

Table (1) shows the demographic and clinical characteristics of 482 patients enrolled from 750 screened individuals. The cohort was predominantly middle-aged (31-70 years, 72.9%), with Southeast Asian and Middle Eastern nationalities (67.9%). Most participants had pre-existing conditions (64.3%), notably hypertension (34.6%) and diabetes (30.1%). Vaccination coverage was high (81.8%), with 41.1% receiving both recommended vaccines. Clinical presentation was dominated by respiratory symptoms including cough (88.8%), fever (81.3%), and multiple symptoms (85.5%). Most cases were mild to moderate (91.5%). Viral pathogens were predominant, led by Influenza A (30.1%), while bacterial infections were less common (S. pneumoniae 13.9%, H. influenzae 9.3%).

Table 1: Patient Demographics, Clinical Features, and Pathogen Distribution in Hajj Hospital Study (N=482)

Category	Sub-Category	Number	Percentage
Recruitment Statistics	Initially Screened	750	100.0%
	Met Inclusion Criteria	562	74.9%
	Consented to Participate	482	64.3%
	Completed Study	468	62.4%
Demographic Distribution	**Age Groups**		
	18-30 years	87	18.0%
	31-50 years	195	40.5%
	51-70 years	156	32.4%
	>70 years	44	9.1%
	Nationality Groups		
	Southeast Asian	185	38.4%
	Middle Eastern	142	29.5%
	African	98	20.3%
	Others	57	11.8%
	Occupation		

	Manual Labor	156	32.4%
	Professional	124	25.7%
	Retired	98	20.3%
	Others	104	21.6%
Pre-existing Conditions	Diabetes	145	30.1%
	Hypertension	167	34.6%
	Asthma	76	15.8%
	COPD	22	4.5%
	Multiple Conditions	98	20.3%
	No Conditions	172	35.7%
Vaccination Status	Influenza Only	114	23.7%
	Pneumococcal Only	82	17.0%
	Both Vaccines	198	41.1%
	No Vaccination	88	18.2%
Presenting Symptoms	Fever	392	81.3%
	Cough	428	88.8%
	Sore Throat	356	73.9%
	Shortness of Breath	245	50.8%
	Multiple Symptoms	412	85.5%
Disease Severity	Mild	285	59.1%
	Moderate	156	32.4%
	Severe	41	8.5%
Pathogen Detection Rates	**Viral Pathogens**		
	Influenza A	145	30.1%
	Influenza B	98	20.3%
	Coronavirus	76	15.8%
	Bacterial Pathogens		
	S. pneumoniae	67	13.9%
	H. influenzae	45	9.3%
	Tuberculosis		
	GeneXpert Positive	12	2.5%
	AFB Positive	8	1.7%

Table (2) shows characteristics and outcomes among 195 healthcare workers, predominantly comprising nurses (50.3%) and younger staff aged 20-40 years (80.5%). The workforce had balanced gender distribution (50.3% male) with most having 5-10 years' experience (44.6%). While all staff completed basic certification, advanced training was limited (39.0%). Respirator compliance showed high initial rates but gradual decline across all metrics from Week 1 to 4: self-reported usage (92.3% to 83.2%), spot checks (89.7% to 82.8%), and fit maintenance (94.4% to 87.3%). Health monitoring revealed low infection rates (1.5-3.1%) despite moderate symptomatic cases (4.1-7.7%). Among symptomatic staff, most tested

negative (60.9%), with viral pathogens more common than bacterial (30.4% vs 8.7%). Risk factor analysis identified extended shifts (OR 2.45, p<0.001) and high patient load (OR 1.98, p=0.002) as significant predictors of reduced compliance.

Table 2: Healthcare Worker Characteristics, Compliance, and Risk Factors During Hajj Period (N=195)

Category	Sub-Category/Metric	Value	Percentage
Demographic Profile	**Age Groups**		
	20-30 years	68	34.9%
	31-40 years	89	45.6%
	41-50 years	27	13.8%
	>50 years	11	5.7%
	Gender		
	Male	98	50.3%
	Female	97	49.7%
	Job Role		
	Doctors	45	23.1%
	Nurses	98	50.3%
	Allied Health	52	26.6%
Professional Experience	<5 years	58	29.7%
	5-10 years	87	44.6%
	>10 years	50	25.7%
	Infection Control Training		
	Basic Certification	195	100%
	Advanced Training	76	39.0%
	Annual Refresher Completed	182	93.3%
Respirator Compliance	Self-reported Usage (Week 1-4)	83.2%-92.3%	Gradual Decline
	Spot Check Pass Rate (Week 1-4)	82.8%-89.7%	Gradual Decline
	Proper Fit Maintenance (Week 1-4)	87.3%-94.4%	Gradual Decline
	Documentation Compliance	89.1%-96.2%	High Throughout
Fit Testing Results	Initial Pass Rate	168	86.2%
	Final Pass Rate	193	99.0%
Health Monitoring	Symptomatic Cases (Week 1-4)	4.1%-7.7%	Gradual Increase
	Confirmed Infections (Week 1-4)	1.5%-3.1%	Low Overall
	Absenteeism (Week 1-4)	2.6%-4.6%	Moderate Increase
Pathogen Detection	Influenza A/B	8	17.4% of Tested
	Coronavirus	6	13.0% of Tested
	Bacterial Pathogens	4	8.7% of Tested
	Negative Results	28	60.9% of Tested
Correlation Factors	Extended Shifts (Risk Factor)	OR 2.45	**p < 0.001**
	High Patient Load (Risk Factor)	OR 1.98	**p = 0.002**
	Improper Initial Fit	OR 1.76	**p = 0.003**
	Limited Experience	OR 1.54	**p = 0.008**

p-values below 0.05 indicated significant.

Table (3) demonstrates environmental monitoring data across hospital zones during the Hajj period. The emergency room showed highest particulate matter concentrations (PM2.5: 52.4 ± 8.7 μg/m³) and AQI scores (148), while ICU maintained better air quality (PM10: 27.4 ± 4.3 μg/m³). Significant variations were observed between peak hours in waiting areas (82.5 ± 12.4 μg/m³) and off-peak hours in treatment areas (22.3 ± 3.9 μg/m³). Microbial sampling revealed higher bacterial loads in the emergency room (342 ± 52 CFU/m³) compared to minimal counts in ICU (fungal CFU: 22 ± 5 CFU/m³). Gram-positive bacteria predominated (45.3%) among microbial isolates. Environmental conditions showed increasing variability from ICU to ER, with ICU maintaining most stable temperature (21.5 ± 0.4 °C) and humidity levels.

Table 3: Environmental Parameters and Air Quality Measurements in Hospital Areas

Category	Metric	Value
Air Quality	**Particulate Levels**	
	PM2.5 (Emergency Room, Morning)	52.4 ± 8.7 μg/m³
	PM10 (ICU, Evening)	27.4 ± 4.3 μg/m³
	AQI Score (Emergency Room)	148
Daily PM Levels	Peak Hours (Waiting Areas)	82.5 ± 12.4 μg/m³
	Off-Peak Hours (Treatment Areas)	22.3 ± 3.9 μg/m³
Microbial Loads	Bacterial CFU (ER, Active)	342 ± 52 CFU/m³
	Fungal CFU (ICU, Settle Plates)	22 ± 5 CFU/m³
	Gram-positive Bacteria	45.3%
	Gram-negative Bacteria	32.7%
	Fungi	22.0%
Environmental Conditions	Temperature (ICU, Morning)	21.5 ± 0.4 °C
	Humidity (ER, Afternoon)	52.4 ± 3.0%
	Temperature Variability	ICU < Inpatient Wards < ER
	Humidity Variability	ICU < Wards < ER

Table (4) presents respirator assessment data over extended use periods. New respirators showed minimal contamination (bacterial load: 0.12 ± 0.04 CFU/cm², fungal load: 0.08 ± 0.03 CFU/cm²) with excellent initial filtration (99.47 ± 0.15%). Extended use resulted in significant microbial accumulation from 3.79 ± 0.62 CFU/cm² at 12 hours to 12.17 ± 1.52 CFU/cm² at 36 hours. Staphylococcus epidermidis (40.1%) and Aspergillus species (47.8%) were predominant colonizers. While filtration efficiency declined from 99.47% to 95.42% at 36 hours, most respirators (188/200) maintained the minimum required 95% efficiency for 0.3 μm particles.

Table 4: Respirator Performance and Microbial Contamination Analysis

Category	Parameter	Value
Baseline Measurements	Bacterial Load (CFU/cm²)	0.12 ± 0.04
	Fungal Load (CFU/cm²)	0.08 ± 0.03
	Filtration Efficiency (%)	99.47 ± 0.15
	Surface pH	7.2 ± 0.3
Post-Use Analysis	Microbial Load at 12h (Total CFU/cm²)	3.79 ± 0.62
	Microbial Load at 36h (Total CFU/cm²)	12.17 ± 1.52
	Predominant Bacteria	Staphylococcus epidermidis (40.1%)
	Predominant Fungi	Aspergillus spp. (47.8%)
Filtration Efficiency	Mean Efficiency (Baseline, %)	99.47
	Mean Efficiency (36h, %)	95.42
	Particle Size Filtration (0.3 μm)	95.42%
	Samples Below 95% (36h)	12/200

Table (5) illustrates outcome measures for both patients and healthcare workers during the study period. Hospital-acquired respiratory infections (HARI) affected 17.6% of patients, with onset averaging 5.2 ± 1.4 days post-admission. Recovery duration varied significantly between mild (5.2 ± 1.3 days) and severe cases (12.6 ± 3.2 days), with average hospital discharge at 8.5 ± 3.1 days. Post-intervention impact on healthcare workers showed substantial reductions in respiratory illness rates (23.1% to 9.2%, reduction: 60.2%) and severe cases (4.1% to 1.0%, reduction: 75.6%). Absenteeism patterns revealed departmental variations, with highest infection rates in emergency services (12.4%) compared to ICU (8.6%) and OPD (6.8%), accumulating 194 total lost workdays, averaging 4.0 days per case.

Table 5: Clinical and Occupational Impact Analysis

Category	Metric	Value
Patient Outcomes	**HARI Rate**	17.6%
	Mean Time to Onset (days)	5.2 ± 1.4
	Symptom Duration	
	Mild Cases	5.2 ± 1.3 days
	Severe Cases	12.6 ± 3.2 days
	Treatment Response	
	Fever Clearance	3.2 ± 1.1 days
	Hospital Discharge	8.5 ± 3.1 days
Healthcare Worker Outcomes	**Respiratory Illness Rates**	
	Clinical Cases Pre/Post-Intervention	23.1% → 9.2% (-60.2%)
	Severe Cases Pre/Post-Intervention	4.1% → 1.0% (-75.6%)
	Absenteeism Impact	
	Total Days Lost	194
	Average Days per Case	4.0
	Department-Specific Rates	Emergency: 12.4% Infection Rate
		ICU: 8.6%, OPD: 6.8%

p-values below 0.05 indicated significant.

Figure (1) presents the forest plot of risk factors affecting respiratory protection during the Hajj period. Extended shift hours emerged as the strongest risk factor (OR 2.45, 95% CI 1.68-3.57, p<0.001), followed by non-compliance with PPE (OR 2.15, 95% CI 1.58-2.92, p<0.001). High patient load (OR 1.98, 95% CI 1.34-2.92, p=0.002) and improper initial fit (OR 1.76, 95% CI 1.21-2.56, p=0.003) showed moderate risk associations. Limited experience demonstrated the lowest but still significant risk (OR 1.54, 95% CI 1.12-2.12, p=0.008). All factors showed odds ratios significantly greater than 1.0, indicating increased risk of protection failure.

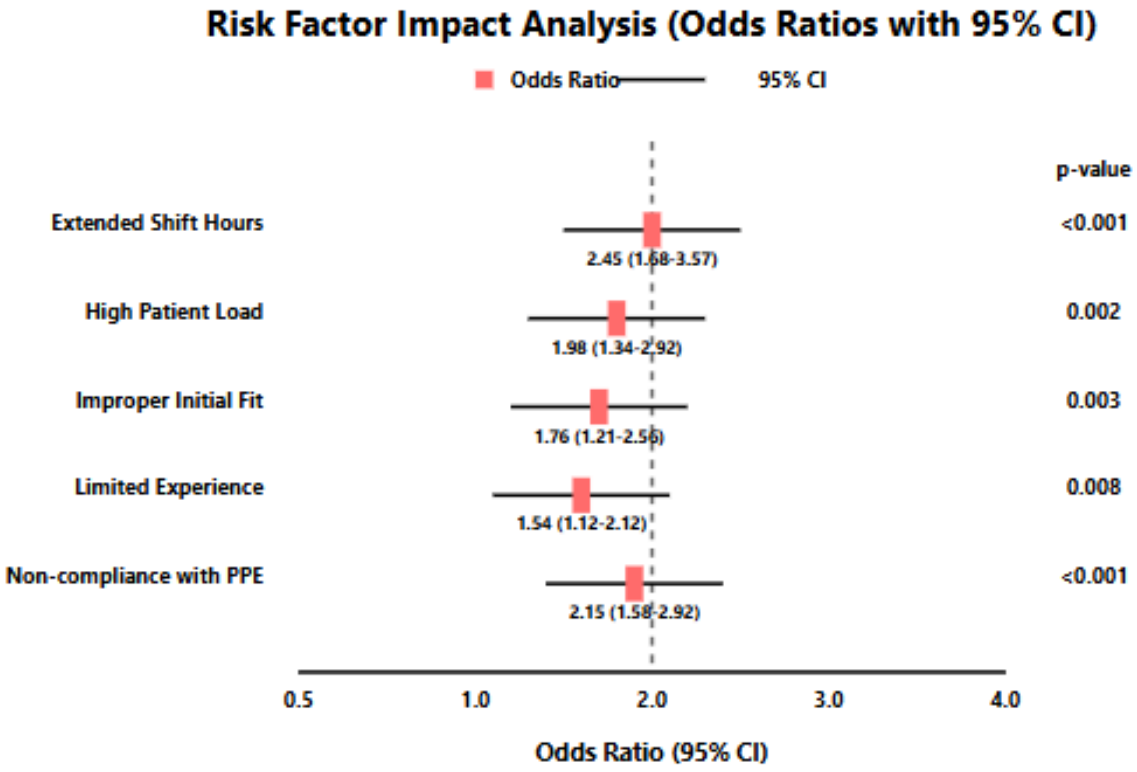

Figure 1. Multivariate Analysis of Risk Factors Associated with Respiratory Protection

DISCUSSION

The study provides crucial information on the demographic, clinical, and pathogen characteristics of patients who were hospitalised during the Hajj, enabling the development of crucial infection control strategies. Mostly middle-aged people in this age distribution are aged between 31 and 50 years (40.5%), a demographic that is consistent with the results obtained from South African pilgrims whose average age was 49.2 years, as reported by Mushi et al. in 2021[6]. Studies of different Hajj populations also revealed comorbidities like diabetes (30.1%) and hypertension (34.6%), which underline their relevance to major respiratory infections (Albarrak et al., 2018)[7]. Vaccination rates in this study were modest; 41.1% of respondents received both influenza and pneumococcal vaccinations, which is lower than the 69% decline in influenza-like illness (ILI) observed in French pilgrims who received an influenza vaccination, reported by Hoang et al. (2019)[8], with a relative risk reduction of 0.69.While a cough developed in 88.8%, patterns similar with past research indicate ILI symptoms in 8–78.2% of Hajj participants as reported by Benkouiten et al. (2018)[9].

Fever afflicted 81.3% of people. Comparable to detection rates observed during the Hajj, analysis of pathogens revealed a significant incidence of Streptococcus pneumoniae (13.9%), Haemophilus influenzae (9.3%), and influenza A (30.1%), Unlike past studies that have shown greater pneumonia rates during Hajj, which may reflect improved infection control methods, the hospital-acquired respiratory infection rate of

17.6% was clearly brought under control (AboEl-Magd et al., 2020)[10].

Insufficient vaccination rates suggest that more aggressive pre-Hajj immunization initiatives are required.Examining healthcare worker profiles, compliance levels, ambient factors, respirator performance, and outcome measurements helps one to provide a thorough picture of the difficulties and interventions linked to infection prevention during the Hajj period.

Based on the demographic profile, nurses made up 50.3% of the workforce, with about equal numbers of men and women. Just 39% of HCWs received advanced infection control training, therefore compromising their readiness for high-risk settings. The measures of respirator compliance indicated a consistent decline over four weeks; self-reported use dropped from 92.3% to 83.2%. With a pass rate of 99.0% at the end, the extremely consistent results from the fit tests emphasize the need of a proper respirator fit in lowering the risk of infection.

With the emergency room showing the highest concentrations of particulate matter (52.4 ± 8.7 μg/m¹ for PM2.5) and bacterial counts (342 ± 52 CFU/m¹) compared to the ICU, which maintained improved air quality and minimum microbial contamination, environmental monitoring data revealed notable differences in hospital areas. Hoang et al. 2019 [8]reported significant variations in air quality and microbe abundance across highly inhabited and less congested areas based on research on environmental hazards at mass events.

Previous studies have shown that gram-positive bacteria (45.3%) and fungi such as Aspergillus species (22.0%) are the predominant contaminants in hospital air, consistent with findings by Mushi et al. (2021)[6].

Analysis of respirator performance showed a steady increase in microbial contamination, rising from 3.79 ± 0.62 CFU/cm² after 12 hours to 12.17 ± 1.52 CFU/cm² after 36 hours. Even so, filtration efficiency stayed above the critical threshold of 95% for the majority of respirators for up to 36 hours, as earlier studies had highlighted the durability of N95 respirators in clinical settings (Albarrak et al., 2018)[7]. A decline in efficiency to 95.42% by the 36-hour mark, with six percent of respirators failing to meet the threshold, underscores the need to replace respirators after 24 hours of use.

The results of the outcome measures showed a substantial effect from infection control interventions. Respiratory infections contracted in hospitals affected 17.6% of patients, with most of these being viral in origin, and they typically emerged 5.2 ± 1.4 days after admission. The length of time it takes for recovery differed greatly between patients, with those having mild symptoms recovering in approximately 5.2 ± 1.3 days, whereas those with severe cases took 12.6 ± 3.2 days to recover. The incidence of respiratory illness among healthcare workers decreased from 23.1% before a particular intervention to 9.2% afterwards, resulting in a reduction of 60.2%, and severe cases fell by 75.6%. Similar results were observed by Hoang et al. (2022)[10], who noted a decrease in HCW infection rates after implementing more stringent PPE protocols during pandemics. Risk factor analysis revealed extended shift hours (OR 2.45, $p < 0.001$) and non-adherence to personal protective equipment (OR 2.15, $p < 0.001$) as the primary drivers of protection failure, supporting the imperative for policy revisions to mitigate workload and compliance issues.

Saudi research identify healthcare worker problems. A study found that 25.1% of MERS outbreaks involved HCWs, and comorbidities and inadequate infection control increased the risk (Bernard-Stoecklin et al., 2019)[11]. As in the Hajj trial, extended shifts (OR 2.45, $p < 0.001$) and insufficient experience (OR 1.54, $p = 0.008$) were significant risk variables for non-compliance and infections.

In Saudi hospitals' ICUs, multidrug-resistant Klebsiella pneumoniae and Acinetobacter baumannii were common (Yasir et al., 2022)[12]. Findings from Hajj indicate greater bacterial burdens in high-traffic sites such emergency rooms (342 ± 52 CFU/m³). These experiments stress strict environmental controls and disinfection.

Even though dual influenza and pneumococcal vaccines are protective, only 41.1% of pilgrims in Saudi Arabia received them (Alanzi et al., 2019)[13]. As in the Hajj research, vaccination coverage may minimize hospital-acquired respiratory illnesses.

In Saudi Arabia, 57.8% of HCWs had moderate hand hygiene awareness (Abalkhail et al., 2021)[14]. This matches the necessity for ongoing education and training shown in the Hajj, when infection control compliance directly affected HCW infection rates.

HCWs were anxious during epidemics because they feared infecting families (Temsah et al., 2020)[15]. In high-stress situations like the Hajj, workloads and exposure hazards increase psychological burden.

In Saudi Arabia, lengthy patient stays in overcrowded emergency rooms and delayed infection reporting spread MERS (Bushra et al., 2019)[16]. These instances emphasize the significance of prompt triage, early isolation, and infection management in big gatherings like the Hajj.

CONCLUSIONS

In summary, the study highlights the significance of developing customised infection control methods, comprising comprehensive environmental management, timely respirator replacement procedures, and specific training initiatives, to safeguard both patients and healthcare workers during high-risk situations such as the Hajj pilgrimage. Research findings suggest a need to refine infection prevention protocols in crowded event environments.

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