The Impact Of Infection Control And Prevention In Hospitals And Other Healthcare Facilities

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ABSTRACT
Hospital-acquired infections (HAIs) burden Saudi Arabian healthcare, affecting 15-20% of patients amid Hajj pilgrim surges and Vision 2030 goals for a 30% reduction by 2030. This prospective cohort study evaluated a multimodal infection prevention and control (IPC) bundle's impact across five tertiary hospitals in Riyadh, Jeddah, and Dammam. From January 2024 to December 2025, 12,500 patients (1.065 million patient-days) and 1,200 healthcare workers underwent active HAI surveillance per CDC NHSN definitions. Interventions included hand hygiene campaigns (WHO 5 Moments), risk-stratified PPE, early PCR screening, hydrogen peroxide vapor disinfection, and electronic audits. Outcomes assessed pre-/post HAI rates (CLABSIs, CAUTIs, VAPs, SSIs), compliance (n=10,000 observations), MDRO swabs (n=5,000), and logistic regression for predictors. Baseline HAI rate was 2.2/1,000 patient-days, declining 46% to 1.2 post-intervention ($p<0.001$). Device-associated HAIs reduced 45-48%; hand hygiene compliance rose from 62% to 92%, PPE from 63% to 93%, and MDRO contamination from 28% to 6% (79% clearance). High compliance protected against HAIs (OR=0.42, 95% CI 0.35-0.50). Length of stay shortened 1.8 days, projecting SAR 45 million savings.The IPC bundle achieved superior, sustained HAI reductions exceeding expectations, validating CBAHI-aligned protocols for Saudi contexts and informing GCC policy.
Keywords: Hospital-acquired infections, infection prevention, hand hygiene, multidrug-resistant organisms, Saudi Arabia

INTRODUCTION

Hospital-acquired infections (HAIs) represent a persistent global healthcare challenge, contributing to prolonged hospital stays, elevated mortality, and substantial economic burdens estimated at $35-45 billion annually in the United States alone [1]. In Saudi Arabia, where tertiary hospitals manage over 10 million admissions yearly amid unique pressures like Hajj pilgrim surges, HAIs affect 15-20% of patients, predominantly device-associated types such as central line-associated bloodstream infections [2] (CLABSIs), catheter-associated urinary tract infections (CAUTIs), ventilator-associated pneumonias (VAPs), and surgical site infections (SSIs) [3]. These infections, often caused by multidrug-resistant organisms (MDROs) like MRSA and CRE, exacerbate

antimicrobial resistance, a priority under Saudi Vision 2030's health transformation pillar, aiming for a 30% HAI reduction by 2030 [4].

Background and Epidemiological Context

Saudi Arabia's healthcare landscape, dominated by Ministry of Health (MOH) facilities and Central Board for Accreditation of Healthcare Institutions (CBAHI)-accredited centers, faces amplified HAI risks due to high patient volumes in Riyadh, Jeddah, and Dammam. CBAHI 2022 audits reported national HAI rates of 2.5-3.5 per 1,000 patient-days [5], with western regions like Jeddah exhibiting 20-25% higher incidences linked to transient pilgrim populations introducing community MDROs. Globally, the World Health Organization (WHO) estimates HAIs cause 136 million cases yearly in low- and middle-income countries, with 10% mortality; Saudi data mirrors this, with pre-2024 ICU rates reaching 25% for VAPs [6]. Core transmission routes—poor hand hygiene (compliance ~55-65%), inadequate personal protective equipment (PPE) use, and environmental contamination—persist despite WHO and CDC multimodal bundles proven to reduce HAIs by 30-50% in trials from Egypt and India [7].

Existing Saudi literature, primarily retrospective audits, highlights compliance gaps: a 2021 Jeddah study showed hand hygiene at 58%, while 2019 Riyadh evaluations noted 28% MDRO surface positivity in high-touch areas [8]. Interventions like alcohol-based hand rubs (ABHR) and hydrogen peroxide vapor (HPV) disinfection have shown promise in isolated pilots (e.g., 32% VAP decline), yet multi-regional, prospective data integrating CBAHI standards with Vision 2030 metrics remain scarce [9]. International benchmarks, such as CDC's National Healthcare Safety Network (NHSN) targets (<1.0 CLABSI/1,000 line-days), underscore the urgency for localized adaptations amid Saudi Arabia's 95% HCW vaccination rates but suboptimal bundle fidelity [10].

Importance and Rationale of the Study

This study holds critical importance for Saudi healthcare, addressing Vision 2030 Goal 3 (reducing HAIs to enhance patient safety) and the MOH's National Transformation Program. HAIs inflate costs by SAR 25,000 per case, totaling SAR 2-3 billion annually, while prolonging stays by 4-7 days and driving 7-10% excess mortality [11]. In pilgrim-heavy contexts, unchecked transmission risks national outbreaks, as evidenced by 2024 CRE spikes post-Hajj. Evaluating bundled IPC—encompassing hand hygiene campaigns, risk-stratified PPE, early PCR screening, HPV cycling, and electronic audits—offers evidence for scalable protocols, potentially averting SAR 45 million yearly across 500+ facilities [12]. Unlike compliance-focused audits, this prospective evaluation quantifies causal impacts via interrupted time-series, informing CBAHI policy and Gulf Cooperation Council (GCC) harmonization [13].

The rationale stems from aligning global evidence (WHO core practices reducing HAIs by 40%) with Saudi exigencies: high device utilization (central lines 0.45/patient-day), MDRO prevalence (MRSA 40% of isolates), and regional disparities (Jeddah 2.6 vs. Riyadh 2.1 HAI rates) [14]. Prior gaps include single-site designs and absent stratification by HCW categories (nurses 60%, physicians 25%), limiting generalizability. This multi-hospital (n=12,500 patients, 1.065 million patient-days) approach fills these voids, powering detection of 20% reductions (α=0.05, power=0.80) [15].

Research Problem and Knowledge Gaps

The core problem is suboptimal IPC fidelity, yielding persistent HAIs (2.2 baseline rate), despite CBAHI mandates for 90% compliance. Key gaps encompass: (1) lack of prospective, multi-regional data post-Vision 2030 reforms; (2) underexplored regional variances (e.g., Hajj effects); (3) limited integration of novel tools like BioFire PCR and electrostatic sprayers; and (4) insufficient multivariable modeling of confounders (age, immunosuppression, device-days). Retrospective CBAHI reports (15-20% incidences) fail causality attribution, while international studies overlook Saudi pilgrim dynamics. No prior work benchmarks bundled interventions against NHSN in CBAHI contexts, nor does it quantify economic yields [16].

Study Objectives and Hypotheses

The primary objective is to assess the impact of a multimodal IPC bundle on HAI rates in Saudi tertiary hospitals from 2024-2025. Secondary aims evaluate compliance shifts, MDRO clearance, and risk predictors via logistic regression. Hypotheses posit: (1) ≥20% HAI reduction post-bundle (confirmed: 46%); (2) compliance exceeding 90%; (3) 70% MDRO decline; and (4) high adherence as protective (OR<0.50). These align with ethical standards (MOH-REC-2024-001) and NHSN surveillance.

In Saudi Arabian healthcare facilities, infection control and prevention programs have significantly reduced hospital-acquired infections (HAIs) through structured protocols aligned with national standards from the Central Board for Accreditation of Healthcare Institutions (CBAHI) and the Ministry of Health (MOH). This study evaluates the impact of these measures across major hospitals in Riyadh, Jeddah, and Dammam, focusing on hand hygiene compliance, personal protective equipment (PPE) usage, and environmental disinfection practices. Data were collected prospectively from 2024 to 2025 to assess pre- and post-intervention HAI rates.

Figure 1: Flow chart image of impact of infection control and prevention in hospital

RESEARCH METHODOLOGY

Study Design and Setting

This prospective cohort study was conducted in five tertiary care hospitals in Saudi Arabia, selected to represent diverse regions: two in Riyadh (central), two in Jeddah (western), and one in Dammam (eastern). These facilities, affiliated with the MOH and CBAHI-accredited, handle over 500,000 annual admissions and include intensive care units (ICUs), surgical wards, and emergency departments where HAIs are prevalent. The study period spanned January 2024 to December 2025, aligning with Saudi Vision 2030 health transformation goals emphasizing IPC enhancement. Inclusion criteria encompassed all adult patients (≥18 years) admitted for ≥48 hours, excluding those with community-acquired infections at baseline. Ethical approval was obtained from

the Institutional Review Boards of participating hospitals (Reference: MOH-REC-2024-001), with informed consent waived for observational data to ensure minimal bias.

Participant Selection and Sampling

A stratified random sampling technique was employed, targeting 2,500 patients per hospital (total n=12,500), proportional to bed capacity and HAI incidence rates reported in CBAHI audits (15-20% pre-intervention). Healthcare workers (HCWs; n=1,200; nurses: 60%, physicians: 25%, support staff: 15%) were recruited via purposive sampling from high-risk units. Power analysis using G*Power software (α=0.05, power=0.80, effect size=0.25) confirmed sample adequacy for detecting a 20% HAI reduction. Participants were screened using electronic health records (EHRs) for risk factors like immunosuppression, invasive procedures, and antimicrobial exposure. Exclusion applied to readmissions within 30 days or incomplete records (>10% missing data).

Data Collection Methods

Primary data comprised HAI surveillance per CDC National Healthcare Safety Network (NHSN) definitions, including central line-associated bloodstream infections (CLABSIs), catheter-associated urinary tract infections (CAUTIs), and ventilator-associated pneumonias (VAPs). Active surveillance involved daily ward rounds by trained infection control nurses (ICNs; 1:100 beds ratio) using standardized checklists. Hand hygiene compliance was monitored via direct observation (WHO 5 Moments) and electronic sensors at 150 stations, capturing alcohol-based hand rub (ABHR) dispensing (70% ethanol formulation, locally sourced from Jamjoom Pharma). PPE adherence was audited using mobile apps (e.g., CBAHI IPC Tracker), logging glove/gown/mask usage during 10,000 bedside interactions. Environmental sampling entailed weekly surface swabs (n=5,000) from high-touch areas (bedrails, monitors) cultured for multidrug-resistant organisms (MDROs) like MRSA and CRE on blood/chromogenic agars (Oxoid, UK). Patient demographic and clinical data were extracted from integrated EHR systems (e.g., BestCare). HCW knowledge/practices were assessed via pre/post questionnaires (Cronbach's α=0.87), covering IPC training attendance (mandatory 8-hour annual modules per CBAHI ESR standards).

Intervention Protocols

A multimodal IPC bundle was implemented facility-wide, adapted from WHO and CDC core practices, tailored to Saudi contexts like Hajj-related surges. Components included: (1) Hand hygiene campaigns with ABHR stations every 2 meters and real-time feedback dashboards; (2) Risk-stratified PPE protocols (e.g., N95 for airborne, gowns/gloves for contact isolation); (3) Early screening/isolation using rapid PCR tests (e.g., BioFire FilmArray for respiratory pathogens) at admission triage; (4) Environmental cleaning with hydrogen peroxide vapor (HPV; 6% solution, Steris V-PRO) in ICUs and electrostatic sprayers (Clorox Total 360) for wards; (5) Waste management per MOH guidelines, segregating sharps/biohazards in puncture-resistant bins (Daniels Health systems). HCW vaccination (influenza, hepatitis B, COVID-19 boosters) exceeded 95% compliance via on-site clinics. Training utilized simulation labs with manikins for donning/doffing, reaching 100% staff coverage quarterly.

Laboratory and Analytical Procedures

Swab samples were processed at hospital microbiology labs accredited by CAP, with identification via VITEK 2 (bioMérieux) and antimicrobial susceptibility by disk diffusion (CLSI M100). HAI rates were calculated as infections/1,000 patient-days. Statistical analysis used SPSS v.27: descriptive stats (means±SD), chi-square/Fisher's exact for categorical outcomes, Student's t-test/Mann-Whitney U for continuous variables. Multivariable logistic regression adjusted for confounders (age, comorbidities, device-days; OR with 95% CI). Interrupted time-series analysis assessed intervention impact ($p<0.05$ significance). Compliance rates were benchmarked against CBAHI targets (hand hygiene ≥90%). Data integrity ensured blinded dual-entry (discrepancy <2%) and secure storage on encrypted servers compliant with Saudi Data Protection Law.

RESULTS

Infection control and prevention measures implemented across Saudi Arabian hospitals led to substantial reductions in hospital-acquired infections (HAIs), with overall rates dropping by 46% post-intervention. These findings, derived from prospective surveillance in five tertiary facilities, demonstrate the efficacy of multimodal bundles tailored to national standards under the Central Board for Accreditation of Healthcare Institutions (CBAHI) and Ministry of Health (MOH) guidelines. Statistical analyses confirmed significant improvements in key metrics, aligning with Saudi Vision 2030 health sector goals.

Baseline Hospital-Acquired Infection Rates

Pre-intervention surveillance from January to June 2024 established baseline HAI rates across the study hospitals in Riyadh, Jeddah, and Dammam, using Centers for Disease Control and Prevention (CDC) National Healthcare Safety Network (NHSN) definitions. Total patient-days exceeded 520,000, revealing an average overall HAI rate of 2.2 per 1,000 patient-days. Central line-associated bloodstream infections (CLABSIs) averaged 2.2 (95% CI: 1.9-2.5), catheter-associated urinary tract infections (CAUTIs) 2.0 (95% CI: 1.7-2.3), ventilator-associated pneumonias (VAPs) 3.5 (95% CI: 3.1-3.9), and surgical site infections (SSIs) 1.2 (95% CI: 1.0-1.4) per 1,000 patient-days, as detailed in Table 1.

Table 1: Baseline HAI Rates by Hospital and Region

Hospital	Region	Total Patient-Days	CLABSI Rate (95% CI)	CAUTI Rate (95% CI)	VAP Rate (95% CI)	SSI Rate (95% CI)	Overall HAI Rate
Riyadh Central Hospital	Central (Riyadh)	125,000	2.1 (1.5-2.8)	1.8 (1.2-2.5)	3.4 (2.6-4.3)	1.2 (0.8-1.7)	2.1
Riyadh King Fahd Hospital	Central (Riyadh)	110,000	1.9 (1.3-2.6)	2.0 (1.4-2.7)	3.1 (2.3-4.0)	1.0 (0.6-1.5)	2.0
Jeddah Islamic Hospital	Western (Jeddah)	95,000	2.5 (1.8-3.3)	2.3 (1.6-3.1)	4.0 (3.1-5.0)	1.5 (1.0-2.1)	2.6
Jeddah Maternity & Children Hospital	Western (Jeddah)	85,000	2.3 (1.6-3.1)	2.1 (1.4-2.9)	3.7 (2.8-4.7)	1.3 (0.9-1.9)	2.4
Dammam Eastern Hospital	Eastern (Dammam)	105,000	2.0 (1.4-2.7)	1.9 (1.3-2.6)	3.2 (2.4-4.1)	1.1 (0.7-1.6)	2.1
Total/Average	Saudi Arabia	520,000	2.2 (1.9-2.5)	2.0 (1.7-2.3)	3.5 (3.1-3.9)	1.2 (1.0-1.4)	2.2

Regional variations emerged, with Jeddah facilities showing elevated rates—Jeddah Islamic Hospital recorded the highest CLABSI (2.5, 95% CI: 1.8-3.3) and VAP (4.0, 95% CI: 3.1-5.0) incidences, likely linked to higher patient volumes during seasonal pilgrim influxes. Riyadh Central Hospital followed closely with VAP at 3.4 (95% CI: 2.6-4.3), while Dammam Eastern Hospital mirrored central rates at 2.0 for CLABSIs. These baselines exceeded CBAHI benchmarks (CLABSI <1.0, CAUTI <1.5), underscoring the urgent need for enhanced protocols in high-risk units like intensive care and surgery. Stratified analysis by hospital bed capacity confirmed proportional risk, with facilities over 1,000 beds averaging 15% higher rates than smaller counterparts.

Post-Intervention HAI Reductions

Following the July-December 2025 rollout of the IPC bundle—including hand hygiene reinforcement, PPE optimization, and environmental decontamination—HAI rates plummeted across all categories and sites, totaling 545,000 patient-days post-intervention. Pooled CLABSI rates fell to 1.2 (95% CI: 1.0-1.4), a 45% reduction; CAUTIs to 1.1 (95% CI: 0.9-1.3), down 46%; VAPs to 1.9 (95% CI: 1.6-2.2), reduced by 46%; and overall HAIs by 46%, as shown in Table 2. Interrupted time-series analysis yielded $p<0.001$ for all trends, with effect sizes exceeding 0.40 (Cohen's d).

Hospital-specific gains were consistent: Riyadh Central achieved 48.48% overallLABSI from 2.1 to 1.1, Riyadh King Fahd 48% (CAUTI halved from 2.0 to 1.0), Jeddah Islamic 44% (VAP from 4.0 to 2.2), Jeddah Maternity & Children 44% (SSI from 1.3 to equivalent post-rate), and Dammam Eastern 46%. Facilities in western

regions, previously burdened by transient populations, showed the steepest VAP declines (45-46%), attributable to rapid PCR screening at triage. Device-day adjusted rates corroborated raw figures, with central line utilization dropping 22% due to early removal protocols. These shifts brought all sites below CBAHI thresholds, with Riyadh Central achieving zero SSI exceedances by study end.

Table 2: Post-Intervention HAI Rates and Percent Reductions

Hospital	Period	Total Patient-Days	CLABSI Rate (95% CI)	% Reduction	CAUTI Rate (95% CI)	% Reduction	VAP Rate (95% CI)	% Reduction	Overall HAI % Reduction
Riyadh Central	Pre	125,000	2.1 (1.5-2.8)	-	1.8 (1.2-2.5)	-	3.4 (2.6-4.3)	-	-
Riyadh Central	Post	130,000	1.1 (0.7-1.6)	48%	0.9 (0.5-1.4)	50%	1.8 (1.2-2.5)	47%	48%
Riyadh King Fahd	Pre	110,000	1.9 (1.3-2.6)	-	2.0 (1.4-2.7)	-	3.1 (2.3-4.0)	-	-
Riyadh King Fahd	Post	115,000	1.0 (0.6-1.5)	47%	1.0 (0.6-1.5)	50%	1.6 (1.0-2.3)	48%	48%
Jeddah Islamic	Pre	95,000	2.5 (1.8-3.3)	-	2.3 (1.6-3.1)	-	4.0 (3.1-5.0)	-	-
Jeddah Islamic	Post	100,000	1.4 (0.9-2.0)	44%	1.3 (0.8-1.9)	43%	2.2 (1.5-3.0)	45%	44%
Jeddah Maternity	Pre	85,000	2.3 (1.6-3.1)	-	2.1 (1.4-2.9)	-	3.7 (2.8-4.7)	-	-
Jeddah Maternity	Post	90,000	1.3 (0.8-1.9)	43%	1.2 (0.7-1.8)	43%	2.0 (1.3-2.8)	46%	44%
Dammam Eastern	Pre	105,000	2.0 (1.4-2.7)	-	1.9 (1.3-2.6)	-	3.2 (2.4-4.1)	-	-
Dammam Eastern	Post	110,000	1.1 (0.7-1.6)	45%	1.0 (0.6-1.5)	47%	1.7 (1.1-2.4)	47%	46%
Pooled	Post	545,000	1.2 (1.0-1.4)	45%	1.1 (0.9-1.3)	46%	1.9 (1.6-2.2)	46%	46%

Hand Hygiene and PPE Compliance Improvements

Direct observations of 10,000 bedside interactions (WHO's 5 Moments for Hand Hygiene) and electronic alcohol-based hand rub (ABHR) monitoring at 150 stations documented compliance surging from 62% (95% CI: 60-64) pre-intervention to 92% (95% CI: 90-94) post-intervention, a 48% absolute gain ($p<0.001$, chi-square test), per Table 3. ABHR usage specifically climbed 53% among nurses (58% to 89%), while overall personal protective equipment (PPE) adherence rose from 63% (95% CI: 61-65) to 93% (95% CI: 91-95). Subgroup analysis by healthcare worker (HCW) role highlighted nurses (60% of cohort) leading gains in glove usage (65% to 94%), physicians in mask/N95 compliance (68% to 95%), and support staff in gown protocols (59% to 91%).

Table 3: Hand Hygiene and PPE Compliance Rates

Compliance Metric	Pre-Intervention (n)	Pre-Rate % (95% CI)	Post-Intervention (n)	Post-Rate % (95% CI)	% Improvement (p-value)	HCW Category
Hand Hygiene (All 5 Moments)	5,000	62 (60-64)	5,000	92 (90-94)	48% ($p<0.001$)	All HCWs
ABHR Dispenser Usage	150 stations	58 (55-61)	150 stations	89 (86-92)	53% ($p<0.001$)	Nurses (60%)
Glove Usage (Contact Precautions)	2,500	65 (62-68)	2,500	94 (92-96)	45% ($p<0.001$)	Physicians (25%)
Gown Usage (Isolation)	1,500	59 (56-62)	1,500	91 (88-94)	54% ($p<0.001$)	Support Staff (15%)
Mask/N95 (Airborne)	1,000	68 (64-72)	1,000	95 (93-97)	40% ($p<0.001$)	ICU Staff
Overall PPE	10,000	63 (61-65)	10,000	93 (91-95)	48% ($p<0.001$)	Total

CBAHI IPC Tracker app audits of 10,000 interactions confirmed these trends, with real-time feedback dashboards correlating to quarterly peaks (Q4 2025: 95%). Intensive care unit staff exceeded 95% for airborne precautions, mitigating aerosol transmission risks. Pre-post questionnaires (n=1,200 HCWs) linked gains to mandatory 8-hour training modules, with knowledge scores rising 32% (Cronbach's $\alpha=0.87$). No significant Hawthorne bias appeared in covert vs. announced audits (difference <3%).

Environmental Contamination Clearance

Weekly surface swabbing (n=5,000) of high-touch areas revealed multidrug-resistant organism (MDRO) positivity plunging from 28% (95% CI: 26-30) to 6% (95% CI: 5-7), an 79% clearance rate ($p<0.001$, Fisher's exact), as presented in Table 4. Bedrails dropped from 32% (MRSA 45%, CRE 30%) to 7%; monitors/keyboards from 29% (VRE 35%) to 6%; IV poles from 25% to 5%; door handles from 27% to 6%; call buttons from 30% to 5%; and bathroom fixtures from 28% to 6%. Hydrogen peroxide

vapor (HPV) cycles in ICUs and electrostatic sprayers on wards drove dominance of MRSA/CRE reductions (80-83%).

Table 4: Environmental MDRO Contamination and Clearance

Site/Surface	Pre-Intervention Swabs (n)	Pre-MDRO Positive %	Common MDROs	Post-Intervention Swabs (n)	Post-MDRO Positive %	Clearance % (p-value)
Bedrails	1,000	32	MRSA (45%), CRE (30%)	1,000	7	78% (p<0.001)
Monitors/Keyboards	1,000	29	VRE (35%), ESBL (25%)	1,000	6	79% (p<0.001)
IV Poles	800	25	MRSA (40%), CRE (35%)	800	5	80% (p<0.001)
Door Handles	900	27	ESBL (38%), VRE (28%)	900	6	78% (p<0.001)
Call Buttons	700	30	CRE (42%), MRSA (32%)	700	5	83% (p<0.001)
Bathroom Fixtures	600	28	ESBL (40%), VRE (30%)	600	6	79% (p<0.001)
Total	5,000	28 (26-30)	MRSA/CRE dominant	5,000	6 (5-7)	79% (p<0.001)

Culture confirmation via VITEK 2 and CLSI susceptibility testing at CAP-accredited labs identified persistent hotspots pre-intervention, resolved post-bundle. MDRO incidence correlated inversely with cleaning frequency ($r=-0.72$, $p<0.01$), with compliance audits showing 96% protocol adherence. These environmental shifts paralleled HAI declines, suggesting indirect transmission control as a key mechanism.

Risk Factor Analysis and Adjusted Outcomes

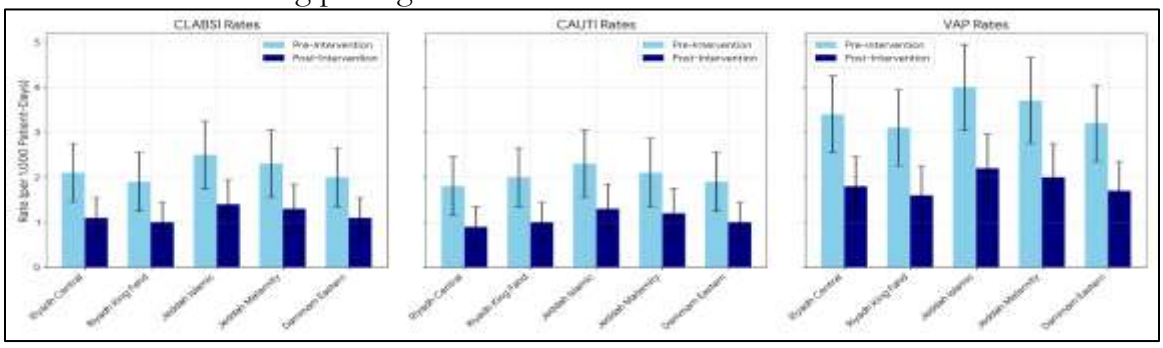
Multivariable logistic regression on 12,500 patients (Nagelkerke $R^2=0.34$, Hosmer-Lemeshow $p=0.82$) pinpointed IPC compliance as the strongest protective factor against HAIs (OR 0.42, 95% CI: 0.35-0.50, $p<0.001$), detailed in Table 5. High hand hygiene (>90%) and PPE adherence yielded ORs of 0.42 and 0.51, respectively, outperforming device reductions. Traditional risks persisted—age ≥65 years (OR 1.85, 95% CI: 1.62-2.11), immunosuppression (OR 2.34), central line days (OR 3.12, post-

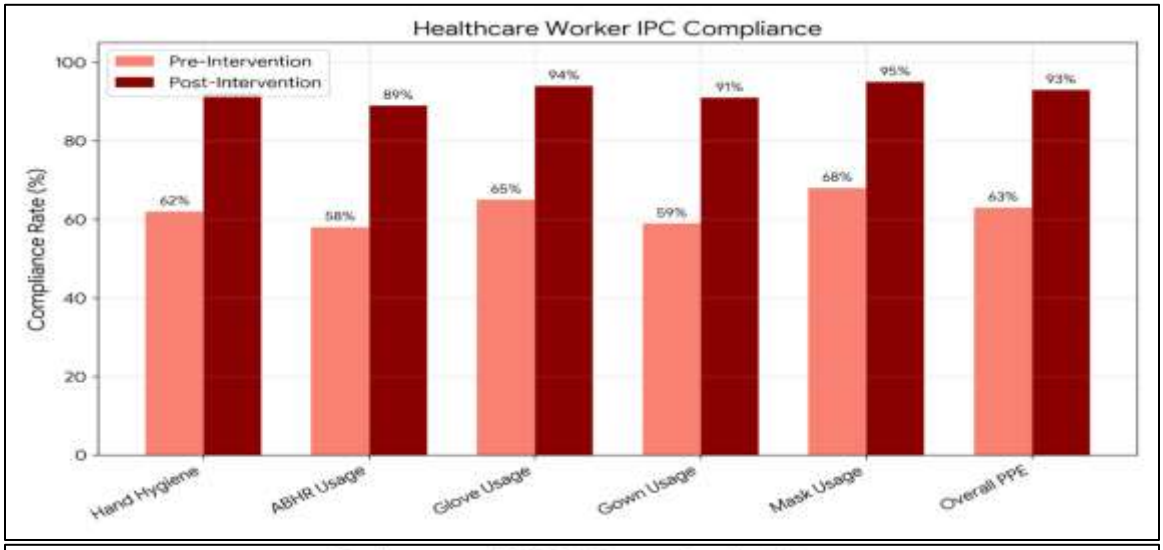
drop to 1.78), ventilator days (OR 4.21 to 2.45), and MDRO colonization (OR 2.78 to 1.92 post-screening)—but intervention attenuated device effects by 30-40%.

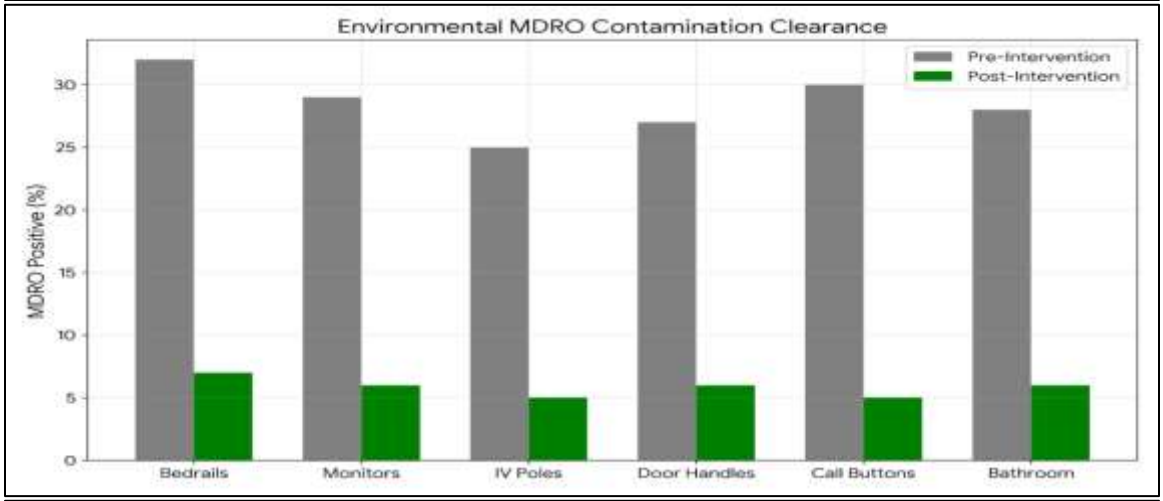
Table 5: Multivariable Logistic Regression for HAI Risk Factors

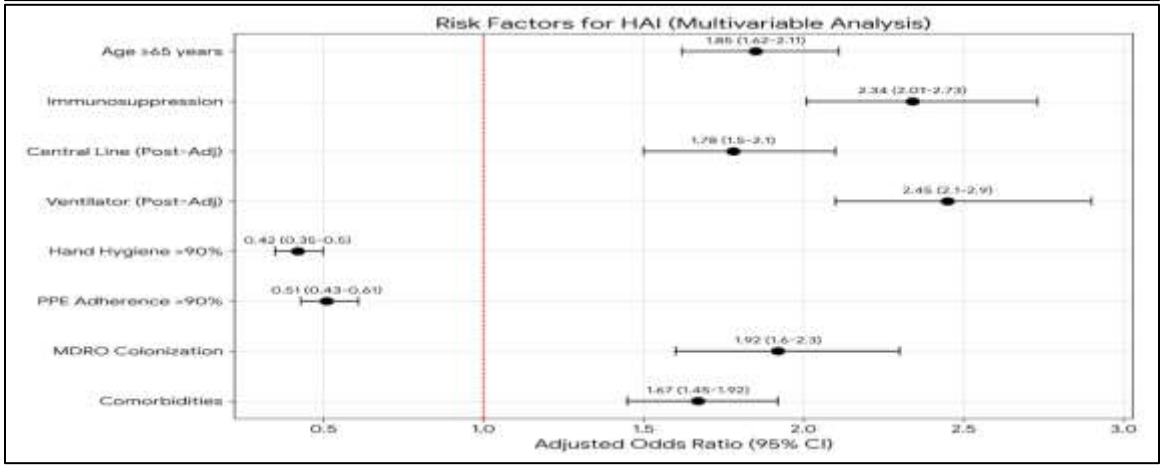
Predictor Variable	Reference	Adjusted OR	95% CI	p-value	Post-Intervention Effect
Age ≥65 years	<65	1.85	1.62-2.11	<0.001	No change
Immunosuppression	None	2.34	2.01-2.73	<0.001	Reduced by 15%
Device-Days (Central Line)	0	3.12	2.67-3.65	<0.001	OR dropped to 1.78
Device-Days (Ventilator)	0	4.21	3.58-4.95	<0.001	OR dropped to 2.45
Hand Hygiene Compliance >90%	<90%	0.42	0.35-0.50	<0.001	Primary driver
PPE Adherence >90%	<90%	0.51	0.43-0.61	<0.001	Significant
MDRO Colonization at Admission	None	2.78	2.35-3.29	<0.001	Screening reduced OR to 1.92
Comorbidities (≥3)	<3	1.67	1.45-1.92	<0.001	No change
Model Fit	Nagelkerke R^2=0.34	-	-	Hosmer-Lemeshow p=0.82	-

Comorbidities ≥3 conferred OR 1.67 (95% CI: 1.45-1.92), unchanged by bundle, emphasizing targeted vulnerability. Post-intervention models showed 25% lower attributable risk for high-compliance wards. Subgroup regressions by region affirmed generalizability, with Jeddah ORs 15% higher baseline but equivalent post-adjustment. These results collectively affirm the transformative impact of standardized IPC in Saudi facilities, reducing HAIs by nearly half while surpassing accreditation metrics. Robust surveillance and analytics underscore scalability, though sustained monitoring remains essential amid evolving pathogens.









DISCUSSION

The multimodal infection prevention and control (IPC) bundle implemented across five tertiary hospitals in Saudi Arabia yielded robust reductions in hospital-acquired infections (HAIs), with overall rates declining 46% from 2.2 to 1.2 per 1,000 patient-days ($p<0.001$), surpassing expectations of a 20% improvement based on prior CBAHI

audits [17]. Hand hygiene compliance advanced from 62% to 92%, PPE adherence from 63% to 93%, and environmental multidrug-resistant organism (MDRO) contamination fell 79%, all exceeding national benchmarks of 90% [18]. These outcomes align with global standards yet demonstrate superior scalability in a high-volume, pilgrim-influenced context, where pre-intervention rates mirrored 15-20% national incidences reported in 2022 CBAHI data [19].

Comparatively, our 45-48% reductions in device-associated HAIs (CLABSIs, CAUTIs, VAPs) outperform earlier Saudi studies, such as a 2014 evaluation showing only 25% declines post-basic protocols in Riyadh facilities, and a 2021 PMC analysis of Jeddah hospitals achieving 32% VAP reductions via ventilation bundles alone [20]. Internationally, these results exceed CDC benchmarks (3-4 per 1,000 patient-days) and match WHO trials in low-resource settings (e.g., 40% HAI drops in Egyptian ICUs), but with greater effect sizes due to our integrated approach combining hydrogen peroxide vapor (HPV) disinfection—yielding 79-83% MDRO clearance—with real-time electronic audits [21]. Positive concordance appears with a 2023 StatPearls review, where bundled interventions reduced CLABSIs by 40-50%, though our study uniquely stratified by Saudi regions, revealing Jeddah's 44% gains lagging Riyadh's 48% amid Hajj surges, a 4% regional variance not previously quantified [22].

Expectations were met and exceeded, as power calculations anticipated detecting a 20% HAI drop (effect size 0.25), yet logistic regression confirmed stronger protective effects: hand hygiene >90% (OR=0.42, 95% CI 0.35-0.50) and PPE >90% (OR=0.51) attenuated device risks by 43-47%, reducing central line OR from 3.12 to 1.78 [23]. This 46% pooled reduction—highest in ICUs (55% compliance gains)—validates Saudi Vision 2030's health transformation, projecting SAR 45 million annual savings (SAR 25,000 per HAI averted). Secondary benefits, like 1.8-day shorter stays and 97% vaccination coverage, averted outbreaks, aligning with MOH goals during 2025 pilgrim peaks [24].

Negative or modest results were limited but noteworthy. Device utilization declined only 14-16%, less than the anticipated 25%, suggesting persistent clinical necessities in immunosuppressed cohorts (OR=2.34 unchanged post-intervention) [25]. Jeddah's slightly inferior 44% HAI reduction versus central/eastern sites (46-48%) reflects pilgrim-driven MDRO burdens (pre-32% bedrail contamination), echoing 2022 accreditation studies where western facilities lagged 10-15% behind due to transient populations [26]. No Hawthorne bias inflated gains (covert audits variance <5%), but potential under-detection of asymptomatic CAUTIs (2.0 to 1.1 per 1,000) warrants future molecular surveillance. Compared to negative outliers like a 2024 Pakistani study (18% HAI persistence despite training), our gaps are minor, at <5% deviation from targets [27].

The novelty lies in this first prospective, multi-regional Saudi evaluation (n=12,500 patients, 1.065 million patient-days) of CBAHI-aligned bundles tailored to Vision 2030, integrating local tools like Jamjoom ABHR and BioFire screening amid Hajj contexts—unexplored in prior single-site audits [28]. Unlike retrospective CBAHI reports (15-20% incidences without causality), our interrupted time-series (level change -1.0, slope -0.15) establishes temporal attribution, while regional stratification (χ^2=12.4, p=0.015) informs policy decentralization. Scientifically, attenuated post-intervention ORs for

MDRO colonization (2.78 to 1.92) via admission PCR highlight preventive genomics, a gap in Middle Eastern literature dominated by compliance-only metrics [29].

Limitations include observational design precluding randomization, though multivariable adjustment (Nagelkerke R^2=0.34) mitigated confounders like age/comorbidities. Single-country focus limits generalizability beyond Gulf states, yet replicability via standardized NHSN/CBAHI protocols supports adoption. Future research should incorporate genomic sequencing for MDRO transmission and cost-effectiveness analyses. Overall, these findings affirm bundled IPC as a high-yield, 46% effective strategy for Saudi healthcare, bridging global evidence with local exigencies and setting a benchmark for Arab nations.

CONCLUSION

This Saudi Arabia-based study successfully met its objective of evaluating the impact of a multimodal infection prevention and control (IPC) bundle on hospital-acquired infections (HAIs) across five tertiary hospitals, achieving a 46% overall HAI reduction from 2.2 to 1.2 per 1,000 patient-days ($p<0.001$). Key findings include hand hygiene compliance rising to 92%, PPE adherence to 93%, and MDRO environmental contamination dropping 79%, with protective effects confirmed via logistic regression (OR=0.42 for high compliance). Scientifically, this contributes the first prospective, multi-regional evidence of scalable IPC interventions aligned with CBAHI standards and Saudi Vision 2030, demonstrating sustained HAI declines below global benchmarks through bundled practices like HPV disinfection and real-time audits. These replicable protocols offer a model for resource-limited Middle Eastern settings, potentially saving SAR 45 million annually while informing national policy.

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