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Infection prevention and control adherence among SARS-CoV-2 infected healthcare workers in Addis Ababa, Ethiopia: lessons for future outbreaks

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Abstract

Background Health care worker (HCW) infections during outbreaks of high-consequence pathogens, from SARS-CoV-2 to Ethiopia's 2025–2026 Marburg outbreak, highlight persistent Infection Prevention and Control (IPC) gaps. We evaluated IPC adherence and its determinants among infected HCWs in Addis Ababa, Ethiopia, to inform future outbreak preparedness.

Methods This census-based cross-sectional study (March 2020–March 2021) evaluated 1152 SARS-CoV-2-infected HCWs with clinical exposures 14 days pre-diagnosis. Environments were classified via an adapted OSHA pyramid into: High-Pathogen Designated Areas isolation and treatment units, General High-Risk Areas [intensive care units, emergency departments, and operating theaters], Medium-Risk Clinical Areas [inpatient and outpatient departments], and Low-Risk Support Areas [administrative and non-clinical zones]. Adherence was defined as correct practice in > 50% of interactions. Bivariate chi-square tests and multivariable logistic regression identified independent determinants for donning/doffing ($n = 742$) and N95 seal-checks ($n = 350$), reporting adjusted odds ratios (aOR) with 95% confidence intervals at $P < 0.05$.

Results Only 19.2% of infected HCWs worked in High-Pathogen Designated Areas. Mask (85.7–97.7%) and glove (68.2–98.0%) adherence was high, but fell below 50% for gowns, coveralls, head caps, and shoe covers. Exceptions included face shields/goggles (52.8%) and N95 use during aerosol-generating procedures (AGPs) (66.5%). N95 seal-check compliance was 34.9%; only 1.1% used fit-tested respirators. Hand hygiene rose from 49.3% pre-interaction to 82.5% post-fluid exposure. Chi-square analyses linked health care professionasl and High-Pathogen Designated Area status with significantly superior adherence. For donning/doffing, lower compliance was predicted by non-High-Pathogen Designated Area placement (General High-Risk Areas aOR = 0.12 (0.07–0.19); Medium-Risk Clinical Areas aOR = 0.08 (0.04–0.14); Low-Risk Support Areas [aOR = 0.07 (0.03–0.17)] and support staff [aOR = 0.35 (0.14–0.88)]; AGP involvement [aOR = 3.61 (2.33–5.58)] and IPC training [aOR = 1.59 (1.05–2.41)] were positive predictors. N95 seal-check odds were lower in General High-Risk Areas aOR = 0.53 (0.30–0.93); Medium-Risk Clinical Areas aOR = 0.33 (0.16–0.66); Low-Risk Support Areas [aOR = 0.25 (0.08–0.77)]. Positive predictors included communal living [aOR = 2.37 (1.29–4.35)],

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IPC training [aOR = 1.71 (1.03–2.83)], and AGP involvement [aOR = 1.71 (1.05–2.80)], while age > 30 [aOR = 0.57 (0.34–0.98)] and stress [aOR = 0.46 (0.28–0.77)] were negative determinants.

Conclusions This study underscores IPC gaps among HCWs especially in non-designated areas, where most infections occurred, highlighting the need for standardized IPC across all healthcare environments.

Keywords COVID-19, Cross-sectional studies, Ethiopia, Guideline adherence, Health Personnel, Infection control, Occupational exposure, Personal protective equipment

Introduction

The emergence of high-consequence respiratory pathogens, most notably SARS-CoV-2, has imposed an unprecedented burden on global health, economic, and social systems. As of late 2024, the World Health Organization reported over 776 million confirmed cases and 7 million deaths globally, with Ethiopia recording over 500,000 cases and 7500 deaths [1–3]. The clinical spectrum of such infections varies widely, ranging from asymptomatic carriage to critical illness requiring intensive care [4, 5]. Healthcare workers (HCWs) remain at the forefront of these outbreaks, facing disproportionate infection risks that are further exacerbated in resource-limited settings characterized by understaffing and constrained supplies [6].

This vulnerability is particularly concerning in developing nations such as Ethiopia, where healthcare systems face chronic understaffing and resource constraints. The potential for infected HCWs to transmit infection in both hospital and community settings underscores the critical importance of robust infection prevention and control (IPC) measures [7]. This was recently underscored by the country's first ever outbreak of Marburg Virus Disease, which occurred between November 2025 and January 2026. Centered in the South Ethiopia and Sidama regions, the outbreak resulted in 14 confirmed cases and a high case fatality rate, with the Ministry of Health identifying infected healthcare workers among the casualties [8].

Effective IPC adherence is the primary defense against occupational acquisition of infectious diseases. This is achieved through systematic training, the provision and appropriate use of personal protective equipment (PPE), and continuous monitoring and evaluation of safety protocols [9, 10]. However, evidence suggests that IPC adherence is often inconsistent across different clinical environments [11]. While specialized isolation units often maintain high standards, general clinical areas may experience a "risk perception gap" that compromises safety [12]. To address this, there is a need for a standardized, task-based evaluation of safety breaches across the entire healthcare facility [13, 14].

Therefore, this research aims to analyze IPC practices of HCWs with laboratory-confirmed infections who had direct face-to-face contact, were involved in aerosol-generating procedures (AGPs), or experienced exposure to body fluids, materials, or surfaces of suspected or confirmed COVID-19 patients, focusing on the critical 14-day window preceding their diagnosis. Utilizing a framework adapted from the OSHA Occupational Risk Pyramid, we categorized clinical environments into High-Pathogen Designated Areas (HPDA), General High-Risk Areas (GHR), Medium-Risk Clinical Areas (MRCA), and Low-Risk Support Areas (LRS). Furthermore, the study specifically assessed adherence to donning and doffing procedures and the performance of pre-use seal checks among HCWs to identify technical and behavioral gaps in respiratory protection. By identifying exactly where adherence fails, whether in specialized units or general wards, this study provides critical data for strengthening occupational safety and institutional resilience. These findings may inform scalable strategies for reinforcing protective measures against current and future health crises with similar transmission patterns.

Materials and methods

Study design and setting

This study employed a facility-based, comparative cross-sectional design utilizing a census sampling approach to evaluate adherence to IPC protocols among HCWs in Addis Ababa, Ethiopia (March 2020–March 2021). By analyzing safety breaches among HCWs with laboratory-confirmed RT-PCR diagnoses, the study identifies vulnerabilities in routine occupational safety relevant to future emerging infectious threats.

Target population

At the time of the pandemic, WHO estimated that there were 104,506 health care professionals in Ethiopia [15]. According to the Addis Ababa City Administration Health Bureau data, there are a total of 6860–7486 health professionals working in primary public health facilities in the city in 2020 [16, 17].

Study population

We identified 1430 HCWs with confirmed SARS-CoV-2 infection in Addis Ababa, Ethiopia through the

Emergency Operating Center (EOC) database. Given the finite size of this registry during the study window, a census sampling method was employed to target all laboratory-confirmed infected HCWs for inclusion, rather than selecting a sample subset. Of these, 1152 HCWs consented to participate in structured interviews regarding their practices 14 days prior to diagnosis.

Inclusion and exclusion criteria:

- Inclusion criteria: HCWs aged ≥ 18 years with laboratory-confirmed SARS-CoV-2 infection who were actively working in a healthcare facility and actively engaged in the care of suspected or confirmed COVID-19 patients during the 14 days prior to diagnosis, and who provided informed consent.
- Exclusion criteria: HCWs who were unable to recall the 14-day period prior to diagnosis, those on extended leave during the exposure window, those not actively working in a healthcare facility, or those not actively engaged in the care of suspected or confirmed COVID-19 patients during the 14 days prior to diagnosis.

Participant flow diagram

From a total of 1430 HCWs with laboratory-confirmed COVID-19 identified in the Addis Ababa City Administration Health Bureau Emergency Operations Center (EOC) database in Addis Ababa, Ethiopia, 1280 consented to participate in the study. HCWs who were unable to recall the 14-day period prior to diagnosis, those on extended leave during the exposure window, those not actively working in a healthcare facility, or those not actively engaged in the care of suspected or confirmed COVID-19 patients during the 14 days prior to diagnosis were excluded based on the established exclusion criteria. This yielded a final sample of 1152 participants who completed the structured questionnaire. This sample was further stratified: 742 HCWs (64.4%) who reported direct face-to-face contact with suspected or confirmed COVID-19 patients were included in the donning and doffing adherence analysis. Within this group, the 350 HCWs (47.2%) who utilized N95 respirators during those interactions were isolated to form the final analytic population for pre-use seal-check and fit-testing compliance (Fig. 1).

Data collection tools, procedures and quality control measures

The data collection instrument was a structured questionnaire primarily adapted from the established World Health Organization (WHO) risk assessment framework designed to evaluate infection prevention and control adherence among HCWs, supplemented with targeted items derived from a comprehensive review of relevant epidemiological literature and institutional protocols [18–21]. To ensure rigorous content and face validity, the compiled instrument was subjected to a formal evaluation and consensus review by an expert panel convened under the national COVID-19 Task Force established by the Ministry of Health (MOH), Ethiopia. This multi-disciplinary committee, encompassing senior infectious disease clinicians and public health experts, systematically evaluated every item for contextual relevance, clinical accuracy, and programmatic feasibility. The instrument was subsequently pilot-tested among 30 HCWs who were excluded from the final analysis cohort to guarantee clarity, comprehensibility, and logistical flow. The data were collected via a paper-based questionnaire, which was filled by trained health care professionals by interviewing each study participant. The questionnaire assessed participants compliance with standard IPC practices, PPE utilization, and hand hygiene protocols during the 14 days preceding their COVID-19 diagnosis. Supervisors conducted daily evaluations of completed questionnaires to ensure completeness, accuracy, and adherence to standardized procedures.

Operational definitions

HCW Categories: in this study, we classified HCWs into supporting staff and health care professionals. The supporting staff comprises of admission and reception clerks, patient transporters, catering personnel, cleaners, ambulance drivers, security guards, administrative workers, and morgue professionals. In contrast, health care professionals include medical doctors, nurses, health

(See figure on next page.)

Fig. 1 STROBE flow diagram tracing the screening and selection of participating HCWs. This diagram traces the selection of HCWs involved in this study, all of whom were deployed across medical facilities in Addis Ababa, Ethiopia. From $N = 1430$ individuals identified in the Addis Ababa City Administration Health Bureau Emergency Operations Center (EOC) registry, $n = 1280$ consented. Applying exclusion criteria omitted 128 individuals, leaving 1152 completed respondents who were subset into two analysis groups: Analytic Population A ($n = 742$) for personnel with documented face-to-face patient contact to track donning and doffing compliance, and Analytic Population B ($n = 350$) to evaluate pre-use seal-checks among those utilizing N95 respirators.

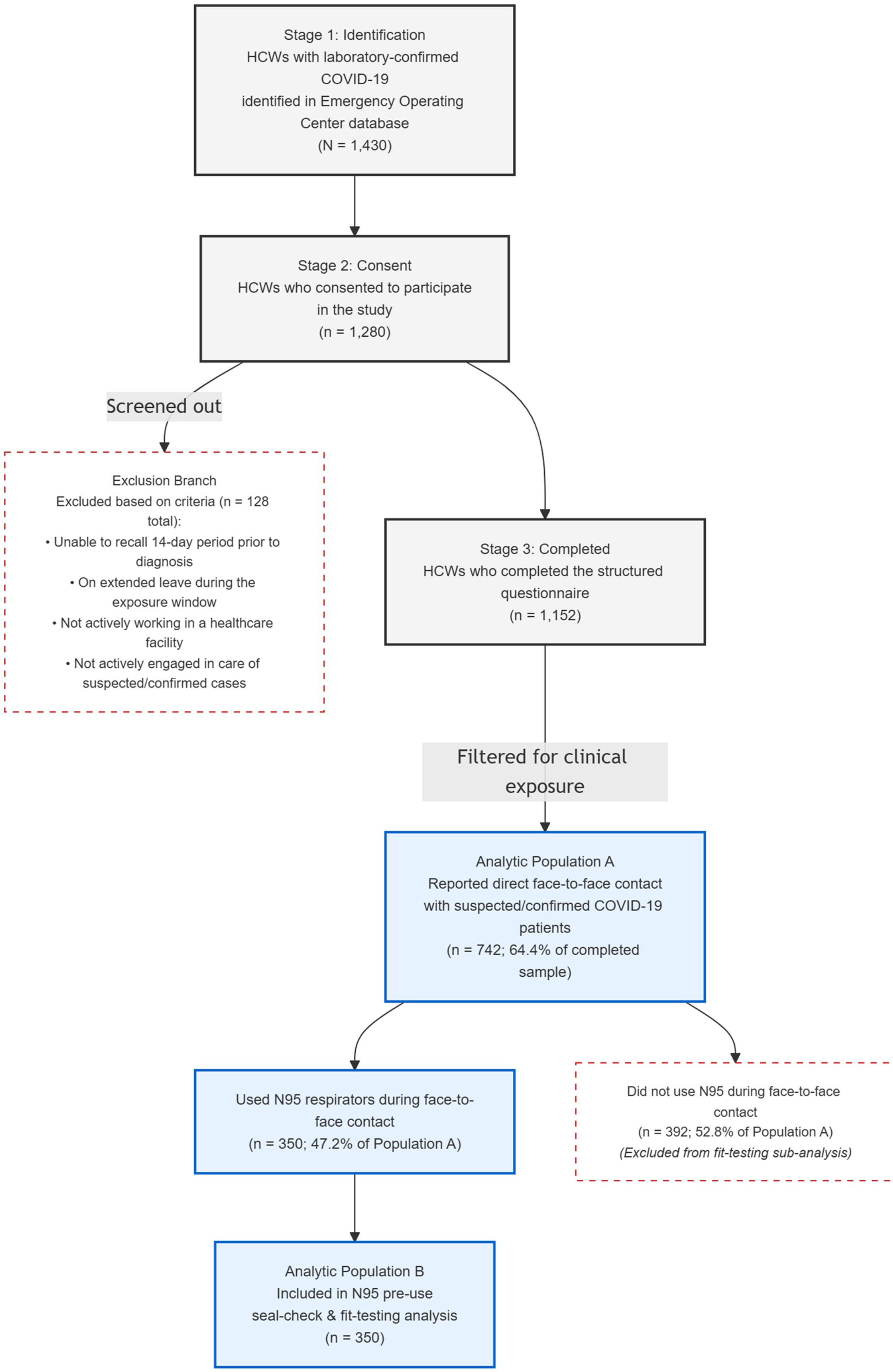

Fig. 1 (See legend on previous page.)

officers, anesthetists, laboratory personnel, dentists, midwives, and pharmacists.

Risk classification based on COVID-19 exposure: We adapted the OSHA Occupational Risk Pyramid for Infectious Diseases to categorize clinical environments based on the potential for contact with infectious sources. HCWs were classified into four distinct areas based on their exposure risk [13].

- High-Pathogen Designated Areas (HPDA): healthcare settings specifically involved in the isolation and treatment of confirmed or suspected infectious cases. This includes designated treatment centers, isolation areas, fever clinics, and medical transport operators moving known cases.
- General High-Risk Areas (GHR): areas with high potential for exposure during specialized medical, postmortem, or laboratory procedures, particularly environments where aerosol-generating procedures (AGPs) are frequently performed, such as intensive care units, emergency rooms, and operating theaters.
- Medium-Risk Clinical Areas (MRCA): settings involving frequent or close contact with the general patient population who are not confirmed cases. This includes roles in general inpatient and outpatient departments, labor wards, laboratories, and pharmacies.
- Low-Risk Support Areas (LRS): roles involving minimal patient interaction or primarily administrative functions, such as administrative offices, laundry facilities, and support staff operating in non-clinical zones.

IPC adherence assessment: For each PPE item, hand hygiene practice, and donning/doffing procedure, adherence was operationally defined as correct clinical practice in > 50% of relevant patient interactions during the 14 days preceding the participant's COVID-19 diagnosis. This specific threshold was pragmatically selected to distinguish HCWs who consistently implemented a given IPC measure, acknowledging that absolute (100%) compliance is rarely achievable in resource-limited settings.

item-specific IPC metrics

- Standard PPE Utilization: adherence was defined as the active deployment of a specified PPE item for more than 50% of relevant patient interactions during the 14-day pre-diagnosis window.
- Multidimensional N95 Assessment: for N95 respirators specifically, we evaluated compliance across three distinct operational dimensions:
  - Frequency of use: defined as active utilization in > 50% of relevant interactions.
  - Pre-use seal-check performance: documented as a binary variable (yes/no) before each clinical entry.
  - Formal fit-testing status: documented as a binary variable (yes/no).

Technical and regulatory frameworks

- Fit testing confirms that the N95 respirator forms a tight seal on the user's face before use, as some respirators fail stipulated safety thresholds [22, 23]. OSHA enforcement guidance recommends initial fit tests for each HCW with the same model, style, and size respirator before use [24]. CDC guidelines recommend seal checks before each use following annual fit testing [25].
- Pre-use seal checks: pre-use seal check: a pre-use seal check is a user-performed verification that an N95 respirator forms an adequate facial seal before each entry into a patient care area. A seal check is performed each time a respirator is used to ensure a facial seal that minimizes particle bypass through gaps between the wearer's skin and the N95 seal [26]. This study assessed pre-use seal check practices only among participants who reported using N95 respirators during face-to-face interactions with suspected or confirmed COVID-19 patients (N = 350). Participants were asked whether they performed a seal check before entering the clinical environment.
- Donning and doffing protocols: donning is defined as appropriate application and use of PPE to achieve intended protection by reducing exposure risk; doffing is the systematic removal of PPE to avoid self-contamination [27].

Data analysis procedure

Data were entered using Epi Info and analyzed with Stata version 14.0 (StataCorp, College Station, TX, USA).

Descriptive Analysis: continuous variables were assessed for normality using the Shapiro–Wilk test and visual inspection of histograms. Normally distributed continuous variables are presented as means with standard deviations (SDs); non-normally distributed variables are presented as medians with interquartile ranges (IQRs). Categorical variables are summarized as frequencies and percentages.

Between-group comparisons for categorical variables were conducted using Pearson's chi-square test, with Fisher's exact test applied when expected cell frequencies were less than five. To quantify the magnitude of associations, Cramér's V effect size measures were calculated, with values interpreted as: > 0.10 = small effect, > 0.30 = medium effect, > 0.50 = large effect. For significant chi-square results, standardized residuals were examined, with values exceeding ± 1.96 considered statistically significant at $\alpha = 0.05$, enabling identification of specific group differences contributing to overall associations.

Two separate multivariable logistic regression models were constructed to identify independent predictors of: (1) pre-use N95 seal-check adherence among N95 users ($N = 350$), and (2) appropriate donning and doffing practices ($N = 742$). Variables with a P-value < 0.2 in univariable logistic regression were considered for entry into the multivariable models. For the N95 seal-check model (outcome: performing pre-use seal check, yes/no), the initial univariable analysis included profession, clinical setting, age, presence of comorbidities, gender, prior IPC training, years of professional service, marital status, presence of stress at the time of event, history of substance abuse, involvement in AGP and average working hours per day. Variables meeting the $P < 0.2$ threshold were entered into the multivariable model. Backward elimination was then applied to minimize the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), yielding the final parsimonious model. For the donning and doffing model (outcome: following recommended procedures for > 50% of interactions, yes/no), the initial univariable analysis included profession, clinical setting, age, gender, prior IPC training, years of professional service, marital status, presence of stress at the time of event, history of substance abuse, presence of comorbidities, involvement in AGP and average working hours per day. Variables meeting the $P < 0.2$ threshold were entered into the multivariable model, followed by backward elimination to minimize AIC and BIC.

Model diagnostics, including the Hosmer–Lemeshow goodness-of-fit test, area under the receiver operating characteristic curve (ROC-AUC), and variance inflation factor (VIF), confirmed appropriate model fit, good discriminatory ability, and no significant multicollinearity for both final models. Statistical significance was set at $P < 0.05$ (two-tailed). Results from multivariable models are presented as adjusted odds ratios (AOR) with 95% confidence intervals (CI).

Ethical considerations

This study was approved by the Ethical Review Committee of the Addis Ababa Health Bureau (5204/227). Permission was obtained from the Addis Ababa Health Bureau, the healthcare facilities where infected HCWs were employed, and the Addis Ababa Emergency Operating Center. Written informed consent was obtained from all participants. Throughout data collection, confidentiality was protected. Participation was voluntary, and participants could withdraw at any time, even after the interview had begun, and could decline to answer any question. All methods were implemented in accordance with relevant guidelines and regulations.

Results

A total of 1152 HCWs with laboratory-confirmed COVID-19 were included. The median age of participants was 29 years (IQR: 27–34; range: 19–88). The median duration of professional experience was 5 years (IQR: 3–8), and the median monthly income was 8,017 Ethiopian Birr. A significant majority (80.8%) of participants worked in areas not specifically designated for COVID-19 care prior to diagnosis. Based on the adapted OSHA Occupational Risk Pyramid, the distribution of work locations in the 14 days prior to diagnosis was: GHR–349 (30.3%), MRCA–400 (34.7%), LRS–182 (15.8%), and HPDA–221 (19.2%). Among infected participants, 1,048 (91.0%) were healthcare professionals, while the remainder were supporting staff. Among healthcare professionals, 412 (35.8%) were doctors and 434 (37.7%) were nurses or midwives. Notable disparities in IPC training coverage were observed by work location, ranging from 31.5% in MRCA to 57.5% in HPDA. Self-reported stress at the time of diagnosis was highest among HCWs in HPDA (62.4%) and GHR (57.6%) (Table 1).

HCW interactions with patients in the 14 days prior to diagnosis

Among HCWs who contracted COVID-19, 64.4% ($n = 742$) reported direct face-to-face contact with suspected or confirmed cases, 55.0% ($n = 631$) handled patient materials, 42.6% ($n = 491$) had contact with contaminated surfaces, 26.1% ($n = 301$) experienced exposure to body fluids, and 17.1% ($n = 197$) were present during AGPs. Uncertainty about exposure was highest for contact with surrounding surfaces (9.4%), followed by handling patient materials (6.9%) and direct contact (6.9%); uncertainty was lowest for AGPs (0.4%) (Fig. 2).

PPE use during direct face-to-face interactions

During direct face-to-face interactions, 87.5% of participants used medical masks for more than half of interactions, and 68.2% did so for gloves. Utilization declined significantly from HPDA to LRS for both mask and glove use ($P < 0.001$, $V = 0.15$ and $V = 0.23$, respectively). Regarding specialized respiratory protection, only 31.3% of participants used N95 respirators for more than half of interactions, with strong variation by work site ($P < 0.001$, $V = 0.36$). In HPDA settings, 74.8% used N95 respirators for more than half of interactions, significantly higher

Table 1 Demographic and occupational characteristics of healthcare personnel infected during the study period in Addis Ababa, Ethiopia from March 2020 to March 2021

Characteristics	Total sample	Non-designated areas (n = 931, 80.8%)			Designated areas (n = 221, 19.2%)
	All HCWs (N = 1152)	LRS (n = 182)	MRCA (n = 400)	GHR (n = 349)	HPDA (n = 221)
Continuous metrics (median [IQR])					
Age (years)	29 (27, 34)	32 (28, 40)	29 (27, 35)	29 (27, 33)	28 (26, 31)
Years of professional experience (years)	5 (3, 8)	6 (4, 10)	5 (3, 10)	5 (3, 8)	4 (2, 7)
Monthly income (ETB) †	8017 (6000, 10470)	6500 (3338, 8170)	8500 (6193, 10470)	9000 (6193, 11300)	8300 (6000, 10150)
Categorical Variables (n (%))					
Gender					
Male	522 (45.3)	75 (41.2)	148 (37.0)	176 (50.4)	123 (55.7)
Female	630 (54.7)	107 (58.8)	252 (63.0)	173 (49.6)	98 (44.3)
Marital status					
Married	529 (45.9)	100 (54.9)	194 (48.5)	162 (46.4)	73 (33.0)
Single	590 (51.2)	70 (38.5)	197 (49.3)	182 (52.1)	141 (63.8)
Widowed/divorced/separated	33 (2.9)	12 (6.6)	9 (2.3)	5 (1.4)	7 (3.2)
Profession					
Doctors	412 (35.8)	11 (6.0)	159 (39.8)	155 (44.4)	87 (39.4)
Nurses/midwife	434 (37.7)	13 (7.1)	191 (47.8)	137 (39.3)	93 (42.1)
Health officers	60 (5.2)	11 (6.0)	25 (6.3)	17 (4.9)	7 (3.2)
Supporting staffs	104 (9.0)	54 (29.7)	17 (4.3)	15 (4.3)	18 (8.1)
Lab. professionals	65 (5.6)	59 (32.4)	0 (0.0)	0 (0.0)	6 (2.7)
Pharmacist	40 (3.5)	31 (17.0)	3 (0.8)	1 (0.3)	5 (2.3)
Anesthetist	23 (2.0)	0 (0.0)	1 (0.3)	21 (6.0)	1 (0.5)
Other healthcare professionals	14 (1.2)	3 (1.6)	4 (1.0)	3 (0.9)	4 (1.8)
IPC training					
No	709 (61.6)	104 (57.1)	274 (68.5)	237 (67.9)	94 (42.5)
Yes	443 (38.4)	78 (42.9)	126 (31.5)	112 (32.1)	127 (57.5)
Living status					
Alone	245 (21.3)	26 (14.3)	86 (21.5)	88 (25.2)	45 (20.4)
With a family, friends or in a camp	907 (78.7)	156 (85.7)	324 (78.5)	261 (74.8)	176 (79.6)
Stressed at the time of the event					
No	509 (44.2)	93 (51.1)	185 (46.3)	148 (42.4)	83 (37.6)
Yes	643 (55.8)	89 (48.9)	215 (53.7)	201 (57.6)	138 (62.4)
Presence of comorbidities					
No	986 (85.6)	150 (82.4)	323 (80.8)	301 (86.2)	212 (95.9)
Yes	166 (14.4)	32 (17.6)	77 (19.2)	48 (13.8)	9 (4.1)
Substance abuse					
No	1117 (97.0)	171 (94.0)	392 (98.0)	338 (96.9)	216 (97.7)
Yes	35 (3.0)	11 (6.0)	8 (2.0)	11 (3.1)	5 (2.3)
Working hours per day					
< 8 h	107 (9.5)	11 (6.6)	38 (9.6)	24 (6.9)	34 (16.0)
8–12 h	644 (57.3)	120 (71.9)	233 (58.5)	177 (51.0)	114 (53.8)
> 12 h	373 (33.2	36 (21.5)	127 (31.9)	146 (42.1)	64 (30.2

ETB Ethiopian Birr, *GHR* General High-Risk Areas, *HPDA* High-Pathogen Designated Areas, *IQR* interquartile range, *IPC* infection prevention and control, *LRS* Low-Risk Support Areas, *MRCA* Medium-Risk Clinical Areas

† Note on income missing data: n = 1118 due to missing values

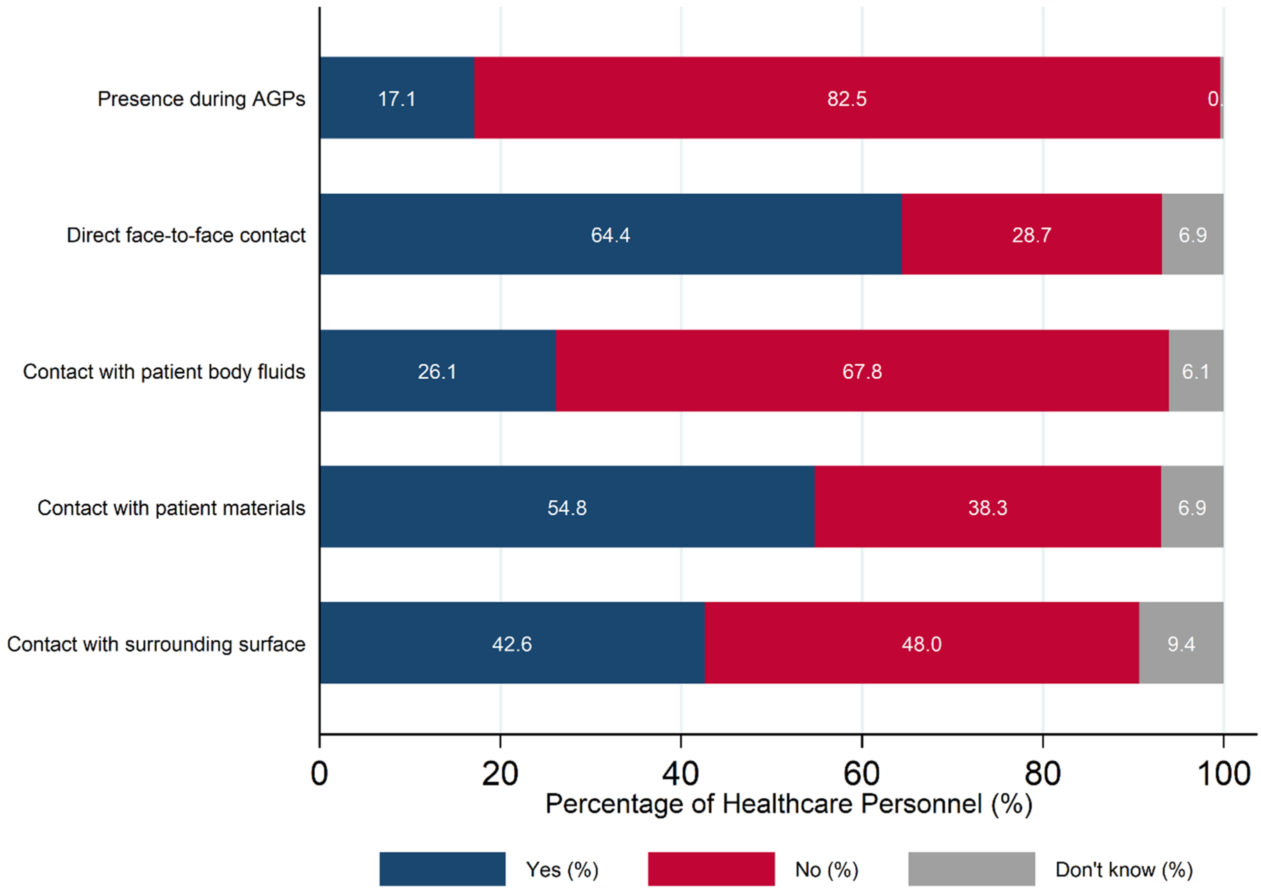

Fig. 2 Clinical exposure patterns among infected healthcare personnel in Addis Ababa, Ethiopia, March 2020–March 2021 ($N = 1152$). Stacked bar chart showing the frequency of self-reported interactions in the 14 days preceding COVID-19 diagnosis. Data labels represent percentages (%); Navy = Yes, Cranberry = No, Gray = Don't know. Among HCWs who contracted COVID-19, 64.4% ($N = 742$) reported direct face-to-face contact, 55.0% ($N = 631$) handled patient materials, 42.6% ($N = 491$) had contact with contaminated surfaces, 26.1% ($N = 301$) experienced exposure to body fluids, and 17.1% ($N = 197$) were present during aerosol-generating procedures (AGPs). Uncertainty about exposure was highest for contact with surrounding surfaces (9.4%), followed by handling patient materials (6.9%) and direct contact (6.9%); uncertainty was lowest for AGPs (0.4%). AGPs: aerosol-generating procedures

than expected (standardized residual = 9.8), compared to 13.0–26.6% in non-designated areas. Among participants who used N95 respirators during face-to-face interactions ($N = 350$), pre-use seal-check compliance was low overall (34.9%), ranging from 20.7% in MRCA to 48.1% in HPDA ($P < 0.001$, $V = 0.24$). Formal N95 fit testing was nearly absent, with only 1.1% of these participants reporting test-fitted respirators and none in MRCA or LRS ($P = 0.328$).

Utilization of face shields, disposable gowns, coverall suits, head caps, and shoe covers exceeded 50% of the time in less than 25% of participants overall. Work site was significantly associated with utilization of all these PPE items ($P < 0.001$ for all), with moderate to large effect sizes: coverall suits ($V = 0.43$), face shields ($V = 0.42$), disposable gowns ($V = 0.34$), head caps ($V = 0.30$), and shoe covers ($V = 0.34$). In addition, disparities in PPE adherence were also evident by professional role. Supporting staff reported less frequent utilization of medical masks ($P = 0.011$, $V = 0.11$) and single-use gloves ($P = 0.011$, $V = 0.16$) compared to healthcare professionals. No significant differences by professional role were observed for other PPE items or for N95 seal-check and fit testing (Table 2).

Multivariable analysis: predictors of N95 pre-use seal-check adherence

Multivariable logistic regression analysis was performed to identify independent predictors of N95 mask pre-use seal-check adherence among HCWs who used N95 respirators during face-to-face interactions. Several socio-demographic factors significantly influenced behavior. HCWs in communal or shared living arrangements (including family, friends, or camps) were more

Table 2 Adherence to personal protective equipment utilization, donning and doffing procedures during direct patient interactions stratified by clinical setting and professional role in Addis Ababa, Ethiopia from March 2020 to March 2021

Exposure modality & PPE type	Compliance level	Total sample *n* (%)	HPDA (% (SR))	GHR (% (SR))	MRCA (% (SR))	LRS (% (SR))	Work setting association χ2 *p*-value, *V*	Healthcare professionals (% (SR))	Supporting staff (% (SR))	Professional role association χ2 p-value, *V*
Medical mask	Never	49 (6.6)	4.4 (−1.1)	2.3 (-2.7)	9.8 (1.9)	14.8 (2.9)	$P<0.001$, $V=0.15$	6.3 (−0.3)	10.6 (1.1)	$P=0.011$, $V=0.11$
	< 50%	44 (5.9)	2.5 (−1.8)	6.6 (0.5)	4.9 (-0.7)	13.6 (2.8)		5.3 (−0.7)	14.9 (2.5)	
	> = 50%	649 (87.5)	93.1 (0.8)	91.0 (0.6)	85.4 (−0.4)	71.6 (−1.5)		88.3 (0.3)	74.5 (−1.0)	
Single use gloves	Never	161 (21.7)	10.7 (−3.0)	15.2 (−2.2)	26.0 (1.5)	50.6 (5.6)	$P<0.001$, $V=0.23$	20.0 (−1.0)	46.8 (3.7)	$P=0.011$, $V=0.16$
	< 50%	75 (10.1)	5.0 (−2.0)	9.4 (−0.4)	15.0 (2.4)	7.4 (−0.8)		10.5 (0.3)	4.3 (−1.3)	
	> = 50%	506 (68.2)	84.3 (2.5)	75.4 (1.39)	58.9 (−1.8)	42.0 (−2.9)		69.5 (0.4)	48.9 (−1.6)	
N−95-respirator	Never	392 (52.8)	16.4 (−6.3)	56.3 (0.8)	66.7 (3.0)	71.6 (2.3)	$P<0.001$, $V=0.36$	51.8 (−0.4)	68.1 (1.4)	$P=0.087$, $V=0.08$
	< 50%	118 (15.9)	8.8 (−2.2)	17.2 (0.5)	20.3 (1.7)	12.3 (−0.8)		16.1 (0.1)	12.8 (−0.5)	
	> = 50%	232 (31.3)	74.8 (9.8)	26.6 (−1.4)	13.0 (−5.1)	16.0 (−2.5)		32.1 (0.4)	19.1 (−1.5)	
Face shields/goggles	Never	475 (64.0)	22.0 (−6.6)	70.7 (1.3)	80.1 (3.2)	76.5 (1.4)	$P<0.001$, $V=0.42$	63.3 (−0.2)	74.5 (0.9)	$P=0.285$, $V=0.06$
	< 50%	96 (12.9)	8.2 (−1.7)	16.4 (1.5)	13.4 (0.2)	9.9 (−0.8)		13.1 (0.1)	10.6 (−0.4)	
	> = 50%	171 (23.0)	69.8 (12.3)	12.9 (−3.39)	6.5 (−5.4)	13.6 (−1.8)		23.6 (0.3)	14.9 (−1.2)	
Disposable gowns	Never	509 (68.6)	34.0 (−5.3)	73.0 (0.9)	82.5 (2.6)	80.2 (1.3)	$P<0.001$, $V=0.34$	68.2 (−0.1)	74.5 (0.5)	$P=0.585$, $V=0.04$
	< 50%	75 (10.1)	8.2 (−0.8)	12.9 (1.4)	8.9 (−0.6)	8.6 (−0.4)		10.1 (−0.0)	10.6 (0.1)	
	> = 50%	158 (21.3)	57.9 (10.0)	14.1 (−2.51)	8.5 (−4.3)	11.1 (−2.0)		21.7 (0.3)	14.9 (−1.0)	
Coverall suit	Never	565 (76.1)	34.0 (−6.1)	83.2 (1.3)	93.5 (3.1)	84.0 (0.8)	$P<0.001$, $V=0.43$	75.8 (−0.1)	80.9 (0.4)	$P=0.189$, $V=0.06$
	< 50%	53 (7.1)	6.9 (−0.1)	9.0 (1.1)	5.3 (−1.1)	7.4 (0.09)		6.9 (−0.2)	10.6 (0.9)	
	> = 50%	124 (16.7)	59.1 (13.1)	7.8 (−3.5)	1.2 (−5.9)	8.6 (−1.78)		17.3 (0.4)	8.5 (−1.4)	
Head cap	Never	470 (63.3)	30.2 (−5.3)	63.3 (−0.0)	79.3 (3.1)	80.2 (1.91)	$P<0.001$, $V=0.30$	62.4 (−0.3)	76.6 (1.1)	$P=0.170$, $V=0.07$
	< 50%	61 (8.2)	7.5 (−0.3)	9.8 (0.9)	7.3 (−0.5)	7.4 (−0.26)		8.5 (0.3)	4.3 (−1.0)	
	> = 50%	211 (28.4)	62.3 (8.0)	27.0 (−0.5)	13.4 (−4.4)	12.3 (−2.72)		29.1 (0.3)	19.1 (−1.2)	
Shoe covers	Never	603 (81.3)	48.4 (−4.6)	86.7 (1.0)	93.5 (2.1)	91.4 (1.01)	$P<0.001$, $V=0.34$	80.9 (−0.1)	87.2 (0.5)	$P=0.624$, $V=0.04$
	< 50%	61 (8.2)	15.1 (3.0)	8.2 (−0.0)	4.9 (−1.8)	4.9 (−1.03)		8.5 (0.3)	4.3 (−1.0)	
	> = 50%	78 (10.5)	36.5 (10.1)	5.1 (−2.7)	1.6 (−4.3)	3.7 (−1.89)		10.6 (0.11)	8.5 (−0.4)	
Respiratory protection metrics & procedural compliance										
Seal check of N-95	No	228 (65.1)	51.9 (−1.9)	67.9 (0.4)	79.3 (1.6)	78.3 (0.8)	$P<0.001$, $V=0.24$	65.4 (0.1)	60.0 (−0.3)	$P=0.669$, $V=0.02$
	Yes	122 (34.9)	48.1 (2.6)	32.1 (−0.5)	20.7 (−2.2)	21.7 (−1.1)		34.6 (−0.1)	40.0 (0.3)	
Fit test of N-95	No	346 (98.9)	97.7 (−0.1)	99.1 (0.0)	100.0 (0.1)	100.0 (0.1)	$P=0.328$, $V=0.09$	98.8 (−0.0)	100.0 (0.1)	$P=1.000$, $V=0.02$
	Yes	4 (1.1)	2.3 (1.2)	0.9 (−0.3)	0.0 (−1.0)	0.0 (−0.5)		1.2 (0.1)	0.0 (−0.4)	
Donning/doffing protocol	Never	423 (57.0)	22.0 (−5.8)	60.9 (0.8)	75.6 (3.9)	56.8 (−0.2)	$P<0.001$, $V=0.34$	58.9 (0.6)	29.8 (−2.5)	$P<0.001$, $V=0.38$
	< 50%	72 (9.7)	10.0 (0.1)	15.2 (2.8)	5.7 (−2.0)	3.7 (−1.7)		10.2 (0.44)	2.1 (−1.7)	
	> = 50%	175 (23.4)	64.2 (10.5)	17.6 (−2.0)	8.1 (−5.0)	9.9 (−2.5)		24.2 (0.3)	14.9 (−1.2)	
	Don't know the steps	72 (9.7)	3.8 (−2.4)	6.3 (−1.8)	10.6 (0.4)	29.6 (5.7)		6.8 (−2.5)	53.2 (9.5)	

GHR General High−Risk Areas, *HPDA* High-Pathogen Designated Areas, *MRCA* Medium-Risk Clinical Areas, *LRS* Low-Risk Support Areas, *SR* standardized adjusted residuals, *V* Cramér's V. Health care professionals: 1048 (91.0%), Supporting staffs: 104 (9.0%)

†Row values inside cross-tabulations represent cell percentages with standardized adjusted residuals in parentheses: % (SR). Sub-analysis size: Evaluation of N95 handling skills (Seal Check, Fit Testing, and Donning/Doffing) was performed exclusively among the subset of active users who reported utilizing *N*-95 respirators at any frequency ($n=350$)

than twice as likely to perform pre-use seal checks [(AOR) = 2.37; 95% CI 1.29–4.35]. In contrast, older age (> 30 years) (AOR = 0.57; 95% CI 0.34–0.98) and being stressed at the time of the event (AOR = 0.46; 95% CI 0.28–0.77) were associated with significantly lower odds of adherence. Clinical exposure and institutional factors also served as strong positive predictors. Involvement in AGPs (AOR = 1.71; 95% CI 1.05–2.80) and receipt of prior IPC training (AOR = 1.71; 95% CI 1.03–2.83) were both associated with increased adherence. The clinical setting played a critical role, showing a clear gradient of risk. Compared to the HPDA reference group, working in GHR was associated with a 47% reduction in the likelihood of adherence (AOR = 0.53; 95% CI 0.30–0.93). This decline was even more pronounced in MRCA, where the odds of performing seal checks dropped by 67% (AOR = 0.33; 95% CI 0.16–0.66). The lowest level of adherence was observed in LRS, representing a 75% reduction in the odds of performing the necessary seal checks (AOR = 0.25; 95% CI 0.08–0.77) (Fig. 3). Model diagnostics: Hosmer–Lemeshow $\chi^2 = 6.59$ ($P = 0.582$), ROC-AUC = 0.714, mean VIF = 1.86.

Adherence to donning and doffing procedures

Overall, 57.0% of participants never followed recommended donning and doffing procedures, with non-adherence highest in MRCA (75.6%) and GHR (60.9%). Only 23.4% of participants consistently followed the recommended steps for more than half of interactions; adherence was highest in HPDA) (64.2%), compared to 17.6% in GHR and 9.9% in LRS. Notably, 9.7% of participants reported being unaware of the recommended steps, with unawareness most frequent in LRS (29.6%) and MRCA (10.6%). Occupational differences were striking: while 58.9% of healthcare professionals reported never following procedures, 53.2% of supporting staff reported a lack of knowledge regarding the recommended steps. Ultimately, only 24.2% of healthcare professionals and 14.9% of supporting staff followed procedures for more than half of interactions (Table 2). Multivariable logistic

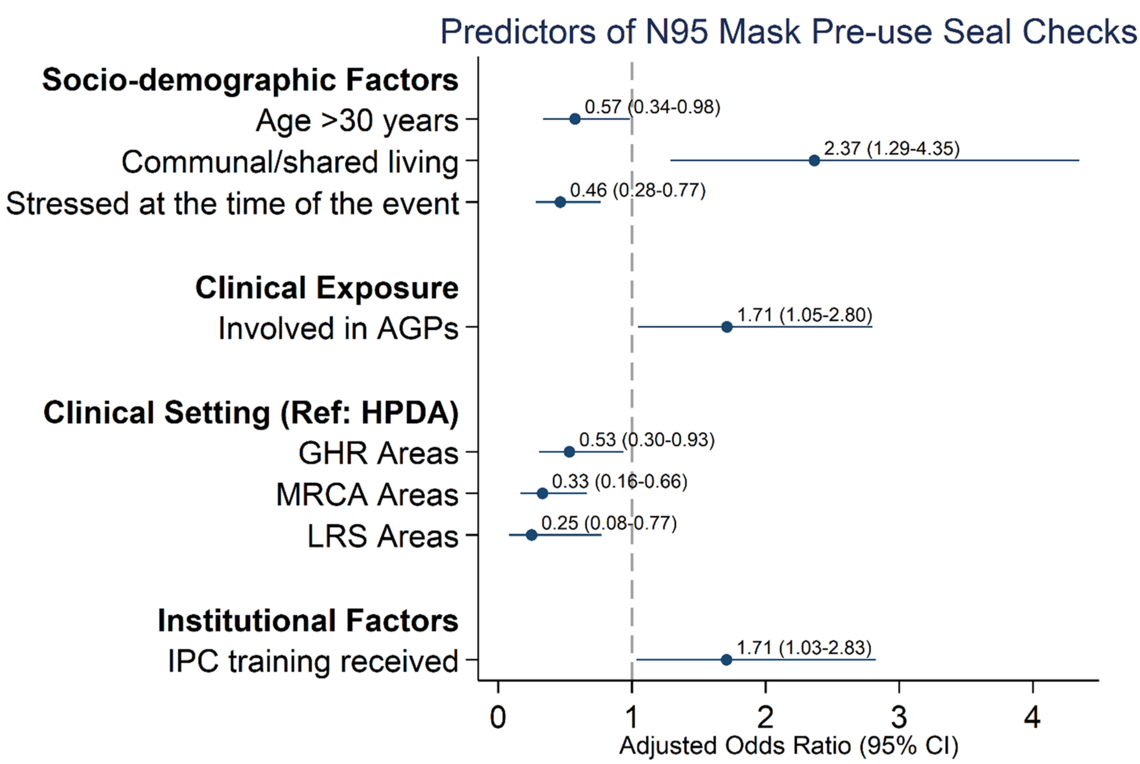

Fig. 3 Predictors of N95 respirator pre-use seal-check adherence among infected healthcare personnel in Addis Ababa, Ethiopia, March 2020–March 2021 ($N = 350$). This forest plot illustrates adjusted odds ratios (AOR) and 95% confidence intervals (CI), where values greater than 1.0 indicate an increased likelihood of seal-check performance. Communal or shared living includes healthcare workers residing with family, friends, or in communal camps. Clinical settings are compared against High-Pathogen Designated Areas (HPDA) as the reference group, with General High-Risk Areas (GHR), Medium-Risk Clinical Areas (MRCA), and Low-Risk Support Areas (LRS) representing descending levels of clinical risk. The model accounts for institutional safety and training factors, including prior infection prevention and control (IPC) training and involvement in aerosol-generating procedures (AGPs). Categorical variables such as age (> 30 years) and stressful events are modeled against their respective reference groups to reflect the change in odds of adherence

regression identified three factors independently associated with adherence. Involvement in AGPs was the strongest predictor; participants who performed AGPs had 3.61 times the odds of adherence compared to those who did not (AOR = 3.61; 95% CI 2.33–5.58; $P < 0.001$). Prior IPC training was also significantly associated with adherence, with trained participants having 59% higher odds of achieving the adherence threshold (AOR = 1.59; 95% CI 1.05–2.41; $P = 0.028$). Work site was a critical determinant of adherence ($P < 0.001$). Using HPDA as the reference group (AOR = 1.00), participants in other clinical areas showed markedly lower compliance: GHR (AOR = 0.12; 95% CI 0.07–0.19), MRCA (AOR = 0.08; 95% CI 0.04–0.14), and LRS (AOR = 0.07; 95% CI 0.03–0.17), representing 88%, 92%, and 93% lower odds of adherence, respectively (Table 3).

PPE use during aerosolizing procedures

During AGPs, over 95% of participants used medical masks and single-use gloves for more than half of interactions. Approximately 66.5% used N95 respirators for more than half of the time. Other PPE items, including face shields, head caps, and disposable gowns, were used by only 40–60% of participants. Chi-square analysis identified significant associations between work site and use of all PPE items during AGPs ($P < 0.05$ for all), with the exception of medical masks ($P = 0.096$) and gloves ($P = 0.153$). The strongest associations were found for coverall suits (Cramér's $V = 0.50$), shoe covers ($V = 0.44$), and N95 respirators ($V = 0.41$). Participants in High-Pathogen Designated Areas (HPDA) demonstrated significantly higher adherence, with over 50% usage rates for coverall suits (SR = 6.3), shoe covers (SR = 5.4), N95 respirators (SR = 3.1), face shields (SR = 4.2), and disposable gowns (SR = 4.0). In contrast, GHR showed negative associations for use of PPE for more than half of the time, particularly for N95 respirators (SR = −1.8), coverall suits (SR = −4.0), face shields (SR = −2.8), disposable gowns (SR = −2.5), head caps (SR = −1.1), and shoe covers (SR = −3.0). No statistically significant associations were identified between PPE utilization and professional category during AGPs (Table 4).

PPE use during interactions with body fluids

During exposure to patient body fluids, 97.7% of participants used medical masks and 93.4% used gloves for more than half of the time. However, only 40.2% used N95 respirators for more than half of the time, with notably higher utilization in HPDA settings. Regarding additional protective equipment, many participants never used face shields (50.8%), disposable gowns (53.8%), coverall suits (65.4%), head caps (53.2%), or shoe covers (70.1%) during contact with body fluids. Non-utilization of these items decreased progressively from HPDA to non-designated areas. Utilization patterns revealed significant site-specific variations ($P < 0.001$ for all), with the exception of medical masks and gloves. HPDA settings exhibited the highest compliance rates (≥ 50%), while MRCA showed markedly lower utilization. Healthcare professionals demonstrated significantly higher compliance than supporting staff, particularly for medical masks (98.0% vs. 66.7%; $P = 0.001$, $V = 0.46$) and gloves (94.9% vs. 16.7%; $P < 0.001$, $V = 0.58$). The disparity was most

Table 3 Multivariable logistic regression analysis identifying factors associated with adherence to donning and doffing procedures during direct face to face contact among infected healthcare personnel in Addis Ababa, Ethiopia from March 2020 to March 2021 ($N = 742$)

Variables	Category	Adherence (≥ 50% of time)			cOR (95% CI)	*P*-value	AOR [95% CI]	P-value
		Total *N* (%)	No *N* (%)	Yes *N* (%)				
IPC training	No	455 (61.3)	373 (65.9)	82 (46.9)	1.00		1.00	
	Yes	287 (38.7)	194 (34.2)	93 (53.1)	2.18 (1.55–3.08)	< 0.001	1.59 (1.05–2.41)	< 0.05*
Site of work	HPDA	159 (21.4)	57 (10.0)	102 (58.3)	1.00		1.00	
	GHR	256 (34.5)	211 (37.2)	45 (25.7)	0.12 (0.075–0.19)	< 0.001	0.12 (0.07–0.19)	< 0.001***
	MRCA	246 (33.2)	226 (39.9)	20 (11.4)	0.05 (0.03–0.09)	< 0.001	0.08 (0.04–0.14)	< 0.001***
	LRS	81 (10.9)	73 (12.9)	8 (4.6)	0.06 (0.03–0.14)	< 0.001	0.07 (0.03–0.17)	< 0.001***
Involved in AGP	No	545 (73.4)	460 (81.1)	85 (48.6)	1.00		1.00	
	Yes	197 (26.6)	107 (18.9)	90 (51.4)	4.6 (3.16–6.54)	< 0.001	3.6 (2.3–5.6)	< 0.001***

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

[*] Model diagnostics: Hosmer–Lemeshow $\chi^2 = 3.72$ ($P = 0.811$), ROC-AUC = 0.823, mean VIF = 1.23*

[*] $P < 0.05$; **$P < 0.01$; **$P < 0.001$

AOR adjusted odds ratio, *cOR* crude odds ratio, *CI* confidence interval, *HPDA* High-Pathogen Designated Areas, *GHR* General High-Risk Areas, *MRCA* Medium-Risk Clinical Areas, *LRS* Low-Risk Support Areas, *IPC* infection prevention and control, *AGPs* aerosol-generating procedures

Table 4 Adherence to personal protective equipment utilization during aerosol generating procedures and contact with body fluids stratified by professional role and clinical setting in Addis Ababa, Ethiopia from March 2020 to March 2021

Exposure modality	Type of PPE	PPE use	Total	Place of work before the diagnosis					Occupation of the HCWs		
			N (%)	HPDA	GHR	MRCA	LRS	χ2 *p*-value, *V*	HCP	SS	χ2 *p*-value, *V*
				% (SR)	% (SR)	% (SR)	% (SR)		% (SR)	% (SR)	
PPE use during AGP ($n = 197$)	Medical mask	Never	3 (1.5)	2.9 (0.9)	0.0 (−1.2)	0.0 (−0.6)	7.1 (1.7)	$P = 0.096$ $V = 0.15$	1.5 (0.0)	0.0 (−0.2)	$P = 1.000$ $V = 0.02$
		< 50%	2 (1.0)	2.9 (1.6)	0.0 (−1.0)	0.0 (−0.5)	0.0 (−0.4)		1.0 (0.0)	0.0 (−0.2)	
		> = 50%	192 (97.5)	94.2 (−0.3)	100 (0.3)	100.0 (0.1)	92.9 (−0.2)		97.4 (−0.0)	100.0 (0.1)	
	Single use gloves	Never	3 (1.5)	1.4 (−0.1)	1.1 (−0.4)	0.0 (−0.6)	7.1 (1.7)	$P = 0.153$ $V = 0.15$	1.5 (0.0)	0.0 (−0.2)	$P = 1.000$ $V = 0.02$
		< 50%	1 (0.5)	0.0 (−0.6)	1.1 (0.8)	0.0 (−0.3)	0.0 (−0.3)		0.5 (0.0)	0.0 (−0.1)	
		> = 50%	193 (98.0)	98.6 (0.1)	97.9 (0.0)	100.0 (0.1)	92.9 (−0.2)		97.9 (0.0)	100.0 (0.0)	
	N-95	Never	51 (25.9)	1.4 (−4.0)	41.5 (3.0)	30.0 (0.4)	35.7 (0.7)	$P < 0.001$ $V = 0.41$	25.8 (−0.0)	33.3 (0.3)	$P = 1.000$ $V = 0.04$
		< 50%	15 (7.6)	1.4 (−1.9)	7.4 (−0.1)	35.0 (4.4)	0.0 (−1.0)		7.7 (0.1)	0.0 (−0.5)	
		> = 50%	131 (66.5)	97.1 (3.1)	51.1 (−1.8)	35.0 (−1.7)	64.3 (−0.1)		66.5 (0.0)	66.7 (0.0)	
	Face shields/googles	Never	73 (37.1)	5.8 (−4.3)	54.3 (2.7)	55.0 (1.3)	50.0 (0.8)	$P < 0.001$ $V = 0.39$	36.6 (−0.1)	66.7 (0.8)	$P = 1.000$ $V = 0.08$
		< 50%	20 (10.2)	4.3 (−1.5)	13.8 (1.1)	15.0 (0.7)	7.1 (−0.4)		10.3 (0.1)	0.0 (−0.6)	
		> = 50%	104 (52.8)	89.9 (4.2)	31.9 (−2.8)	30.0 (−1.4)	42.9 (−0.5)		53.1 (0.1)	33.3 (−0.5)	
	Gowns	Never	91 (46.2)	18.8 (−3.3)	60.6 (2.1)	70.0 (1.6)	50.0 (0.2)	$P < 0.001$ $V = 0.34$	45.9 (−0.1)	66.7 (0.5)	$P = 1.000$ $V = 0.06$
		< 50%	20 (10.2)	5.8 (−1.1)	12.8 (0.8)	15.0 (0.7)	7.1 (−0.4)		10.3 (0.1)	0.0 (−0.6)	
		> = 50%	86 (43.7)	75.4 (4.0)	26.6 (−2.5)	15.0 (−1.9)	42.9 (−0.1)		43.8 (0.0)	33.3 (−0.3)	
	Coverall suit	Never	111 (56.3)	15.9 (−4.5)	76.6 (2.6)	95.0 (2.3)	64.3 (0.4)	$P < 0.001$ $V = 0.50$	56.2 (−0.0)	66.7 (0.2)	$P = 1.000$ $V = 0.04$
		< 50%	14 (7.1)	1.4 (−1.8)	11.7 (1.7)	5.0 (−0.4)	7.1 (0.0)		7.2 (0.1)	0.0 (−0.5)	
		> = 50%	72 (36.5)	82.6 (6.3)	11.7 (−4.0)	0.0 (−2.7)	28.6 (−0.5)		36.6 (0.0)	33.3 (−0.1)	
	Head cap	Never	73 (37.1)	11.6 (−3.5)	45.7 (1.4)	70.0 (2.4)	57.1 (1.2)	$P < 0.001$ $V = 0.30$	36.6 (−0.1)	66.7 (0.8)	$P = 0.625$ $V = 0.08$
		< 50%	10 (5.1)	4.3 (−0.3)	5.3 (0.1)	5.0 (0.0)	7.1 (0.3)		5.2 (0.1)	0.0 (−0.4)	
		> = 50%	114 (57.9)	84.1 (2.9)	48.9 (−1.1)	25.0 (−1.9)	35.7 (−1.1)		58.2 (0.1)	33.3 (−0.6)	
	Shoe covers	Never	126 (64.0)	24.6 (−4.1)	81.9 (2.2)	100.0 (2.0)	85.7 (1.0)	$P < 0.001$ $V = 0.44$	63.9 (−0.0)	66.7 (0.1)	$P = 1.000$ $V = 0.04$
		< 50%	18 (9.1)	14.5 (1.5)	7.4 (−0.5)	0.0 (−1.4)	7.1 (−0.3)		9.3 (0.1)	0.0 (−0.5)	
		> = 50%	53 (26.9)	60.9 (5.4)	10.6 (−3.0)	0.0 (−2.3)	7.1 (−1.4)		26.8 (−0.0)	33.3 (0.2)	

Table 4 (continued)

Exposure modality	Type of PPE	PPE use	Total	Place of work before the diagnosis					Occupation of the HCWs		
			N (%)	HPDA % (SR)	GHR % (SR)	MRCA % (SR)	LRS % (SR)	χ2 p-value, V	HCP % (SR)	SS % (SR)	χ2 p-value, V
PPE use during contact with patient body fluids ($n = 301$)	Medical mask	Never	4 (1.3)	2.4 (0.9)	0.0 (−1.2)	2.4 (0.9)	0.0 (−0.6)	$P = 0.081$ $V = 0.14$	1.4 (0.0)	0.0 (−0.3)	$P = 0.001$ $V = 0.46$
		< 50%	3 (1.0)	3.6 (2.4)	0.0 (−1.1)	0.0 (−0.9)	0.0 (−0.5)		0.3 (−1.1)	33.3 (7.9)	
		> = 50%	294 (97.7)	94.0 (−0.3)	100.0 (0.3)	97.6 (0.0)	100.0 (0.1)		98.3 (0.1)	66.7 (−0.8)	
	Single use gloves	Never	12 (4.0)	2.4 (−0.7)	3.6 (−0.2)	4.8 (0.4)	8.7 (1.1)	$P = 0.189$ $V = 0.12$	2.4 (−1.4)	83.3 (9.7)	$P < 0.001$ $V = 0.58$
		< 50%	8 (2.7)	0.0 (−1.5)	2.7 (0.0)	6.0 (1.9)	0.0 (−0.8)		2.7 (0.1)	0.0 (−0.4)	
		> = 50%	281 (93.4)	97.6 (0.4)	93.8 (0.0)	89.2 (−0.4)	91.3 (−0.1)		94.9 (0.3)	16.7 (−1.9)	
	N−95	Never	143 (47.5)	21.7 (−3.4)	51.8 (0.7)	66.3 (2.5)	52.2 (0.3)	$P < 0.001$ $V = 0.34$	46.8 (−0.2)	83.3 (1.3)	$P = 0.332$ $V = 0.10$
		< 50%	37 (12.3)	3.6 (−2.3)	11.6 (−0.2)	21.7 (2.4)	13.0 (0.1)		12.5 (0.1)	0.0 (−0.9)	
		> = 50%	121 (40.2)	74.7 (5.0)	36.6 (−0.6)	12.0 (−4.1)	34.8 (−0.4)		40.7 (0.1)	16.7 (−0.9)	
	Face shields/googles	Never	153 (50.8)	13.3 (−4.8)	66.1 (2.3)	69.9 (2.4)	43.5 (−0.5)	$P < 0.001$ $V = 0.42$	50.2 (−0.2)	83.3 (1.1)	$P = 0.408$ $V = 0.10$
		< 50%	37 (12.3)	6.0 (−1.6)	10.7 (−0.5)	15.7 (0.9)	30.4 (2.5)		12.5 (0.1)	0.0 (−0.9)	
		> = 50%	111 (36.9)	80.7 (6.6)	23.2 (−2.4)	14.5 (−3.4)	26.1 (−0.9)		37.3 (0.1)	16.7 (−0.8)	
	Gowns	Never	162 (53.8)	20.5 (−4.1)	67.9 (2.0)	71.1 (2.1)	43.5 (−0.7)	$P < 0.001$ $V = 0.37$	52.9 (−0.2)	100.0 (1.5)	$P = 0.088$ $V = 0.13$
		< 50%	27 (9.0)	3.6 (−1.6)	8.9 (0.0)	12.0 (0.9)	17.4 (1.4)		9.2 (0.1)	0.0 (−0.7)	
		> = 50%	112 (37.2)	75.9 (5.8)	23.2 (−2.4)	16.9 (−3.0)	39.1 (0.2)		38.0 (0.2)	0.0 (−1.5)	
	Coverall suit	Never	197 (65.4)	20.5 (−5.1)	81.3 (2.1)	88.0 (2.5)	69.6 (0.2)	$P < 0.001$ $V = 0.46$	65.1 (−0.1)	83.3 (0.5)	$P = 0.774$ $V = 0.06$
		< 50%	18 (6.0)	3.6 (−0.9)	7.1 (0.5)	6.0 (0.0)	8.7 (0.5)		6.1 (0.1)	0.0 (−0.6)	
		> = 50%	86 (28.6)	75.9 (8.1)	11.6 (−3.4)	6.0 (−3.8)	21.7 (−0.6)		28.8 (0.1)	16.7 (−0.6)	
	Head cap	Never	160 (53.2)	16.9 (−4.5)	56.3 (0.5)	79.5 (3.3)	73.9 (1.4)	$P < 0.001$ $V = 0.35$	52.5 (−0.2)	83.3 (1.0)	$P = 0.463$ $V = 0.09$
		< 50%	17 (5.6)	8.4 (1.1)	4.5 (−0.5)	3.6 (−0.8)	8.7 (0.6)		5.8 (0.1)	0.0 (−0.6)	
		> = 50%	124 (41.2)	74.7 (4.8)	39.3 (−0.3)	16.9 (−3.5)	17.4 (−1.8)		41.7 (0.1)	16.7 (−0.9)	
	Shoe covers	Never	211 (70.1)	27.7 (−4.6)	85.7 (2.0)	89.2 (2.1)	78.3 (0.5)	$P < 0.001$ $V = 0.41$	69.8 (−0.1)	83.3 (0.4)	$P = 1.000$ $V = 0.05$
		< 50%	25 (8.3)	19.3 (3.5)	5.4 (−1.1)	2.4 (−1.9)	4.3 (−0.7)		8.5 (0.1)	0.0 (−0.7)	
		> = 50%	65 (21.6)	53.0 (6.2)	8.9 (−2.9)	8.4 (−2.6)	17.4 (−0.4)		21.7 (0.0)	16.7 (−0.3)	

SR standardized residuals, High-Pathogen Designated Areas (*HPDA*), General High-Risk Areas (*GHR*), Medium-Risk Clinical Areas (*MRCA*), Low-Risk Support Areas (*LRS*), *HCPs* health care professionals, *SS* supporting staff, *AGE* Aerosol Generating Procedures. Statistical significance (*P*-values) and effect sizes (Cramér's V) are included to illustrate the strength of the association between workplace designation and protocol compliance pronounced for gloves, where adherence among supporting staff was only 16.7% compared to 94.9% among healthcare professionals. While trends suggested lower utilization of gowns, face shields, and coverall suits among supporting staff, these differences did not reach statistical significance (Table 4).

PPE use during contact with patient materials and surfaces

During interactions with patient materials and surrounding surfaces, medical masks were the most consistently used PPE. Adherence for mask use during material handling and surface contact was 89.1% and 85.7%, respectively, with utilization increasing significantly from LRS to HPDA ($P<0.001$, $V=0.14$). Single-use gloves were the second most common PPE, used by 73.5% of participants during material interactions and 63.1% during surface contact. Glove utilization in LRS was approximately 31–32%, rising sharply to over 89% in HPDA settings ($P<0.001$, $V=0.27$–0.28).Specialized respiratory protection remained low across both environmental domains, with only 32.2% of participants using N95 respirators during material interactions and 38.1% during surface contact. However, utilization was consistently higher in HPDA zones (up to 80.2%) compared to non-specialized areas ($P<0.001$, $V=0.37$–0.40). Other PPE items, including face shields, disposable gowns, coverall suits, head caps, and shoe covers, were used by only 10–30% of participants for more than half of interactions, with even lower adherence in non-designated areas.

Chi-square analysis revealed significant associations between work site and utilization of all PPE items ($P<0.001$ for all), with very strong effect sizes for coverall suits ($V=0.47$–0.50), face shields ($V=0.44$–0.46), and shoe covers ($V=0.37$–0.42). Participants in HPDA settings demonstrated significantly higher adherence rates ($\geq 50\%$), characterized by strong positive standardized residuals for coverall suits (SR = 13.0 for materials, 11.6 for surfaces), face shields (SR = 11.7 for materials, 10.2 for surfaces), and disposable gowns (SR = 10.1 for materials). Regarding professional categories, healthcare professionals generally reported higher PPE utilization than supporting staff. Significant associations were noted for medical masks and gloves during handling of patient materials ($P=0.028$, $V=0.10$ and $P=0.013$, $V=0.12$, respectively). Coverall suit usage during surface contact showed a significant difference by occupation ($P=0.003$, Cramér's $V=0.168$). No significant associations were found between professional category and the use of other PPE items during these environmental interactions (Table 5).

Hand hygiene practices of infected HCWs

Before direct face-to-face patient contact, 49.3% of participants practiced hand hygiene for more than half of interactions. Adherence increased to 72.6% following direct patient contact and reached 82.5% after contact with environmental surfaces. Comparative analysis revealed a consistent increase in hand hygiene compliance from LRS to HPDA. Compliance rates for performing hand hygiene for more than half of interactions improved from 32.1 to 62.9% before direct patient contact, from 51.9 to 81.1% after direct contact, and from 60.4 to 88.8% after surface contact. After contact with patient body fluids, 87.7% of participants adhered to hand hygiene practices. These rates remained notably high across all work sites: 91.3% in LRS, 84.3% in MRCA, 89.3% in GHR, and 88.0% in HPDA. Chi-square analysis revealed significant associations between hand hygiene practices and work site ($P<0.001$ for most interactions), with the notable exception of hand hygiene following contact with body fluids ($P=0.215$). Participants in HPDA demonstrated the highest adherence before direct patient contact [(SR) =2.4]. Conversely, staff in LRS were significantly more likely to report never performing hand hygiene before direct contact (SR = 3.3), after direct contact (SR = 4.8), or after exposure to body fluids (SR = 3.7).

A significant disparity in hand hygiene practices was identified between healthcare professionals and supporting staff. Before face-to-face contact, 50.6% of healthcare professionals adhered to hand hygiene protocols for more than half of interactions, compared to 29.8% of supporting staff. This gap was most pronounced after exposure to body fluids, with compliance rates of 89.2% for healthcare professionals versus 16.7% for supporting staff. Supporting staff were nearly 3.5 times more likely than professionals to never perform hand hygiene after direct contact (42.6% vs. 12.4%; SR = 5.1). Statistical analysis confirmed significant differences in compliance across all interactions ($P<0.001$ for all). Supporting staff were significantly more likely to report never performing hand hygiene before contact (SR = 2.9), after contact (SR = 5.1), following exposure to body fluids (SR = 1.5), and after surface contact (SR = 2.7). Alcohol-based hand rub was the most common method used across all patient interactions (Table 6).

Discussion

This study evaluated IPC adherence among COVID-19–infected HCWs during the 14 days preceding their diagnosis. Key findings included suboptimal use of fluid-resistant PPE, reactive hand hygiene patterns (higher after contact than before), significant gaps in N95 seal-checking, N95 fit testing, and donning/doffing

Table 5 Adherence to personal protective equipment utilization during contact with patient materials and contaminated surfaces stratified by clinical setting and professional role in Addis Ababa, Ethiopia from March 2020 to March 2021

Exposure Modality	Type of PPE	PPE use	Total *N* (%)	Place of work before the diagnosis of COVID 19					Occupation		
				HPDA	GHR	MRCA	LRS	χ2 p-value, V	HCPs	SS	χ2 p-value, V
				% (SR)	% (SR)	% (SR)	% (SR)		% (SR)	% (SR)	
PPE use during contact with patient materials (n = 631)	Medical mask	Never	39 (6.2)	2.8 (−1.6)	3.2 (−1.8)	8.2 (1.2)	18.3 (3.8)	$P<0.001$ $V=0.14$	5.9 (-0.2)	9.8 (0.9)	$P=0.028$ $V=0.102$
		< 50%	30 (4.8)	2.1 (−1.4)	4.1 (−0.5)	4.3 (−0.3)	15.0 (3.6)		4.2 (−0.6)	12.2 (2.2)	
		> = 50%	562 (89.1)	95.0 (0.8)	92.8 (0.6)	87.5 (−0.2)	66.7 (−1.8)		89.8 (0.2)	78.0 (−0.8)	
	Single use gloves	Never	117 (18.5)	6.4 (−3.4)	13.1 (−1.9)	21.6 (1.0)	56.7 (6.9)	$P<0.001$ $V=0.27$	17.3 (−0.7)	36.6 (2.7)	$P=0.013$ $V=0.123$
		< 50%	50 (7.9)	4.3 (−1.6)	5.9 (−1.1)	11.5 (1.9)	11.7 (1.0)		8.1 (0.2)	4.9 (−0.7)	
		> = 50%	464 (73.5)	89.4 (2.2)	81.1 (1.3)	66.8 (−1.1)	31.7 (−3.8)		74.6 (0.3)	58.5 (−1.1)	
	N-95	Never	343 (54.4)	16.3 (−6.1)	55.4 (0.2)	72.1 (3.5)	78.3 (2.5)	$P<0.001$ $V=0.40$	53.7 (−0.2)	63.4 (0.8)	$P=0.195$ $V=0.072$
		< 50%	85 (13.5)	6.4 (−2.3)	15.8 (0.9)	15.4 (0.8)	15.0 (0.3)		13.2 (−0.2)	17.1 (0.6)	
		> = 50%	203 (32.2)	77.3 (9.5)	28.8 (−0.9)	12.5 (−5.0)	6.7 (−3.5)		33.1 (0.4)	19.5 (−1.4)	
	Faceshields/googles	Never	418 (66.2)	21.3 (−6.6)	74.8 (1.6)	82.7 (2.9)	83.3 (1.6)	$P<0.001$ $V=0.44$	66.1 (0.0)	68.3 (0.2)	$P=0.772$ $V=0.026$
		< 50%	66 (10.5)	7.8 (−1.0)	13.5 (1.4)	8.2 (−1.0)	13.3 (0.7)		10.3 (−0.1)	12.2 (0.3)	
		> = 50%	147 (23.3)	70.9 (11.7)	11.7 (−3.6)	9.1 (−4.2)	3.3 (−3.2)		23.6 (0.1)	19.5 (−0.5)	
	Gowns	Never	444 (70.4)	31.2 (−5.5)	76.6 (1.1)	86.1 (2.7)	85.0 (1.4)	$P<0.001$ $V=0.38$	70.5 (0.0)	68.3 (−0.2)	$P=0.697$ $V=0.031$
		< 50%	56 (8.9)	9.2 (0.1)	11.7 (1.4)	4.3 (−2.2)	13.3 (1.2)		8.6 (−0.2)	12.2 (0.7)	
		> = 50%	131 (20.8)	59.6 (10.1)	11.7 (−3.0)	9.6 (−3.5)	1.7 (−3.3)		20.8 (0.1)	19.5 (−0.2)	
	Coverall suit	Never	488 (77.3)	31.9 (−6.1)	86.0 (1.5)	94.7 (2.9)	91.7 (1.3)	$P<0.001$ $V=0.47$	77.5 (0.0)	75.6 (−0.1)	$P=0.092$ $V=0.089$
		< 50%	43 (6.8)	8.5 (0.8)	8.6 (1.0)	3.8 (−1.6)	6.7 (0.0)		6.3 (−0.5)	14.6 (1.9)	
		> = 50%	100 (15.8)	59.6 (13.0)	5.4 (−3.9)	1.4 (−5.2)	1.7 (−2.8)		16.3 (0.3)	9.8 (−1.0)	
	Head cap	Never	404 (64.0)	27.7 (−5.4)	68.9 (0.9)	77.4 (2.4)	85.0 (2.0)	$P<0.001$ $V=0.32$	63.4 (−0.2)	73.2 (0.7)	$P=0.508$ $V=0.050$
		< 50%	40 (6.3)	7.1 (0.4)	5.9 (−0.3)	5.3 (−0.6)	10.0 (1.1)		6.4 (0.1)	4.9 (−0.4)	
		> = 50%	187 (29.6)	65.2 (7.8)	25.2 (−1.2)	17.3 (−3.3)	5.0 (−3.5)		30.2 (0.2)	22.0 (−0.9)	
	Shoe covers	Never	515 (81.6)	46.8 (−4.6)	88.3 (1.1)	94.7 (2.1)	93.3 (1.0)	$P<0.001$ $V=0.37$	81.5 (0.0)	82.9 (0.1)	$P=1.000$ $V=0.010$
		< 50%	47 (7.4)	14.2 (2.9)	7.2 (−0.1)	3.4 (−2.2)	6.7 (−0.2)		7.5 (0.0)	7.3 (0.0)	
		> = 50%	69 (10.9)	39.0 (10.1)	4.5 (−2.9)	1.9 (−3.9)	0.0 (−2.6)		11.0 (0.1)	9.8 (−0.2)	

Table 5 (continued)

Exposure Modality	Type of PPE	PPE use	Total *N* (%)	Place of work before the diagnosis of COVID 19					Occupation		
				HPDA	GHR	MRCA	LRS	χ2 p-value, V	HCPs	SS	χ2 p-value, V
				% (SR)	% (SR)	% (SR)	% (SR)		% (SR)	% (SR)	
PPE use during contact with patient surfaces around patients ($n=491$)	Medical mask	Never	47 (9.6)	4.3 (−1.8)	5.7 (−1.6)	11.8 (0.9)	29.2 (4.4)	$P<0.001$ $V=0.14$	9.5 (−0.1)	11.1 (0.3)	$P=0.431$ $V=0.052$
		< 50%	23 (4.7)	3.4 (−0.6)	4.6 (−0.1)	5.2 (0.3)	6.3 (0.5)		4.4 (−0.3)	8.3 (1.0)	
		> = 50%	421 (85.7)	92.2 (0.8)	89.7 (0.6)	83.0 (−0.4)	64.6 (−1.6)		86.2 (0.1)	80.6 (−0.3)	
	Single use gloves	Never	145 (29.5)	4.3 (−5.0)	26.4 (−0.8)	41.2 (2.7)	64.6 (4.5)	$P<0.001$ $V=0.28$	28.4 (−0.5)	44.4 (1.7)	$P=0.136$ $V=0.092$
		< 50%	36 (7.3)	4.3 (−1.2)	6.9 (−0.2)	11.1 (1.7)	4.2 (−0.8)		7.5 (0.1)	5.6 (−0.4)	
		> = 50%	310 (63.1)	91.4 (3.8)	66.7 (0.6)	47.7 (−2.4)	31.3 (−2.8)		64.2 (0.3)	50.0 (−1.0)	
	N-95	Never	234 (47.7)	12.1 (−5.6)	50.0 (0.5)	64.7 (3.1)	70.8 (2.3)	$P<0.001$ $V=0.37$	47.0 (−0.2)	55.6 (0.7)	$P=0.207$ $V=0.078$
		< 50%	70 (14.3)	7.8 (−1.9)	16.7 (0.8)	17.6 (1.1)	10.4 (−0.7)		13.8 (−0.2)	19.4 (0.8)	
		> = 50%	187 (38.1)	80.2 (7.4)	33.3 (−1.0)	17.6 (−4.1)	18.8 (−2.2)		39.1 (0.4)	25.0 (−1.3)	
	Face shields	Never	316 (64.4)	15.5 (−6.6)	76.4 (2.0)	82.4 (2.8)	81.3 (1.5)	$P<0.001$ $V=0.46$	64.2 (−0.1)	66.7 (0.2)	$P=0.300$ $V=0.071$
		< 50%	52 (10.6)	12.1 (0.5)	11.5 (0.4)	8.5 (−0.8)	10.4 (0.0)		10.1 (−0.3)	16.7 (1.1)	
		> = 50%	123 (25.1)	72.4 (10.2)	12.1 (−3.4)	9.2 (−3.9)	8.3 (−2.3)		25.7 (0.3)	16.7 (−1.0)	
	Gowns	Never	345 (70.3)	23.3 (−6.0)	81.6 (1.8)	88.9 (2.8)	83.3 (1.1)	$P<0.001$ $V=0.45$	70.1 (0.0)	72.2 (0.1)	$P=0.137$ $V=0.091$
		< 50%	45 (9.2)	13.8 (1.7)	8.6 (−0.2)	5.9 (−1.3)	10.4 (0.3)		8.6 (−0.4)	16.7 (1.5)	
		> = 50%	101 (20.6)	62.9 (10.1)	9.8 (−3.1)	5.2 (−4.2)	6.3 (−2.2)		21.3 (0.4)	11.1 (−1.3)	
	Coverall suit	Never	373 (76.0)	25.9 (−6.2)	89.1 (2.0)	94.1 (2.6)	91.7 (1.3)	$P<0.001$ $V=0.50$	76.0 (0.0)	75.0 (−0.1)	$P=0.003$ $V=0.168$
		< 50%	31 (6.3)	11.2 (2.1)	5.2 (−0.6)	3.9 (−1.2)	6.3 (0.0)		5.3 (−0.9)	19.4 (3.1)	
		> = 50%	87 (17.7)	62.9 (11.6)	5.7 (−3.8)	2.0 (−4.6)	2.1 (−2.6)		18.7 (0.5)	5.6 (−1.7)	
	Head cap	Never	312 (63.5)	19.0 (−6.0)	71.3 (1.3)	81.0 (2.7)	87.5 (2.1)	$P<0.001$ $V=0.39$	62.6 (−0.2)	75.0 (0.9)	$P=0.186$ $V=0.079$
		< 50%	34 (6.9)	12.1 (2.1)	4.6 (−1.2)	5.9 (−0.5)	6.3 (−0.2)		6.8 (−0.1)	8.3 (0.3)	
		> = 50%	145 (29.5)	69.0 (7.8)	24.1 (−1.3)	13.1 (−3.8)	6.3 (−3.0)		30.5 (0.4)	16.7 (−1.4)	
	Shoe covers	Never	389 (79.2)	37.1 (−5.1)	92.5 (2.0)	92.8 (1.9)	89.6 (0.8)	$P<0.001$ $V=0.42$	79.1 (0.0)	80.6 (0.1)	$P=0.275$ $V=0.074$
		< 50%	42 (8.6)	21.6 (4.8)	4.6 (−1.8)	3.9 (−2.0)	6.3 (−0.6)		8.1 (−0.3)	13.9 (1.1)	
		> = 50%	60 (12.2)	41.4 (9.0)	2.9 (−3.5)	3.3 (−3.2)	4.2 (−1.6)		12.7 (0.3)	5.6 (−1.1)	

SR standardized residuals, High-Pathogen Designated Areas (*HPDA*), General High-Risk Areas (*GHR*), Medium-Risk Clinical Areas (*MRCA*), Low-Risk Support Areas (*LRS*), *HCPs* health care professionals, *SS* supporting staff. Statistical significance (*P*-values) and effect sizes (Cramér's V) are included to illustrate the strength of the association between workplace designation and protocol compliance

Table 6 Adherence to hand hygiene practices among healthcare personnel stratified by clinical setting and professional role in Addis Ababa, Ethiopia from March 2020 to March 2021

Hand hygiene practice		Total *N* (%)	Place of work before the diagnosis of COVID 19				Occupation	
			HPDA	GHR	MRCA	LRS	HCPs	SSs
			% (SR)	% (SR)	% (SR)	% (SR)	% (SR)	% (SR)
Hand hygiene practice before direct face to face contact	Never	212 (28.6)	15.7 (−3.0)	24.6 (−1.2)	34.6 (1.8)	48.1 (3.3)	27.1 (−0.8)	51.1 (2.9)
	< 50%	164 (22.1)	21.4 (−0.2)	23.4 (0.5)	22.0 (−0.1)	19.8 (−0.5)	22.3 (0.1)	19.1 (−0.4)
	> = 50%	366 (49.3)	62.9 (2.4)	52.0 (0.6)	43.5 (−1.3)	32.1 (−2.2)	50.6 (0.5)	29.8 (−1.9)
	χ2 (Cramér's V)		*P* < 0.001 (*V* = 0.16)				*P* = 0.002 (*V* = 0.13)	
Material used during hand hygiene practice before direct face to face contact	Alcohol	449 (84.7)	85.8 (0.1)	81.3 (−0.5)	88.2 (0.5)	83.3 (−0.1)	85.0 (0.1)	78.3 (−0.3)
	Soap and water	77 (14.5)	14.2 (−0.1)	18.1 (1.3)	10.6 (−1.3)	14.3 (−0.0)	14.2 (−0.19)	21.7 (0.9)
	Water	4 (0.8)	0.0 (−1.0)	0.5 (−0.4)	1.2 (0.7)	2.4 (1.2)	0.8 (0.1)	0.0 (−0.4)
	χ2 (Cramér's V)		*P* = 0.231 (*V* = 0.08)				*P* = 0.465 (*V* = 0.046)	
Hand hygiene practice after direct face to face contact	Never	106 (14.3)	11.3 (−1.0)	8.6 (−2.4)	15.4 (0.5)	34.6 (4.8)	12.4 (−1.3)	42.6 (5.1)
	< 50%	97 (13.1)	7.5 (−1.9)	14.8 (0.8)	14.6 (0.7)	13.6 (0.1)	13.1 (0.0)	12.8 (−0.1)
	> = 50%	539 (72.6)	81.1 (1.3)	76.6 (0.7)	69.9 (−0.5)	51.9 (−2.2)	74.5 (0.6)	44.7 (−2.3)
	χ2 (Cramér's V)		*P* < 0.001 (*V* = 0.15)				*P* < 0.001 (*V* = 0.21)	
Material used during hand hygiene practice after direct face to face contact	Alcohol	485 (76.5)	74.3 (−0.3)	78.2 (0.3)	76.8 (0.1)	73.6 (−0.2)	76.8 (0.1)	70.4 (−0.3)
	Soap and water	146 (23.0)	25.7 (0.7)	21.8 (−0.4)	22.2 (−0.2)	24.5 (0.2)	22.7 (−0.2)	29.6 (0.9)
	Water	3 (0.5)	0.0 (−0.8)	0.0 (−1.1)	1.0 (1.0)	1.9 (1.5)	0.5 (0.1)	0.0 (−0.4)
	χ2 (Cramér's V)		*P* = 0.421 (*V* = 0.07)				*P* = 0.465 (*V* = 0.05)	
Hand hygiene practice after contact with body fluids	Never	13 (4.3)	2.4 (−0.8)	1.8 (−1.3)	9.6 (2.3)	4.3 (0.0)	4.1 (−0.2)	16.7 (1.5)
	< 50%	24 (8.0)	9.6 (0.5)	8.9 (0.4)	6.0 (−0.6)	4.3 (−0.6)	6.8 (−0.7)	66.7 (5.1)
	> = 50%	264 (87.7)	88.0 (0.0)	89.3 (0.2)	84.3 (−0.3)	91.3 (0.2)	89.2 (0.3)	16.7 (−1.9)
	χ2 (Cramér's V)		*P* = 0.215 (*V* = 0.12)				*P* < 0.001 (*V* = 0.33)	
Material used during hand hygiene practice after contact with body fluids	Alcohol	206 (71.5)	69.1 (−0.3)	70.9 (−0.1)	73.3 (0.2)	77.3 (0.3)	71.4 (−0.0)	80.0 (0.2)
	Soap and water	82 (28.5)	30.9 (0.4)	29.1 (0.1)	26.7 (−0.3)	22.7 (−0.5)	28.6 (0.0)	20.0 (−0.4)
	χ2 (Cramér's V)		*P* = 0.867 (*V* = 0.05)				*P* = 1.000 (*V* = −0.03)	
Hand hygiene practice after contact with surfaces	No	86 (17.5)	11.2 (−1.6)	12.6 (−1.5)	20.9 (1.0)	39.6 (3.7)	16.0 (−0.8)	36.1 (2.7)
	Yes	405 (82.5	88.8 (0.8)	87.4 (0.7)	79.1 (−0.5)	60.4 (−1.7)	84.0 (0.4)	63.9 (−1.2)
	χ2 (Cramér's V)		*P* < 0.001 (*V* = 0.22)				*P* < 0.001 (*V* = −0.14)	
Material used during hand hygiene practice after contact with surfaces	Alcohol	323 (79.8)	73.8 (−0.7)	83.6 (0.5)	84.3 (0.6)	62.1 (−1.1)	79.8 (0.0)	78.3 (−0.1)
	Soap and water	82 (20.2)	26.2 (1.4)	16.4 (−1.0)	15.7 (−1.1)	37.9 (2.1)	20.2 (−0.0)	21.7 (0.2)
	χ2 (Cramér's V)		*P* = 0.013 (*V* = 0.16)				*P* = 0.793 (*V* = 0.01)	

SR standardized residuals, High-Pathogen Designated Areas (*HPDA*), General High-Risk Areas (*GHR*), Medium-Risk Clinical Areas (*MRCA*), Low-Risk Support Areas (*LRS*), *HCPs* health care professionals, *SS* supporting staff. Statistical significance (*P*-values) and effect sizes (Cramer's V) are included to illustrate the strength of the association between workplace designation and protocol compliance

procedures. A consistent gradient of adherence was observed, with superior practices in HPDA compared to non-designated areas, and among healthcare professionals compared to supporting staff. After multivariable logistic regression, among HCWs with direct face-to-face contact, donning and doffing adherence was significantly associated with work site, IPC training, professional category, and involvement in AGPs. In contrast, among those who used N95 respirators during face-to-face contact, pre-use seal-check adherence was associated with work site, age (> 30), stress, communal living, IPC training, and AGPs.

A significant majority of study participants (80.8 percent) were working in clinical areas not specifically designated for infectious disease care, indicating that the primary risk of infection resided within the general hospital environment rather than high-containment units [28]. This reveals a critical "protection gap" where lower perceived risk relaxed IPC vigilance compared to dedicated units [29]. These findings suggest that future pandemic preparedness could benefit from evaluating a more distributed deployment of IPC measures across all patient-facing environments, rather than restricting these intensive resources exclusively to designated high-risk units. Furthermore, the infection rate in low risk areas and among supporting staffs highlights a vulnerability to horizontal transmission in shared, non-clinical spaces where standard precautions are frequently deprioritized [29, 30].

Mask adherence

Our observed mask adherence (85.7–97.7%) mirrors rates reported in Addis Ababa and Eastern Ethiopia [31–33], yet exceeds figures from other parts of the country [34, 35], an urban–rural disparity likely driven by superior resource availability and heightened risk perception in urban centers during the pandemic peak [36]. Furthermore, healthcare professionals demonstrated greater adherence than supporting staff, a socio-professional discrepancy previously documented in regional health facilities [37]. We also identified a distinct spatial gradient, with compliance significantly higher in designated high-risk units than non-designated areas, consistent with global observations [38–41]. The presence of infection among these workers despite high reported adherence suggests either localized protocol relaxation in communal, staff-only zones driving peer-to-peer transmission, or an artifact of social desirability bias inflating self-reported compliance [42, 43].

Glove adherence

Glove adherence was high during AGPs (98.0%) but lower during surface contact (63.1%), exceeding studies from Uganda and Southwest Ethiopia [38, 44]. However, these figures trail the near-universal compliance observed in Burkina Faso, Saudi Arabia, Pakistan, and China [41, 45–47]. A pronounced gradient also emerged, with adherence significantly higher in designated areas—a pattern mirroring trends in Uganda and Ghana that is likely driven by risk perception [38, 45, 48]. Furthermore, the wide professional gap in glove use during exposure to bodily fluids isolates support staff handling infectious waste as the most vulnerable cohort, reflecting inequities in safety training and systemic exclusion from formal IPC orientation. Conversely, lower compliance during surface contact might suggest habituation to low-threat tasks or a failure to recognize the built environment as a viable transmission vector [49].

N95 respirator utilization and fit testing

N95 respirator utilization was higher during AGPs (66.5%) than during face-to-face contact (< 40%), exceeding figures from Nigeria (< 10%) but mirroring baseline trends in Addis Ababa (21.2%) [32, 50]. A profound systemic gap was the near-total absence of formal fit testing; 98.9% of HCWs had never been tested, representing an implementation deficit far wider than those reported in Qatar and Australia [51, 52]. Furthermore, 65% of respondents failed to perform pre-use seal checks, a failure rate notably higher than in Nepal [53]. This dual absence of fit-testing and routine seal checks critically compromises sealing integrity, rendering N95s functionally equivalent to standard surgical masks [54, 55]. This fosters a false sense of security among personnel, as peripheral leakage entirely bypasses the respirator's superior filtration media [56]. Consequently, public health authorities in resource-limited settings should prioritize pairing respirator procurement with qualitative fit-testing infrastructure to ensure functional safety barriers during future airborne health crises.

Determinants of seal-check adherence

Multivariable analysis identified work site as the primary determinant of pre-use seal-check adherence, alongside age, acute stress, communal living, IPC training, and AGP involvement. Personnel in HPDA exhibited superior compliance, driven by heightened institutional safety cultures and peer accountability, whereas those in general wards operated under a false sense of security. This indicates that environmental context often overrides procedural necessity, leading to a relaxation of WHO-recommended protocols despite uniform biological risks [57]. Conversely, HCWs aged over 30 years had lower adherence odds, potentially reflecting generational gaps in recent training or lower risk perception. Compliance was also heavily compromised by acute stress, which likely impairs the cognitive bandwidth and attention to detail required for precision safety steps, suggesting that institutional mental health support could be a direct driver of IPC adherence [11]. Interestingly, cohabiting with family or a community more than doubled adherence odds, a phenomenon likely driven by an 'altruistic protection' mechanism to safeguard household members. Finally, the positive impact of IPC training and AGP involvement underscores how high-risk procedural exposure reinforces perceived severity and safety hygiene. Ultimately, advancing healthcare safety cultures requires shifting beyond technical training to address the environmental and psychological barriers—such as stress and location-based risk misperceptions—that hinder universal N95 compliance.

Donning and doffing adherence

Errors in donning and doffing PPE critically drive autoinoculation and pathogen transmission to HCWs [58, 59]. Descriptively, we observed a distinct knowledge-behavior gap across roles: supporting staff primarily exhibited a knowledge deficit (53.1% unaware of procedural steps), whereas healthcare professionals demonstrated a behavioral disconnect (7.3% unaware but 56.8% non-compliant). While these descriptive differences align with literature from Nepal and Saudi Arabia linking profession to baseline knowledge [60] [61], professional category lost significance after multivariable adjustment, suggesting that supporting staff require basic education while HCPs need active implementation support. Instead, multivariable analysis established work site as the primary determinant of compliance, capturing a severe adherence decay outside specialized units that trails metrics from Saudi Arabia, India, and Canada [60, 62, 63]. Compared to HPDA, personnel in GHR; AOR 0.12 (0.07–0.19), MRCA; AOR 0.08 (0.04–0.14), and LRS; AOR 0.07 (0.03–0.17) exhibited 88–93% lower odds of proper technique. This steep spatial gradient likely reflects the high cognitive load of doffing, which frequently coincides with end-of-shift fatigue when physical exhaustion peaks alongside self-contamination risks [64]; conversely, designated units benefit from a more rigorous technical culture and stringent peer supervision [40]. Ultimately, the independent predictive power of AGP involvement [AOR 3.61 (2.33–5.58)] and prior IPC training [AOR 1.59 (1.05–2.41)] reinforces the perspective that heightened risk perception and institutional reinforcement remain central to sustaining protective clinical behaviors [65].

Eye protection

Although systematic reviews establish that mandatory eye protection significantly reduces infection risks among HCWs [66], utilization across the different interactions with patients was low (23–52.8%). Adherence peaked during AGPs and direct face-to-face contact but dropped during body fluid exposure, surface decontamination, and material handling, suggesting that personnel prioritize eye protection only when splash or inhalation threats are immediately visible. These low rates align with data from South Wollo (31.9%) and Addis Ababa (19%), Ethiopia [32, 67], and mirror suboptimal adherence trends in Burkina Faso (1.56%), Pakistan (45%), and Saudi Arabia (68%), while contrasting sharply with the 100% compliance reported among Korean frontline nurses [45–47, 68]. This widespread omission likely stems from documented practical barriers, such as fogging-induced visibility impairment, alongside heat and dehydration issues reported by up to 76% of participants in similar climates [69]. Furthermore, neglecting eye protection during surface and material manipulation highlights a failure to recognize the built environment as a viable transmission vehicle. Ultimately, this risk-dependent, inconsistent approach likely compounds the vulnerability of staff in non-specialized wards where standard precautions are routinely deprioritized [70].

Fluid-resistant PPE

Utilization of disposable gowns, coverall suits, head caps, and shoe covers averaged below 50% across most patient interactions, though compliance scaled progressively from non-designated units to HPDA. This low adherence mirrors trends in Addis Ababa (hair protection: 18%, gown: 72.4%) [33] and Southwest Ethiopia (39.8%) [44], but trails the high gown utilization reported in Korea (98%), Burkina Faso (95.6%), Pakistan (90%), and Saudi Arabia (85%) [45–47] [68]. This global–local disparity is likely driven by systemic supply constraints, which act as a primary barrier in resource-limited settings even among personnel with robust conceptual IPC knowledge [71]. During bodily fluid exposure, a stark precaution gap emerged: while mask and glove compliance was high (97.7%), over 70% of staff omitted shoe covers and more than 50% lacked gowns or shields. This behavior was heavily dictated by institutional geography rather than objective biological risk; compliance was rigorously maintained within designated units but declined precipitously across all non-designated areas. This spatial disparity misaligns with epidemiological realities, given that patient care vectors within non-designated wards remain highly infectious. Furthermore, support staff handling contaminated materials demonstrated significantly lower adherence than health care professionals ($P < 0.001$; glove usage: 58.5% vs. 74.6%, $P = 0.013$). Ultimately, these findings underscore a critical vulnerability where HCW risk perception is tethered to professional status and administrative zone labels rather than the objective presence of pathogens.

Hand hygiene practice

Hand hygiene adherence was heavily reactive, ranging from 49.3% before face-to-face contact to 82.5% following bodily fluid exposure. These metrics trail superior adherence benchmarks in Nigeria and India while matching trends observed in Greece [72–74]. Locally, our results contextualize a multicenter Ethiopian pandemic compliance rate of 81.4% [75], a national pooled baseline of 38%, and a higher Addis Ababa subgroup performance of 73% [76]. Globally, post-pandemic interventions elevated overall compliance to 74% from historical baselines spanning 5% to 89% [58]. In our study, adherence was highest (> 80%) following contact with body fluids or contaminated surfaces. Crucially, the marked decline from 74.4% post-interaction to 49.3% pre-contact echoes global meta-analytical evidence that HCWs prioritize self-protection over patient safety [58], escalating cross-contamination risks when perceived acquisition threats are low [65, 77]. Such reactive adherence patterns create a significant window for healthcare associated infections, as the most critical step for preventing cross contamination, hand hygiene prior to contact, remains the least practiced. While HPDA generally exhibited superior adherence, aligning with university hospital data from Germany and Uganda [38, 40], we identified a unique 'Body Fluid Exception' where institutional geography had no significant impact ($P=0.215$). This might suggest that the visceral trigger of visible fluids or disgust acts as an innate psychological modifier that completely overrides administrative ward classifications. Conversely, professional role introduced severe compliance disparities; healthcare professionals maintained significantly better compliance than support staff, mirroring trends in Ghana, Uganda, and Somalia [39, 78]. The dramatic collapse from 89.2% among healthcare professionals to 16.7% among support staff after fluid exposure reveals a staggering 72.5% gap. Because support personnel routinely manipulate heavily contaminated waste and linens, this profound discrepancy exposes a critical, unaddressed institutional transmission pathway.

Policy implications and speculations for future pandemic preparedness

The strong institutional gradient across adherence measures demonstrates that IPC compliance is shaped by environmental context, risk perception, and psychological states rather than clinical knowledge alone. To close the "protection gap" where most infections occurred, future preparedness frameworks should mandate universal minimum IPC standards across all clinical areas, regardless of administrative designation. Interventions should leverage collectivist altruism by framing safety protocols around family preservation rather than self-protection, while integrating stress-reduction elements into training to safeguard cognitive bandwidth. Furthermore, systemic vulnerabilities must be addressed by securing fit-testing infrastructure within respirator procurement budgets, mitigating transmission in shared staff spaces like breakrooms, and eliminating socio-professional inequities through inclusive training and equitable PPE allocation for support staff. Finally, to counteract the high cognitive load and fatigue of end-of-shift doffing, passive protocols should be reinforced with practical, real-world safeguards like visual checklists and peer-audited buddy systems.

Limitations of the study

Several limitations contextually frame our findings. First, the cross-sectional design precludes causal inference, capturing epidemiological associations rather than definitive causal pathways. Second, selecting an infected-only HCW cohort introduces selection bias, as risk perceptions and compliance behaviors may systematically diverge from uninfected peers, while an inherent "healthy worker effect", omitting personnel who were severely ill, deceased, or left employment—potentially underestimates true institutional risks. Third, the restriction to Addis Ababa limits nationwide generalizability, as capital-city resources, caseloads, and training access differ substantially from rural hospitals. Similarly, the single-country setting and early temporal window (March 2020–March 2021) restrict generalizability to external healthcare systems or current stable contexts with normalized PPE supply chains and stabilized IPC guidelines. Additionally, non-participation bias remains possible if non-responders maintained systematically distinct behaviors.Fourth, information and measurement bias cannot be excluded; lacking objective direct observations, our data rely on self-reports vulnerable to social desirability and 14-day recall decay, which disproportionately impacts low-salience routine habits (e.g., hand hygiene, seal-checking) compared to memorable high-risk exposures. Furthermore, the standard but arbitrary $>50\%$ dichotomous adherence threshold may misclassify borderline compliance, suggesting a future pivot toward continuous or exposure-weighted risk metrics. Finally, despite robust multivariable adjustment, residual confounding from unmeasured variables, such as immediate point-of-care PPE availability, peer influence, individual risk perception, and pre-pandemic baseline training, remains possible.

Conclusions and recommendations

This study identifies significant protection gaps across multiple IPC domains, characterized by suboptimal N95 fit-testing, inconsistent pre-use seal checks, donning and doffing non-adherence, and reactive hand hygiene practice. These deficits form a distinct adherence gradient where better practices in designated settings prepared for high-consequence pathogens and among health professionals contrast with systemic vulnerabilities in general clinical environments and among support staff. With most infections occurring outside specialized units, primary occupational risk resides in general wards, driven by work site as an important determinant of adherence. Multivariable analysis confirms lower compliance odds in non-designated settings for both donning/doffing and pre-use seal-checks, with AGP involvement and IPC training acting as key positive predictors. To strengthen institutional resilience against high-consequence pathogens, we recommend standardization of IPC protocols across all clinical environments.

Abbreviations

AGP	Aerosol-generating procedure
AIC	Akaike Information Criterion
AOR	Adjusted odds ratio
BIC	Bayesian Information Criterion
CDC	Centers for Disease Control and Prevention
CI	Confidence interval
COVID-19	Coronavirus disease 2019
cOR	Crude odds ratio
EOC	Emergency Operating Center
ERC	Ethical Review Committee
GHR	General High-Risk Areas
HCP	Healthcare professional
HCW	Healthcare worker
HPDA	High-Pathogen Designated Areas
ICU	Intensive care unit
IPC	Infection prevention and control
IQR	Interquartile range
LRS	Low-Risk Support Areas
MRCA	Medium-Risk Clinical Areas
N95	N95 respirator
OSHA	Occupational Safety and Health Administration
PPE	Personal protective equipment
ROC-AUC	Receiver operating characteristic Area under the curve
RT-PCR	Reverse transcription polymerase chain reaction
SD	Standard deviations
SR	Standardized residual
SS	Supporting staff
VIF	Variance inflation factor
WHO	World Health Organization

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

Author contributions

ZA: conceptualization, data curation, methodology, project administration, formal analysis, investigation, visualization, software, supervision, writing of the original draft, review and editing. TE: software, formal analysis, review and editing BR: conceptualization, supervision, project administration, Funding acquisition WW: conceptualization, supervision, project administration, review and editing SG: conceptualization, Writing – original draft, review and editing AH and BE: data curation, writing original draft, review and editing MW,RWY and SY: conceptualization, supervision, resources BB: Software and formal analysis TF and ZC: conceptualization, project administration, funding acquisition, resources, supervision BH: conceptualization, data curation, formal analysis, methodology, writing original draft, review and editing.

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Data availability

Supporting data for the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This research was reviewed and approved by the Ethical Review Committee (ERC) of the Addis Ababa Health Bureau (Ref: 5204/227) in Ethiopia. Informed consent was obtained from all individual participants involved in the study

Consent for publication

Not applicable.

Competing interests

The authors declare that there are no competing interests.

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References

1. Maliszewska M, Mattoo A, Van der Mensbrugghe D. The potential impact of COVID-19 on GDP and trade: a preliminary assessment. 2020. https://doi.org/10.1596/1813-9450-9211.
2. World Health Organization. WHO COVID-19 dashboard: COVID-19 cases. 2024. https://data.who.int/dashboards/covid19/cases. Accessed 13 Nov 2024.
3. Worldometer. Ethiopia COVID - Coronavirus Statistics. 2024. https://www.worldometers.info/coronavirus/country/ethiopia/. Accessed 13 Nov 2024.
4. Guan W-J, Ni Z-Y, Hu Y, Liang W-H, Ou C-Q, He J-X, et al. Clinical characteristics of coronavirus disease 2019 in China. N Engl J Med. 2019;382:1708–20. https://doi.org/10.1056/NEJMoa2002032.
5. Cao J, Tu W-J, Cheng W, Yu L, Liu Y-K, Hu X, et al. Clinical features and short-term outcomes of 102 patients with coronavirus disease 2019 in Wuhan, China. Clin Infect Dis. 2019;71:748–55. https://doi.org/10.1093/cid/ciaa243.
6. Koontalay A, Suksatan W, Prabsangob K, Sadang JM. Healthcare workers' burdens during the COVID-19 Pandemic: a qualitative systematic review. J Multidiscip Healthc. 2021;14:3015–25. https://doi.org/10.2147/JMDH.S330041.
7. Gholami M, Fawad I, Shadan S, Rowaiee R, Ghanem H, Hassan Khamis A, et al. COVID-19 and healthcare workers: a systematic review and meta-analysis. Int J Infect Dis. 2021;104:335–46. https://doi.org/10.1016/j.ijid.2021.01.013.
8. World Health Organization Regional Office for Africa. Ethiopia declares end of first-ever Marburg virus disease outbreak. 2026. https://www.afro.who.int/countries/ethiopia/news/ethiopia-declares-end-first-ever-marburg-virus-disease-outbreak. Accessed 20 Mar 2026.
9. El-Sokkary RH, El-Kholy A, Mohy Eldin S, Khater WS, Gad DM, Bahgat S, et al. Characteristics and predicting factors of Corona Virus Disease-2019 (COVID-19) among healthcare providers in a developing country. PLoS ONE. 2019;16:e0245672. https://doi.org/10.1371/journal.pone.0245672.
10. Verbeek JH, Rajamaki B, Ijaz S, Sauni R, Toomey E, Blackwood B, et al. Personal protective equipment for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff. Cochrane Database Syst Rev. 2020;4:CD011621. https://doi.org/10.1002/14651858.CD011621.pub4.
11. Houghton C, Meskell P, Delaney H, Smalle M, Glenton C, Booth A, et al. Barriers and facilitators to healthcare workers' adherence with infection prevention and control (IPC) guidelines for respiratory infectious diseases: a rapid qualitative evidence synthesis. Cochrane Database Syst Rev. 2020;4:CD013582. https://doi.org/10.1002/14651858.CD013582.
12. Bergman ZR, Usher M, Olson A, Chipman JG, Brunsvold ME, Beilman G, et al. Comparison of outcomes and process of care for patients treated at hospitals dedicated for COVID-19 care vs other hospitals. JAMA Netw Open. 2022;5:e220873. https://doi.org/10.1001/jamanetworkopen.2022.0873.
13. Occupational Safety and Health Administration. Guidance on Preparing Workplaces for COVID-19. 2020. https://www.osha.gov/sites/default/files/publications/OSHA3990.pdf. Accessed 23 Feb 2026.
14. Olaru ID, Ferrand RA, Magwenzi MT, Robertson V, Musenyereki V, Kranzer K. Risk assessment for rationalizing the use of personal protective equipment for SARS-CoV2 in healthcare settings with special focus on low- and middle-income settings. Clin Microbiol Infect. 2021;27:169–71. https://doi.org/10.1016/j.cmi.2020.10.015.
15. World Health Organization. How Ethiopia prepared its health workforce for the COVID-19 response. WHO Primary Health Care Country Case Study

Compendium. 2020. https://www.who.int/news-room/feature-stories/detail/how-ethiopia-prepared-its-health-workforce-for-the-covid-19-response. Accessed 12 June 2026.
16. Arage SM, Daba DB, Dessalegn AY. Organizational commitment of health professionals and associated factors in primary healthcare facilities of Addis Ababa, Ethiopia: a multi-center cross-sectional study. Front Public Health. 2022;10:981621. https://doi.org/10.3389/fpubh.2022.981621.
17. Girma F, Worku F, Alayu M, Bizuneh H. Turnover intention among health professionals working at primary public health facilities in Addis Ababa, Ethiopia: facility based cross-sectional study. Prim Health Care. 2021;11(7):3–25.
18. Kerai S, Singh R, Saxena KN, Desai SD. Assessment of risk factors for coronavirus disease-2019 in healthcare workers: a case–control study. Indian J Crit Care Med. 2019;26:76–84. https://doi.org/10.5005/jp-journals-10071-24071.
19. Jin Y-H, Huang Q, Wang Y-Y, Zeng X-T, Luo L-S, Pan Z-Y, et al. Perceived infection transmission routes, infection control practices, psychosocial changes, and management of COVID-19 infected healthcare workers in a tertiary acute care hospital in Wuhan: a cross-sectional survey. Mil Med Res. 2020;7:24. https://doi.org/10.1186/s40779-020-00254-8.
20. Ferioli M, Cisternino C, Leo V, Pisani L, Palange P, Nava S. Protecting healthcare workers from SARS-CoV-2 infection: practical indications. Eur Respir Rev. 2020;29:200068. https://doi.org/10.1183/16000617.0068-2020.
21. Ran L, Chen X, Wang Y, Wu W, Zhang L, Tan X. Risk factors of healthcare workers with coronavirus disease 2019: a retrospective cohort study in a designated hospital of Wuhan in China. Clin Infect Dis. 2020;71:2218–21. https://doi.org/10.1093/cid/ciaa287.
22. Mottay L, Le Roux J, Perumal R, Esmail A, Timm L, Sivarasu S, et al. KN95 filtering facepiece respirators distributed in South Africa fail safety testing protocols. South Afr Med J Suid-Afr Tydskr Vir Geneeskd. 2020. https://doi.org/10.7196/SAMJ.2021.v111i3.15381.
23. Fakherpour A, Jahangiri M, Jansz J. A systematic review of passing fit testing of the masks and respirators used during the COVID-19 pandemic: Part 1-quantitative fit test procedures. PLoS ONE. 2023;18:e0293129. https://doi.org/10.1371/journal.pone.0293129.
24. Occupational Safety and Health Administration. Enforcement guidance for respiratory protection and the N95 shortage due to the coronavirus disease 2019 (COVID-19) pandemic. 2020. https://www.osha.gov/laws-regs/standardinterpretations/2020-04-03. Accessed 23 Feb 2026.
25. National Institute for Occupational Safety and Health. Filtering Out Confusion: Frequently Asked Questions about Respiratory Protection: User Seal Check. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health; 2018. https://doi.org/10.26616/NIOSHPUB2018130.
26. Clinical Excellence Commission. Respiratory Protection Program Manual, Version 2.0. 2023. https://www.cec.health.nsw.gov.au/__data/assets/pdf_file/0004/696712/Respiratory-Protection-Program-Manual.pdf. Accessed 13 July 2026.
27. Centers for Disease Control and Prevention. Donning and Doffing PPE: Proper Wearing, Removal, and Disposal. 2023. https://www.cdc.gov/niosh/learning/safetyculturehc/module-3/8.html. Accessed 21 Jan 2025.
28. Bielicki JA, Duval X, Gobat N, Goossens H, Koopmans M, Tacconelli E, et al. Monitoring approaches for health-care workers during the COVID-19 pandemic. Lancet Infect Dis. 2020;20:e261–7. https://doi.org/10.1016/S1473-3099.
29. Jung J, Kim S-K, Lee Y, Park S, Lim Y-J, Kim EO, et al. Rates of COVID-19 infection among healthcare workers in designated COVID-19 wards and general wards. J Korean Med Sci. 2022;37:e308. https://doi.org/10.3346/jkms.2022.37.e308.
30. Narayanan MP, Mohan A, Chandran P, Neelakandan D, Jose BP. Adherence to infection prevention and control practices among health care workers and its outcome in non-COVID areas in a tertiary care hospital. Int J Med Public Health. 2021;11:146–9. https://doi.org/10.5530/ijmedph.2021.3.26.
31. Azmeraw B, Yimenu Y. Personal Protection Equipment Utilization and Hand Hygiene Practice during COVID-19 Pandemic: A Narrative Review. J Infect Dis Epidemiol. 2020;6:181. https://doi.org/10.23937/2474-3658/1510181.
32. Deressa W, Worku A, Abebe W, Gizaw M, Amogne W. Availability and use of personal protective equipment and satisfaction of healthcare professionals during COVID-19 pandemic in Addis Ababa, Ethiopia. Arch Public Health. 2021. https://doi.org/10.1186/s13690-021-00668-3.
33. Deressa W, Worku A, Abebe W, Gizaw M, Amogne W. Risk perceptions and preventive practices of COVID-19 among healthcare professionals in public hospitals in Addis Ababa, Ethiopia. PLoS ONE. 2021;16:e0242471. https://doi.org/10.1371/journal.pone.0242471.
34. Keleb A, Ademas A, Lingerew M, Sisay T, Berihun G, Adane M. Prevention practice of COVID-19 using personal protective equipment and hand hygiene among healthcare workers in public hospitals of south wollo zone. Ethiopia Front Public Health. 2021;9:782705. https://doi.org/10.3389/fpubh.2021.782705.
35. Daba C, Atamo A, Gebretsadik Weldehanna D, Oli A, Debela SA, Luke AO, et al. Infection prevention and control compliance of healthcare workers towards COVID-19 in conflict-affected public hospitals of Ethiopia. BMJ Open. 2023;13:e074492. https://doi.org/10.1136/bmjopen-2023-074492.
36. Mulu GB, Kebede WM, Worku SA, Mittiku YM, Ayelign B. Preparedness and responses of healthcare providers to combat the spread of COVID-19 among north shewa zone hospitals, Amhara, Ethiopia, 2020. Infect Drug Resist. 2020;13:3171–8. https://doi.org/10.2147/IDR.S265829.
37. Tadesse T, Tesfaye T, Alemu T, Haileselassie W. Healthcare worker's knowledge, attitude, and practice of proper face mask utilization, and associated factors in police health facilities of Addis Ababa. Ethiopia J Multidiscip Healthc. 2020;13:1203. https://doi.org/10.2147/JMDH.S277133.
38. Limenyande MJ-M, Kobusingye JO, Tindyebwa T, Akongo D, Isunju JB, Musoke D. Factors associated with compliance with infection prevention and control measures during the COVID-19 pandemic among healthcare workers in Kampala City, Uganda. PLoS ONE. 2023;18:e0293732. https://doi.org/10.1371/journal.pone.0293732.
39. Ashinyo ME, Dubik SD, Duti V, Amegah KE, Ashinyo A, Asare BA, et al. Infection prevention and control compliance among exposed healthcare workers in COVID-19 treatment centers in Ghana: a descriptive cross-sectional study. PLoS ONE. 2021;16:e0248282. https://doi.org/10.1371/journal.pone.0248282.
40. Neuwirth MM, Mattner F, Otchwemah R. Adherence to personal protective equipment use among healthcare workers caring for confirmed COVID-19 and alleged non-COVID-19 patients. Antimicrob Resist Infect Control. 2020;9:199. https://doi.org/10.1186/s13756-020-00864-w.
41. Yang Q, Wang X, Zhou Q, Tan L, Zhang X, Lai X. Healthcare workers' behaviors on infection prevention and control and their determinants during the COVID-19 pandemic: a cross-sectional study based on the theoretical domains framework in Wuhan, China. Arch Public Health. 2021;79:118. https://doi.org/10.1186/s13690-021-00641-0.
42. Nguyen LH, Drew DA, Graham MS, Joshi AD, Guo C-G, Ma W, et al. Risk of COVID-19 among front-line health-care workers and the general community: a prospective cohort study. Lancet Public Health. 2020;5:e475–83. https://doi.org/10.1016/S2468-2667.
43. Grépin KA, Mueller V, Wu N, Rabbani A. Unmasking the truth: Experimental evidence of facemask compliance in Bangladesh, Kenya, and Nigeria during the COVID-19 pandemic. PLOS Glob Public Health. 2023;3:e0001086. https://doi.org/10.1371/journal.pgph.0001086.
44. GebreEyesus FA, Geleta OT, Shiferaw BZ, Tarekegn TT, Amlak BT, Emeria MS, et al. Health care providers' preparedness and health care protection against the third wave of COVID-19 pandemics in a resource-limited setting in Southwest Ethiopia: a multi-center cross-sectional study. Pan Afr Med J. 2023;44:53. https://doi.org/10.11604/pamj.2023.44.53.31428.
45. Dori D, Tapsoba I, Bavouma Sombié C, Zimé-Diawara H, Ouédraogo M, Semdé R, et al. Personal protective equipment wearing in the context of COVID-19 in a hospital in Burkina Faso. Sante Publique Vandoeuvre-Nancy Fr. 2022;34:837–46. https://doi.org/10.3917/spub.226.0837.
46. Mustafa ZU, Majeed HK, Latif S, Salman M, Hayat K, Mallhi TH, et al. Adherence to infection prevention and control measures among health-care workers serving in COVID-19 treatment centers in Punjab, Pakistan. Disaster Med Public Health Prep. 2023;17:e298. https://doi.org/10.1017/dmp.2022.252.
47. Albeladi FI, Alluli MM, Daghriri KA, Almalki YH, Wafi MY, Otaif FA, et al. Level of adherence to COVID-19 preventive measures among health care workers in Saudi Arabia. Cureus. 2021;13:e15969. https://doi.org/10.7759/cureus.15969.
48. Brooks SK, Greenberg N, Wessely S, Rubin GJ. Factors affecting healthcare workers' compliance with social and behavioural infection control measures during emerging infectious disease outbreaks: rapid evidence

review. BMJ Open. 2021;11:e049857. https://doi.org/10.1136/bmjopen-2021-049857.
49. Di Giuseppe G, Pelullo CP, Paolantonio A, Della Polla G, Pavia M. Healthcare workers' willingness to receive influenza vaccination in the context of the COVID-19 pandemic: a survey in Southern Italy. Vaccines. 2021;9:766. https://doi.org/10.3390/vaccines9070766.
50. Orji B, Oliveras E, Odio B, Anoke C, Onuoha H, Ugwa E, et al. Knowledge, attitudes and practices of infection prevention and control among healthcare workers during the COVID-19 pandemic: a descriptive cross-sectional study in three Nigerian states. BMC Health Serv Res. 2023;23:253. https://doi.org/10.1186/s12913-023-09218-9.
51. Gangaram P, Pillay Y, Alinier G. Paramedics' knowledge, attitudes, and practices regarding the use of personal protective equipment against COVID-19. Qatar Med J. 2022;2022:50. https://doi.org/10.5339/qmj.2022.50.
52. Hackett L, Zhang M (Meilun), Casey M, Miller J, Smith J, Low C, et al. N-95/P2 respirator compliance with fit testing recommendations and respirator satisfaction amongst hospital staff. Infect Dis Health. 2024;29:144–51. https://doi.org/10.1016/j.idh.2024.04.001.
53. Ghimire P, Dhungel S, Pokhrel A. Knowledge, attitude and practice of healthcare workers towards Coronavirus Disease 2020 (COVID-19) pandemic. J Nepal Health Res Counc. 2019;29:293–300. https://doi.org/10.33314/jnhrc.v18i2.2658.
54. Noti JD, Lindsley WG, Blachere FM, Cao G, Kashon ML, Thewlis RE, et al. Detection of infectious influenza virus in cough aerosols generated in a simulated patient examination room. Clin Infect Dis. 2012;54:1569–77. https://doi.org/10.1093/cid/cis237.
55. Regli A, Sommerfield A, von Ungern-Sternberg BS. The role of fit testing N95/FFP2/FFP3 masks: a narrative review. Anaesthesia. 2021;76:91–100. https://doi.org/10.1111/anae.15261.
56. O'Kelly E, Arora A, Pirog S, Ward J, Clarkson PJ. Comparing the fit of N95, KN95, surgical, and cloth face masks and assessing the accuracy of fit checking. PLoS ONE. 2021;16:e0245688. https://doi.org/10.1371/journal.pone.0245688.
57. World Health Organization. Infection prevention and control during health care when coronavirus disease (COVID-19) is suspected or confirmed: Interim guidance. Geneva: World Health Organization; 2021. https://www.who.int/publications/i/item/WHO-2019-nCoV-IPC-2021.1.
58. Wang Y, Yang J, Qiao F, Feng B, Hu F, Xi Z-A, et al. Compared hand hygiene compliance among healthcare providers before and after the COVID-19 pandemic: a rapid review and meta-analysis. Am J Infect Control. 2022;50:563–71. https://doi.org/10.1016/j.ajic.2021.11.030.
59. Krein SL, Mayer J, Harrod M, Weston LE, Gregory L, Petersen L, et al. Identification and characterization of failures in infectious agent transmission precaution practices in hospitals. JAMA Intern Med. 2018;178:1016–22. https://doi.org/10.1001/jamainternmed.2018.1898.
60. Ashoor M, Alshammari S, Alzahrani F, Almulhem N, Almubarak Z, Alhayek A, et al. Knowledge and practice of protective personal equipment (PPE) among healthcare providers in Saudi Arabia during the early stages of COVID-19 pandemic in 2020. J Prev Med Hyg. 2022;62(4):E830. https://doi.org/10.15167/2421-4248/jpmh2021.62.4.2177.
61. Pandey S, Poudel S, Gaire A, Poudel R, Subedi P, Gurung J, et al. Knowledge, attitude and reported practice regarding donning and doffing of personal protective equipment among frontline healthcare workers against COVID-19 in Nepal: a cross-sectional study. PLoS Glob Public Health. 2021;1:e0000066. https://doi.org/10.1371/journal.pgph.0000066.
62. Piché-Renaud P-P, Groves HE, Kitano T, Arnold C, Thomas A, Streitenberger L, et al. Healthcare worker perception of a global outbreak of novel coronavirus (COVID-19) and personal protective equipment: survey of a pediatric tertiary-care hospital. Infect Control Hosp Epidemiol. 2020. https://doi.org/10.1017/ice.2020.415.
63. Choudhary A, Saurabh K, Kumar A, Arun N. A cross-sectional survey to assess the preparedness of healthcare workers of isolation intensive care units for anticipated another wave of the COVID-19 pandemic in a tertiary care center. Cureus. 2024;16:e54949. https://doi.org/10.7759/cureus.54949.
64. Gurses AP, Dietz AS, Nowakowski E, Andonian J, Schiffhauer M, Billman C, et al. Human factors-based risk analysis to improve the safety of doffing enhanced personal protective equipment. Infect Control Hosp Epidemiol. 2019;40:178–86. https://doi.org/10.1017/ice.2018.292.
65. Atif S, Lorcy A, Dubé E. Healthcare workers' attitudes toward hand hygiene practices: results of a multicentre qualitative study in Quebec. Can J Infect Control/Revue Canadienne de Prévention des Infect. 2019;1(34):1.
66. Byambasuren O, Beller E, Clark J, Collignon P, Glasziou P. The effect of eye protection on SARS-CoV-2 transmission: a systematic review. Antimicrob Resist Infect Control. 2021;10:156. https://doi.org/10.1186/s13756-021-01025-3.
67. Min HS, Moon S, Jang Y, Cho I, Jeon J, Sung HK. The use of personal protective equipment among frontline nurses in a nationally designated COVID-19 hospital during the pandemic. Infect Chemother. 2021;53:705. https://doi.org/10.3947/ic.2021.0094.
68. Den Boon S, Vallenas C, Ferri M, Norris SL. Incorporating health workers' perspectives into a WHO guideline on personal protective equipment developed during an Ebola virus disease outbreak. F1000Res. 2018;7:45. https://doi.org/10.12688/f1000research.12922.2.
69. Ha JF. The COVID-19 pandemic and face shields. Br J Surg. 2020;107:e398. https://doi.org/10.1002/bjs.11842.
70. Zhu S, Kahsay KM, Gui L. Knowledge, attitudes and practices related to standard precautions among nurses: a comparative study. J Clin Nurs. 2019;28:3538–46. https://doi.org/10.1111/jocn.14945.
71. Akpabio AA, Onukak AE, Udoette SB, Umoh VA. Safety practices and Covid-19 antibody positivity among health care workers in a tertiary hospital in Southern Nigeria. West Afr J Med. 2021;38:930–5.
72. Singh Gambhir R, Singh Dhaliwal J, Aggarwal A, Anand S, Anand V, Kaur Bhangu A. Covid-19: a survey on knowledge, awareness and hygiene practices among dental health professionals in an Indian scenario. Rocz Panstw Zakl Hig. 2020;71:223–9. https://doi.org/10.32394/rpzh.2020.0115.
73. Papagiannis D, Malli F, Raptis DG, Papathanasiou IV, Fradelos EC, Daniil Z, et al. Assessment of knowledge, attitudes, and practices towards new coronavirus (SARS-CoV-2) of health care professionals in Greece before the outbreak period. Int J Environ Res Public Health. 2020;17:4925. https://doi.org/10.3390/ijerph17144925.
74. Jemal B, Aweke Z, Mola S, Hailu S, Abiy S, Dendir G, et al. Knowledge, attitude, and practice of healthcare workers toward COVID-19 and its prevention in Ethiopia: a multicenter study. SAGE Open Med. 2021;9:20503121211034388. https://doi.org/10.1177/20503121211034389.
75. Soboksa NE, Negassa B, Kanno G, Ashuro Z, Gudeta D. Hand hygiene compliance and associated factors among healthcare workers in Ethiopia: a systematic review and meta-analysis. Adv Prev Med. 2021;2021:1–10. https://doi.org/10.1155/2021/7235248.
76. Borg MA, Benbachir M, Cookson BD, Redjeb SB, Elnasser Z, Rasslan O, et al. Self-protection as a driver for hand hygiene among healthcare workers. Infect Control Hosp Epidemiol. 2009;30:578–80. https://doi.org/10.1086/597511.
77. Kamacooko O, Kitonsa J, Bahemuka UM, Kibengo FM, Wajja A, Basajja V, et al. Knowledge, attitudes, and practices regarding COVID-19 among healthcare workers in Uganda: a cross-sectional survey. Int J Environ Res Public Health. 2021;18:7004. https://doi.org/10.3390/ijerph18137004.
78. Janay AI, Kilic B, Unal B. Healthcare workers' compliance with COVID-19 prevention and control measures at De Martino Hospital, Mogadishu, Somalia: a cross-sectional study. BMC Infect Dis. 2024;24:1046. https://doi.org/10.1186/s12879-024-09819-7.

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