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Nature and Science

MARSLAND PRESS
Multidisciplinary Academic Journal Publisher

Characterizing the Occupational versus Community Risk of COVID-19 Infection among Healthcare Workers: Teachings for this pandemic and beyond

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Abstract: Objectives: To present study was designed to characterize the portion of occupational versus community-acquired COVID-19 among infected healthcare workers (HCWs), by estimating the levels of in-hospital versus community exposure to high-risk situations and their respective associations with a positive history of COVID-19 infection. **Method:** A cross-sectional study was carried out between 1st January and 15th February 2021, involving 614 HCWs from all-type healthcare institutions of Jeddah, Saudi Arabia. An online questionnaire was implemented via official emailing to explore several dimensions of occupational and non-occupational exposure to COVID-19, including participation in high-risk care situations, performance of high-risk procedures, other occupational risk factors, high-risk situations within community, besides the levels of adherence to preventive measures within hospital and in community. Scores (range=0-10) were calculated on each of these exposure dimensions. **Result:** The prevalence of COVID-19 infection among the participants was 32.6% (95%CI=28.9-36.4%). A ROC curve analysis model was explored to explain the risk of COVID-19 associated with cumulative exposure to occupational and community factors. The model showed an AUC=0.694 (95%CI=0.651-0.737), which was not much higher compared to in-hospital exposure to high-risk care situations (AUC=0.674) or in-hospital cumulative exposure (AUC=0.663). The risk of COVID-19 was independently associated with the level of exposure to high-risk care situations (OR=1.20), high-risk situations within community (OR=1.07), and failure to perform fit test for N95 respirator (OR=1.85), besides factors related to the type of facility and department of affiliation. **Conclusion:** The increased risk for COVID-19 infection among HCWs is a multifactorial and multifaceted issue with several implications. It implies accurate identification of the risk profiles and continuous monitoring of the environmental and behavioral hazards to adapt the baseline levels of awareness and protection of the healthcare personnel.

[Mashal Al-Sayali, Abdullah Jaber Alsahafi, Khalid Hamdan Al-Anazi, Abdullah Mohammed Algarni, Nagham Khalid Abdulrahman, Ibrahim Mohammed Asiri, Nidal Abduljaleel Tashkandy, Moutaz Mansour Wali, Rami Abdullah Altowergi, Anwar Ali Alzahrani, Faten Mohammed Felemban, Seadah Masad Almutairi, Tahani Saleh Saeed Alshehri, Reem Jameel Mesari, Wafa Ahamd Basfr, Sultan Hassan Hamzah Albarqi, Hisham Yahya Alghamdi, Afra Yousef S Kulthum, Rula Hasen Mohammed Felemban, Rehab MAnzili Alruwail, Ghada Naji Dewedar, Yousef Mohammed Al Hazmi, Manal Fahad Hazzaa Alharbi. **Characterizing the Occupational versus Community Risk of COVID-19 Infection among Healthcare Workers: Teachings for this pandemic and beyond**. Nat Sci 2022; 20(3);66-82]. ISSN 1545-0740 (print); ISSN 2375-7167 (online). http://www.sciencepub.net/nature. 8. doi:10.7537/marsnsj200322.08.

Keywords: Occupational, Community Risk, COVID-19, pandemic, beyond

1. Introduction

The ongoing COVID-19 crisis, which has been considered a pandemic since March 2020, is spread by Severe Acute Respiratory Coronavirus 2 (SARS-CoV-2). It has infected more than 250 million people, and around 5 million died around the world

(1). The direct impacts and long-term knock-on effects of this pandemic on all fields of the human life, economics and industries are devastating (2–6).

One of the fields that were more particularly impacted is the healthcare sector. The daily increase of new COVID-19 cases has demanded the services of more health care workers (HCWs), whom role is vital in combatting the disease and reducing its morbidity and mortality (7–9). On the other hand, HCWs are at a greater risk for being infected with SARS-CoV-2 compared to the general population, due to their profession; and COVID-19 was recognized as an occupational disease in many countries (10–13). Early reports from international studies showed that HCWs accounted for 10% to 26% of all confirmed COVID-19 cases, with infection rates reaching up to 36%, and several hospital outbreaks were reported resulting in a soaring number of occupational COVID-19 cases. Analysis of the same reports show that, although the overall mortality rates due to COVID-19 in HCWs is comparable to that in the general population, cases of death among HCWs are significantly younger (11,12,14–19). Such impact represents an excess burden to the healthcare systems, endangering their resilience and viability during and beyond the pandemic. Besides these major challenges, HCWs are exposed to psychological distress (20,21), along with the risk of the virus transmission to their families, who are less protected and may be more vulnerable (22).

The risk of COVID-19 infection among HCWs is further associated with several occupational factors within the healthcare profession. Particular procedures, notably those involving airway management such as aerosol-generating procedures and tracheal intubation, expose HCWs to greater risk of virus transmission despite the adequate use of personal protective equipment (PPE) (23–27). Nonetheless, it appears difficult to estimate the share of occupational exposure to the virus in the overall burden of COVID-19 among HCWs. The role of community-associated risk factors in the spread and transmission of COVID-19 among HCWs may also be substantial and cumulate with the occupational risk. Some data show that the most significant COVID-19 risk factors for healthcare workers (HCP) are community exposure and the prevalence of the disease in the locality, and not the patient interaction or the clinical procedures (28).

To present study was designed to characterize the portion of occupational versus community-acquired COVID-19 among infected HCWs, by estimating the levels of in-hospital versus community exposure to high-risk situations and their respective associations with a positive history of COVID-19 infection.

2. Methods

Design and Setting

A cross-sectional study was carried out between 1st January and 15th February 2021, involving all healthcare institutions of Jeddah, Saudi Arabia. The study protocol was ethically approved by the Directorate of Health Affairs, Ministry of Health (MoH), Jeddah, Saudi Arabia.

Population and Sampling

The study included care and non-care healthcare workers (HCWs) who were officially registered and working in any of the MoH, other governmental, private or semi-private health facilities located in Jeddah districts, during the study period.

Sample minimum size calculation (N=378) used a single proportion estimate method to detect an unknown COVID-19 infection rate (P=50%) among a total 55,000 HCWs of Jeddah, with 80% statistical power, 0.05 type 1 error and 95% confidence interval. A convenience sampling method was used to include all valid participations.

Data collection

A comprehensive, structured questionnaire was designed by authors, and was used in the present study as well as for a previous study. The specific parts that were used for present study are the following:

- **Part 1** comprising demographic and professional data, such as gender, age, department, type of healthcare facility, bed capacity, etc.
- **Part 3** assessing the occupational exposure to COVID-19, and comprised 3 sections: 1) level of participation (never vs once or twice vs many times) in high-risk situations such as direct care to suspected or confirmed COVID-19 patient, patient transport, aerosol generating procedure, etc. (7 items); 2) level of exposure (never vs already performed) to high-risk procedures such as endotracheal intubation/extubation, high-flow nasal canula, cardiopulmonary resuscitation, etc. (13 items); 3) other factors related to the work environment such as easy access to hand hygiene, receipt of fit test for N95 respirators, etc. (6 items).
- **Part 4** assessing the level of exposure (no, probably yes, yes) to high-risk situations within community, such as direct care to a family member with suspected or confirmed COVID-19 infection, contact with relative with

suspected or confirmed COVID-19, etc. (5 items).

- **Part 5** Levels of adherence, from never or rarely=0 to always=4, to preventive measures, as assessed separately within hospital (8 items) and community (6 items).
- **Part 6** included COVID-19 infection status, as well as self-assessed severity level, onset symptoms using a predefined list of 13 symptoms, and lieu where the course of illness was spent (quarantine, home isolation, isolation ward, regular ward hospitalization, ICU or other).
- **Part 7** explored the likelihood, from extremely unlikely=1 to extremely likely=5, of being infected from different source persons including: patient in health facility, colleague, member of the household, relative, or other person. Thus, each participant attributed a likelihood score to each potential source.

The questionnaire underwent face and content validity by the research team, with the concurrence of an independent methodologist. Sections 1 and 2 from Part 3, as well as Parts 4 and 5 of the questionnaire underwent reliability testing to explore the suitability of calculating scores for each type of exposure.

Study variables

The explained variable

The explained variable was the COVID-19 infection rate. It was calculated as the percentage of participants who have been diagnosed with COVID-19 among the total participants or the given sub-category.

Explanatory variables

Explanatory variables consisted of the demographic and professional factors in addition to the different levels of exposure as defined using the following scores:

1) Exposure to in-hospital high-risk care situations, calculated as the sum of the levels of exposure to the 7 predefined situations.
2) Level of exposure to high-risk procedures, calculated as the sum of the levels of exposure to the 13 predefined procedures.
3) Level of exposure to in-community high-risk situations, calculated as the sum of the levels of exposure to the 5 predefined situations.
4) Level of adherence to preventive measures during hospital service, calculated and the sum of the levels of adherence to the 8 corresponding preventive measures.
5) Level of adherence to preventive measures within community, calculated and the sum of the levels of adherence to the 6 corresponding preventive measures.

All 5 scores were adjusted to the scale 0-10, and were analyzed as scaled variables.

Procedure

The questionnaire was edited online using the Google Sheet platform. The contact numbers of all HCWs of Jeddah were obtained from the Directorate of Health Affairs division of Jeddah. A concise message was sent to all eligible individuals, presenting the objectives and importance of the study, specifying the voluntary nature of the participation, and providing the link for the online survey.

Statistical methods

Data was uploaded from the online survey platform as Excel sheet, which was cleaned and recoded, then transferred to SPSS version 21.0 for Windows (SPSS Inc., Chicago, IL, USA) for statistical analysis.

Descriptive statistics were used to explore data variables, which were presented as frequency and percentage for categorical variables and mean ± standard deviation (SD) for scaled variables.

Chi-square test was used to analyze the correlation between COVID-19 infection rate and the different factors' categories. Logistic regression was used to analyze the relationship of the different exposure scores with the COVID-19 status; results are presented as odd ratios (OR) with 95% confidence interval (95%CI).

Receiver operating characteristics (ROC) curve analysis was performed to test the significance of a model of cumulative exposure combining both occupational and community exposure levels, by reference to occupation or community exposure separately. Results are presented as ROC curves with area under the curve (AUC).

A multivariate logistic regression model was carried out to analyze the independent factors associated with COVID-19; the model included all factors and exposure scores that showed significance in the univariate analyses. Results are presented as OR with 95%CI.

To determine the occupational versus community source of COVID-19 infection, source likelihood scores were analyzed in correlation with the exposure scores using Pearson's correlation test. This analysis hypothesized that strong and consistent correlations between source likelihood and exposure scores would suggest the reliability of the participants in determining the source of infection.

The null hypothesis was rejected for a p value or Log-rank value of <0.05, as applicable.

3. Results

Participants' characteristics and COVID-19 infection rates

Of 614 healthcare professionals that were included, 200 declared having contracted COVID-19, accounting for a prevalence of 32.6% (95%CI=28.9-36.4%). The prevalence of COVID-19 was higher among age group 30-49 (35.9% vs 26.0%, p=0.014), certain high-risk nationalities (41.0% vs 30.2%, p=0.018), and non-MoH governmental hospitals (70.0% vs ≤50%, p<0.001) compared to their counterparts respectively. Additionally, a higher COVID-19 prevalence was observed in participants working in departments with high bad capacity (43.2% vs <34%, p<.001) as well as those with highly exposed practice including emergency room (43.8%), intensive care (46.0%) and isolation ward (50.5%) by comparison to other departments (23.8%-30.8%) and the difference was statistically significant (p=0.001) (**Table 1**). The clinical characteristics of COVID-19 cases including severity, presenting symptoms and management are depicted in **Table 2**.

Table 1: Participants' demographic and professional characteristics and their association with COVID-19 infection (N=614)

Parameter	Category	Total, N (%)	COVID-19 infection rate, N (%)	p-value
Gender	Female	362 (59.0)	108 (29.8)	
	Male	252 (41.0)	92 (36.5)	.083
Age (years)	Up to 29	90 (14.7)	26 (28.9)	
	30-39	258 (42.0)	94 (36.4)	
	40-49	152 (24.8)	53 (34.9)	
	50-59	95 (15.5)	24 (25.3)	
	60 and above	19 (3.1)	3 (15.8)	.115
Age-stratified risk exposure	High exposure (30-49 years)	410 (66.8)	147 (35.9)	
	Low exposure (others)	204 (33.3)	53 (26.0)	.014*
Nationality	Saudi Arabia	274 (44.6)	84 (30.7)	
	Philippines	101 (16.4)	30 (29.7)	
	Egypt	105 (17.1)	31 (29.5)	
	India	57 (9.3)	23 (40.4)	
	Sudan	19 (3.1)	7 (36.8)	
	Other	58 (9.4)	25 (43.1)	.312
Nationality-stratified risk exposure	High exposure[§]	134 (21.8)	55 (41.0)	
	Low exposure (others)	480 (78.1)	145 (30.2)	.018*
Facility type	MoH	283 (46.1)	83 (29.3)	
	Non-MoH Governmental	70 (11.4)	49 (70.0)	
	Private	249 (40.6)	62 (24.9)	
	Other	12 (2.0)	6 (50.0)	<.001*
Bed capacity	Less than 50	52 (8.5)	9 (17.3)	
	50-100	103 (16.8)	22 (21.4)	
	100-200	141 (23.0)	37 (26.2)	
	More than 200	259 (42.2)	112 (43.2)	
	Not applicable	59 (9.6)	20 (33.9)	<.001*
Occupation type	Non-care	48 (7.8)	15 (31.3)	
	Care	566 (92.2)	185 (32.7)	.839
Position	Physician	237 (38.6)	71 (30.0)	
	Nurse	197 (32.1)	72 (36.5)	
	Laboratory personnel	47 (7.7)	12 (25.5)	
	Pharmacist	25 (4.1)	11 (44.0)	
	Physical / Respiratory therapist	29 (4.7)	10 (34.5)	
	Other	31 (5.1)	9 (29.0)	.548
Department	Emergency room (ER)	89 (14.5)	39 (43.8)	
	Intensive care unit (ICU)	63 (10.3)	29 (46.0)	
	Insolation ward	44 (7.2)	22 (50.5)	
	Inpatient - medical ward	56 (9.1)	17 (30.4)	
	Inpatient - Surgical ward	26 (4.2)	8 (30.8)	

	Outpatient clinic	84 (13.7)	22 (26.2)	
	Lab., imaging, Pharmacy, etc.	71 (11.6)	20 (28.2)	
	Other Departments	181 (29.5)	43 (23.8)	.001*
Department-stratified risk exposure	High exposure[⌘]	196 (32.0)	90 (45.9)	
	Low exposure	418 (68.1)	110 (26.3)	<.001*

MoH: Ministry of Health
[§] High-exposure nationalities: India, Sudan, and others than Saudi, Egypt and Philippines.
[⌘] High-exposure departments: Emergency room, intensive care unit, and isolation ward

Table 2: Clinical characteristics of COVID-19 cases (N=200)

Parameter	Category	Frequency	Percentage
Self-assessed severity	Asymptomatic	20	10.0
	Mild	119	59.5
	Moderate	52	26.0
	Severe	9	4.5
Symptoms	Fever	152	76.0
	Sore throat	147	73.5
	Cough	137	68.5
	Myalgia	133	66.5
	Fatigue	126	60.5
	Anosmia	100	50.0
	Loss of appetite	82	41.0
	Shortness of breath	60	30.0
	Diarrhea	58	29.0
	Chills	53	26.5
	Nausea or vomiting	30	15.0
	Headache	17	8.5
	Others	19	9.5
Management	Quarantine	64	32.0
	Home isolation	103	51.5
	Isolation ward	21	10.5
	Regular ward hospitalization	6	3.0
	ICU	3	1.5
	Other	3	1.5

Occupational exposure to high-risk care situations and high-risk procedures and their association with COVID-19 infection rate

Table 3 shows higher prevalence of COVID-19 among healthcare professional who were frequently exposed to several care situations, such as direct care to suspected or confirmed COVID-19 patients, patient transportation, or aerosol generating procedures compared with their counterpart. Further, performing high-risk procedures such as endotracheal intubation (53.3% vs 28.2%, p<0.001), bronchoscopy (60.0% vs 31.4%, p=0.003) and nasopharyngeal swab (43.3% vs 27.6%, p<0.001) was associated with higher risk of COVID-19 infection.

Furthermore, COVID-19 infection rate was higher among participants who had not performed fit test for N95 respirators compared with those who have performed it (40.9% vs 28.8%, p<0.001) (**Table 4**).

Occupational exposure, adherence to preventive measures and association with COVID-19 infection

Levels of adherence to preventive measure during hospital service are depicted in **Figure 1**. The assessment of the following scales showed good reliability with Cronbach's alpha values for level of exposure to in-hospital high-risk care situation (0.846), in-hospital high-risk procedure (0.888), and in-hospital adherence to preventive measures (0.808). We observed relatively high levels of adherence to preventive measure within hospital, with a mean adherence score of 7.21 out of 10 (SD=1.95). The rate of COVID-19 infection was significantly associated with the levels of exposures (scaled scores 0-10) to high-risk care situation (OR=1.24, p<0.001) and high-risk procedures (OR=1.14, p<0.001), but not with the level of adherence to preventive measures during hospital service (OR=1.00, p=0.913) (**Table 5**).

Community exposure, adherence to preventive measures and association with COVID-19 infection

The scales measuring levels of exposure to high-risk situations and levels of adherence to preventive measure within the community showed good reliability with Cronbach's alpha 0.790 and 0.870 respectively (**Table 5**). We observed high levels of adherence to preventive measure within community with a mean adherence score of 9.37 out of 10 (SD=1.25) (**Figure 2**, **Table 5**). On the other hand, only the level of exposure to high-risk situations (scaled score 0-10) was significantly associated with the risk of COVID-19 infection (OR=1.13, p<0.001). (**Table 5**).

Model of cumulative exposure to COVID-19

A ROC curve analysis model was explored to explain the risk of COVID-19 associated with cumulative exposure to occupational and community risk among healthcare providers. The ROC curve model showed an AUC=0.694 (95%CI=0.651-0.737), which was not much higher compared to in-hospital exposure to high-risk care situations (AUC=0.674) or in-hospital cumulative exposure (AUC=0.663) (**Figure 3**).

Table 3. Occupational exposure to high-risk care situations and high-risk procedures and their association with COVID-19 infection rate (N=614)

Exposure	**Levels of exposure, infection rates**						**p-value**
	Never/NA		**Yes, once or twice**		**Yes, many times**		
Care situation	**N**	**IR**	**N**	**IR**	**N**	**IR**	
Direct care to suspected or confirmed COVID-19 patient	170 (27.7)	**20.0%**	154 (25.1)	**24.7%**	290(47.2)	**44.1%**	<.001*
Patient transportation	438(71.3)	**25.3%**	96(15.6)	**43.8%**	80(13.0)	**58.8%**	<.001*
Aerosol generating procedure	381(62.1)	**25.7%**	91(14.8)	**38.5%**	142(23.1)	**47.2%**	<.001*
Close contact with a confirmed COVID-19 patient	210(34.2)	**20.5%**	162 (25.4)	**26.5%**	242(39.4)	**47.1%**	<.001*
Close contact with a confirmed COVID-19 colleague	196 (31.9)	**23.0%**	256 (41.7)	**32.8%**	162 (26.4)	**43.8%**	<.001*
Contact with patients on noninvasive ventilation in HEPA room	432 (70.4)	**29.6**	87 (14.2)	**37.9**	95 (15.5)	**41.1%**	.051
Work in area with possible or confirmed cases without social distancing	336 (54.7)	**21.7%**	121 (19.7)	**47.1%**	157 (25.6)	**44.6%**	<.001*
High-risk procedure	**Never or not applicable**		**Already performed**		**p-value**
	N (%)	**IR**	**N (%)**	**IR**	
Endotracheal intubation	507 (82.6)	**28.2%**	107 (17.4)	**53.3%**	<.001*
Endotracheal extubation	555 (90.4)	**31.5%**	59 (9.6)	**42.4%**	.091
Bronchoscopy	589 (95.9)	**31.4%**	25 (4.1)	**60.0%**	.003*
Open suctioning	510 (83.1)	**29.2%**	104 (16.9)	**49.0%**	<.001*
High-flow nasal cannula	483 (78.7)	**31.1%**	131 (21.3)	**38.2%**	.123
Mini bronchoalveolar lavage	582 (94.8)	**31.4%**	32 (5.2)	**53.1%**	.011*
Cardiopulmonary resuscitation	501 (81.6)	**32.3%**	113 (18.4)	**33.6%**	.791
Nasopharyngeal swab	420 (68.4)	**27.6%**	194 (31.6)	**43.3%**	<.001*
Nebulizer treatment/manual ventilation	478 (77.9)	**30.3%**	136 (22.1)	**40.4%**	.026*
Physical proning of patient	530 (86.3)	**30.8%**	84 (13.7)	**44.0%**	.016*

Disconnecting patient from ventilator	558 (90.9)	**31.7%**	56 (9.1)	**41.1%**	.155
NIPPV	558 (90.9)	**31.7%**	56 (9.1)	**41.1%**	.155
Tracheostomy	560 (91.2)	**31.3%**	54 (8.8)	**46.3%**	.024*

IR: Infection rate, calculated as the percentage of participants who declared being diagnosed with COVID-19 in the given exposure level.
HEPA: High-efficiency particulate air; NIPPV: Noninvasive positive pressure ventilation.
Test used: chi square test; * statistically significant result (p<0.05)

Table 4. Other work environment factors of COVID-19 infection among healthcare professional

Parameter	**Levels of exposure, infection rates**						**p-value**
	Yes		**No**		**Not applicable**		
	N (%)	**IR**	**N (%)**	**IR**	**N (%)**	**IR**	
Received formal IPC and or PPE training in the last 6 months	504 (82.1)	**32.9%**	100 (16.3)	**31.0%**	10 (1.6)	**30.0%**	**.917**
Performed fit test for N95 respirators	479 (78.0)	**28.8%**	88 (14.3)	**40.9%**	47 (7.7)	**55.3%**	**<.001***
Aerosol generating procedures conducted in rooms with negative pressure	339 (55.2)	**29.2%**	192 (31.3)	**39.1%**	83 (13.5)	**31.3%**	**.064**
Health facility has a functional triaging system	524 (85.3)	**34.7%**	79 (12.9)	**19.0%**	11 (1.8)	**27.3%**	**.019***
Hospital administration regularly informs about newly diagnosed COVID cases, including cases among HCWs	445 (72.5)	**33.9%**	156 (25.4)	**28.8%**	13 (2.1)	**30.8%**	**.501**
Easy access to hand hygiene utility at all times within the department	578 (94.1)	**33.0%**	31 (5.0)	**22.6%**	5 (0.8)	**40.0%**	**.451**

IR: Infection rate, calculated as the percentage of participants who declared being diagnosed with COVID-19 in the given exposure level.
Test used: chi square test; * statistically significant result (p<0.05)

Table 5. In-hospital and community exposure to COVID-19 and adherence to preventive measures – Reliability of the scales, scores and associated risk of COVID-19 infection

Scale (Levels)	**No. items**	**Cronbach's alpha**	**Conclusion**	**Scaled score**§			**Associated risk of COVID-19**			
				Mean	**SD**	**Median**	**OR**	**95%CI**		**p-value**
Exposure										
In-hospital high-risk care situations (0-2)	7	0.846	High internal consistency	3.84	2.90	3.6	1.24	1.16	1.31	<.001*
In-hospital high-risk procedures (0-1)	13	0.888	High internal consistency	1.44	2.24	0.8	1.14	1.06	1.23	<.001*
In-community high-risk situations (0-2)	5	0.790	Good internal consistency	2.91	3.19	2.0	1.13	1.07	1.19	<.001*
Adherence										

In-hospital adherence to preventive measures (0-4)	8	0.808	High internal consistency	7.21	1.95	7.5	1.00	0.91	1.09	.913
In-community adherence to preventive measures (0-4)	6	0.870	High internal consistency	9.37	1.25	10.0	0.94	0.82	1.07	.326

§ Scores are scaled from 0 to 10, where higher values indicate higher level of exposure or adherence, as applicable. OR: Odds ratio of the risk of COVID-19 infection as a function of the given exposure or adherence score; * statistically significant association.

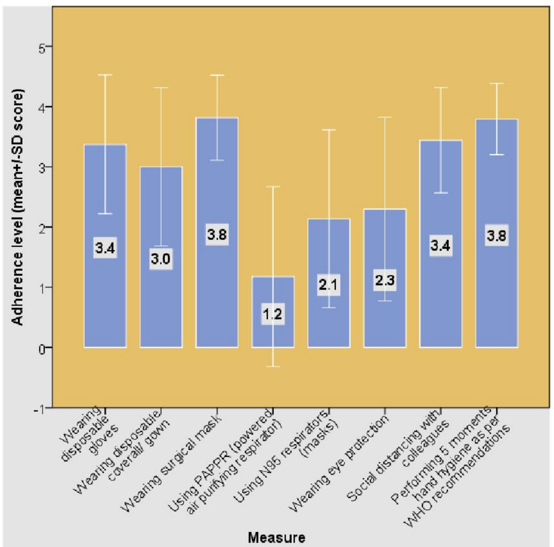

Figure 1: Levels of adherence among healthcare workers to preventive measures during service
Bars represent the mean scores of adherence to the given preventive measure; higher scores indicate higher levels of adherence. Error bars represent the standard deviation.

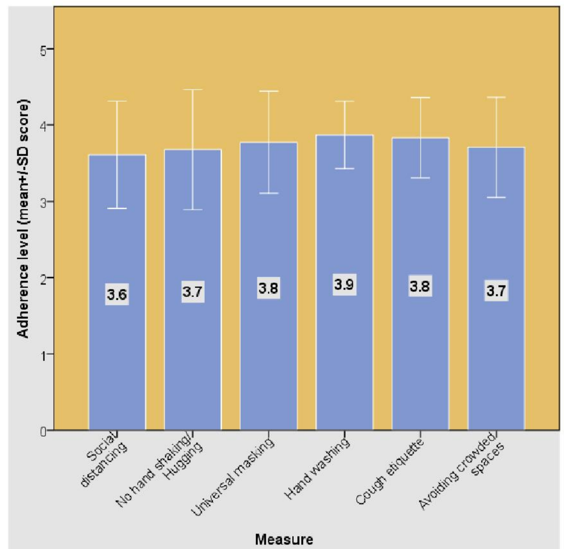

Figure 2. Levels of adherence among healthcare workers to preventive measures in community
Bars represent the mean scores of adherence to the given preventive measure; higher scores indicate higher levels of adherence. Error bars represent the standard deviation.

Independent factors associated with COVID-19 infection

The multivariate risk model showed the significance of working in high-risk departments (OR=2.18, p=0.001) in non-MoH governmental hospitals (OR=5.77, p<0.001) with high bed capacity (OR=3.58, p=0.004) were independently associated with high risk of COVID-19 infection. Further, the level of exposure to high-risk care situations (OR=1.20, p<0.001) or to high-risk situation within community (OR=1.07, p=0.029) were also independently associated with COVID-19 infection. Finally, failure to perform fit test for N95 respirator was associated with 1.85 odd ratio of COVID-19 infection (**Table 6**).

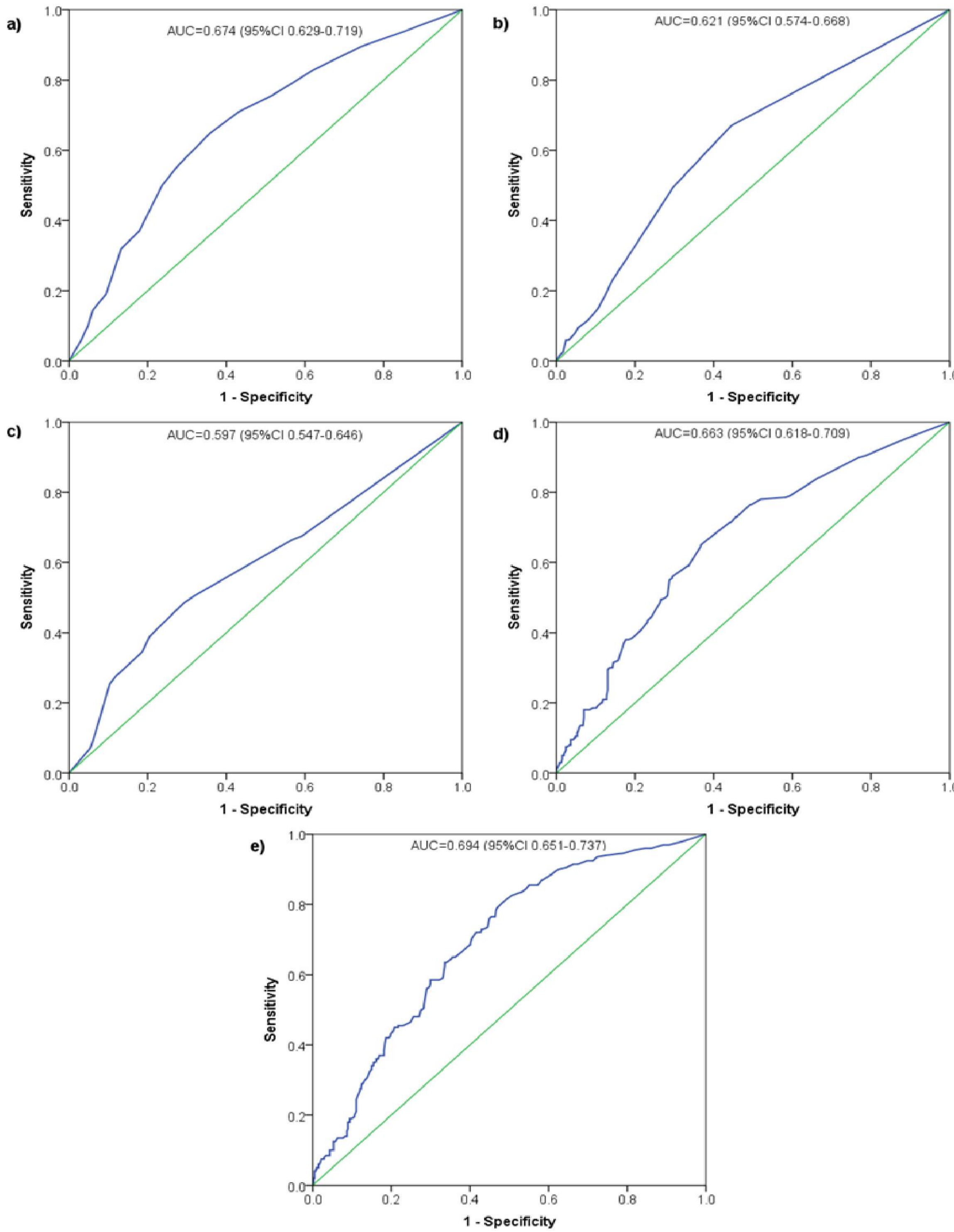

Figure 3. Significance of in-hospital, community and overall cumulative exposure models

Figures represent the ROC curves for the risk of COVID-19 infection as a function of the in-hospital exposure to high-risk care situations (**Figure a**), high-risk procedures (**Figure b**), in-community high-risk situation (**Figure c**), in-hospital cumulative exposure (**Figure d**), and overall, in-hospital and community cumulative exposure (**Figure e**). The overall cumulative exposure model was the most significant, with the highest AUC value of 0.694.

Exploring the source of COVID-19 infection

By considering COVID-19 positive participants (N=200), the most frequently perceived sources of COVID-19 infection were a patient or colleagues in health facility, with respective mean likelihood scores of 3.65 and 3.23 out of 5. The level of exposure to high-risk care situation was positively correlated with the perceived likelihood of being infected by a patient in the facility; and the relationship was weakly positive (R=0.24) and statistically significant (p<0.001). The level of exposure to high-risk situations in community was negatively correlated with the likelihood of being infected by a patient in the facility weakly negative (R= -0.31, p<0.001) and positively correlated with the likelihood score of being infected by a member of the household (R=0.21, p=0.003) (**Table 7**).

Table 6. Occupational and community independent risk factors for COVID-19 infection among healthcare professionals

Scale (Levels)	Value	Associated risk of COVID-19			
		OR	95%CI		p-value
Facility type	MoH	Ref	-	-	<.001*
	Non-MoH Gov.	5.77	3.05	10.92	<.001*
	Private	1.08	0.67	1.72	.757
	Other	3.14	0.89	11.12	.076
Bed capacity	<50	Ref	-	-	.041*
	50-100	2.51	.95	6.59	.062
	100-200	2.16	.86	5.41	.101
	More than 200	3.58	1.49	8.62	.004*
	Not applicable	3.44	1.21	9.76	.020*
Department §	Low risk	Ref	-	-	-
	High risk	2.18	1.36	3.50	.001*
In-hospital high-risk care situations	(Score)	1.20	1.10	1.30	<.001*
In-hospital high-risk procedures	(Score)	1.01	0.92	1.11	.842
In-community high-risk situations	(Score)	1.07	1.01	1.14	.029*
Performed fit test for N95 respirators	Yes	Ref			.003*
	No	1.85	1.06	3.25	.031*
	NA	2.84	1.41	5.70	.003*

Multivariate binary logistic regression;
OR: Odds ratio of the risk of COVID-19 infection;
§High-risk departments: Emergency room, intensive care unit, and isolation ward

Table 7. Correlation between occupational vs community exposure and self-perceived source of infection (N=200)

Perceived source of infection	Likelihood score		Exposure scores			
	Mean	SD	High-risk care situation	High-risk procedure	In-hospital cumulative exposure	Community exposure
Patient in health facility	3.65	1.46	0.24 (<0.001*)	-0.02 (.790)	0.14 (.046*)	-0.31 (<.001*)
Colleague in health facility	3.23	1.20	-0.09 (.225)	-0.09 (.219)	-0.10 (.159)	-0.00 (.987)
Member of the household	2.40	1.05	-0.09 (.197)	-0.05 (.527)	-0.08 (.256)	0.21 (.003*)
Other relative or friend	2.38	1.15	-0.05 (.521)	-0.03 (.706)	-0.04 (.549)	0.12 (.131)
Other person	2.23	1.02	0.07 (.312)	0.07 (.330)	0.08 (.252)	-0.02 (.769)

Values are Pearson's correlation coefficient R (p-value).
* Statistically significant result (p<0.05)

4. Discussion

Summary and Context

The COVID-19 crisis is an unprecedented experience in the human history; not only because of the extent of the pandemic, but also by consideration of the technological and scientific context in which it evolved. This should bring us to humility and constructive criticism, in order to draw all lessons to improve our management and preparedness for this crisis and beyond. Among the important issues are those related to the protection of the frontline healthcare workers, because such issues are directly related to the viability and resilience of the healthcare systems.

The present work probed into a delicate and challenging objective, which is to characterize the source of COVID-19 infection among HCWs and to estimate the share of the occupational source. The main challenge is related to the specific risk of COVID-19 infection among HCWs being the result of a cumulative exposure to occupational and community risk factors. To overcome this challenge, the cumulative exposure to COVID-19 was the starting hypothesis of the present study, and the occupational source of infection was modeled using a subtractive analytical approach combined with self-perceived source of infection. The increased risk for COVID-19 infection among HCWs is a multifactorial and multifaceted issue with several epidemiological, clinical, public health and legal implications. The present section will discuss the implications of the main findings and attempt to draw the relevant teachings for the management of the COVID-19 crisis and beyond.

Higher risk despite adherence to preventive measures

Despite the high levels of adherence to preventive measures, both within hospital (mean adherence level=7.21 out of 10) and community (9.37 out of 10), HCWs were at high risk of COVID-19 during the first year of the pandemic. The overall prevalence of COVID-19 in the present study was estimated to be as high as 32.6%, which was significantly associated with the levels of occupational and community exposure, besides other demographic and professional factors. This is extremely high by reference with the 1.1% prevalence among the general Saudi population at the study endpoint (29). It should be considered that our study did not consider cases of mortality, as the data was collected by direct survey of the HCWs. On the other hand, voluntary participation may have induced a selection bias where COVID-19 positive HCWs were more incline to participate in the study, which would result in an overestimated prevalence. A systematic review and meta-analysis including 97 studies in 2020 estimated the overall prevalence of COVID-19 infection among HCWs between 7% and 11% depending on the diagnostic method (30). Still, such figures are frankly higher by reference to those in the general population.

The first question that comes to mind is the level of efficacy of the preventive measures implemented in the healthcare environment and personal protective equipment (PPE), and whether they are adapted to the level of exposure (31,32). The second question is whether the levels of adherence to these preventive measures are accurately appraised. Strict adherence to the criteria set by the World Health Organization (WHO) was estimated to be achieved by 1.4% of the HCWs, "regardless of medical profession, specialty or place of employment", while the adherence to each distinct criterion ranged from 6.8% to 90.8% (33). The third question is to what extent are the current preventive measures and PPE practicable and tolerable, notably for long use? Several studies reported inconvenience and skin injuries resulting from PPE use, exposing to indirect risks of COVID-19 (34). From the previous questions, another question, more visionary, evolves: should the adherence level be integrated in the efficacy criteria of the preventive measures and PPE? Such vision may be proposed to stimulate more innovative designs of tools and strategies that would enable better tolerance and adherence with lesser efforts and risk of error or misuse. The health, societal, and economic impact of the COVID-19 crisis should not only trigger innovation in research and technology (35), but open our vision to more holistic approaches to design and performance appraisal.

COVID-19 as an "occupational disease"

Findings from the present study bring forward the question whether COVID-19 should be considered as an occupational disease. This concern was expressed early at the beginning of the pandemic, and was presented as a continuous learning from major historical respiratory epidemics and pandemics where frontline workers incurred disproportionate morbidity and mortality compared to the general population (36–38). Occupational disease is a legal designation that involves financial compensation of the victims; however, the definition of the concept may differ depending on the country's policy. A highly cited study from Italy showed that, as of May 2020, 19.4% of the total COVID-19 cases were classified as being occupationally acquired, resulting in compensation claims applications in 67.6% of the cases. Furthermore, 71.6% of the total compensation claims applications for COVID-19 originated from the healthcare and social sector (39). Nevertheless, by the time of writing this paper, i.e. in October 2021, COVID-19 is still not considered as an occupational disease in Italy but as a work accident, although 17 other countries of the European Union have already recognized it as an occupational disease (40). On the other hand, by the end of 2020, several countries such as Argentina, Japan, South Africa, and the USA had accepted COVID-19 as an occupational disease, subject or not to fulfilling certain criteria (41).

In the ongoing COVID-19 crisis, as in other comparable epidemics such as the severe acute respiratory syndrome (SARS) and Middle Eastern respiratory syndrome (MERS), recognition of the occupational status of the disease may constitute a key step for a better anticipation of the crisis impact on HCWs and consequently on the health care system. Furthermore, such measure enables considering both the acute effects as well as the delayed or persistent manifestations of the disease and the eventual related chronic functional deficits (42–45). On the other hand, some may argue that what applies to HCWs should apply to all likely exposed professions such as the police and military officers, firefighters, social workers, bus drivers, etc. (46). However, it would be reasonable and more pertinent to weigh the level of the occupational risk and consider the evidence-based disparities in morbidity and mortality between the different professions. A study by Zhang M. attempted to model the differential risk of COVID-19 infection by occupation group, using real world data. The model showed that the approximately 48% of COVID-19 risk is explained by the level of exposure and physical proximity, and that HCWs are at the top of the exposure list notably those in dental care (47). Such consideration should be added to the level of activity during lockdown periods, which differed across the different sectors and incontestably impacted the level of occupational exposure (39).

In line with the previous observations and hypotheses, our study demonstrated the importance of occupational factors in the risk of COVID-19 infection among HCWs. The ROC curve model showed the substantial contribution of the occupational levels of exposure to COVID-19 by substruction from the cumulative occupational and community exposure model. These findings were supported by the correlation analyses that showed a relative consistency of exposure levels with the perceived source of infection. For example, the community exposure score was inversely correlated with the likelihood of being infected by a patient ($R = -0.31$, $p<0.001$) and positively correlated with the likelihood of being infected by a member of the household ($R = 0.20$, $p=0.003$). On the other hand, the level of exposure to high-risk care situations was positively correlation with the likelihood of being infected by a patient in the facility ($R = 0.24$, $p<0.001$). This further suggests that the HCWs may have a certain level of discernment towards the potential source of infection. Although such model does not allow determining the source of infection at the individual level, it supports the relevance of considering COVID-19 as an occupational disease.

Differential risk within the same profession: anticipated versus unanticipated risks

Besides considering the differential risk of COVID-19 infection across the different occupations, we should also consider the specific hazards associated with certain roles and procedures within the same profession. Our study demonstrates a high disparity in the risk of COVID-19 infection among HCWs depending on the nature of care situations and procedures they were frequently performing, besides other more specific factors that will be discussed in the subsequent section.

What was interesting to note is that the level of exposure to high-risk care situations was independently associated with 1.2-fold risk of COVID-19 infection, while the level of exposure to high-risk procedures was not significant in the same multivariate model. This is probably explained by the level of protection and precaution being anticipatingly increased when performing a high-risk procedure, while high-risk care situations - such as close contact with a patient or patient transportation - may often be unanticipated. By assuming that the days are over when shortages of personal protection equipment (PPE) constituted the major factor of vulnerability among HCWs, such observation and hypothesis take the analysis further. Indeed, this suggests that the major threat of occupational COVID-19 remaining for HCWs resides in unintended circumstances coinciding with low levels of alertness. Early studies from Wuhan, China, where the COVID-19 pandemic emerged, showed that suboptimal practice in hand hygiene or inappropriate use of PPE before routine care were associated with up to 465-fold risk of infection, by reference to appropriate PPE use while performing high-risk procedures (48,49). This highlights the importance of adjusting the baseline level of alertness and protection considering these unintended hazard situations, besides the specific measures for high-risk procedures or activities. Further measures and preventive strategies may be implemented in the care facilities to reduce the overall hazard level of the working environment regardless of the specific exposure to high-risk care situations.

Other occupational risk factors of COVID-19

Among the specific risks that are worth highlighting is the role of inadequate mask fit testing as a risk factor for COVID-19 infection in the occupational setting. The present study showed that HCWs who used respirators without performing a fit test were exposed to a 1.85-fold risk of COVID-19 infection independent from any other cofactors. This is consistent with a randomized clinical trial that compared non-fitting and fitted N95/FFP2 masks among HCWs, and demonstrated that N95/FFP2 respirators provide twice greater protection from viral respiratory infections (50). The mask fit testing principle consists of ensuring that the model, type and size of the facepiece of the respirator are suitable to the HCW's face shape so that no air or particles may leak in or out. Although the fit testing should be done by a competent person at the selection of the respirator for the given HCW, HCWs should be enabled to correctly perform fit checking every time they wear the respirator. A well-fitted N95/FPP2 respirator is assigned a protection factor superior to 10, which means that it enables reducing "the number of inhaled particles by at least 10-fold" (51).

Another major occupational risk factor is the affiliation of the HCWs including the type and bad capacity of the facility and the nature or specialty of the department. By reference to the Ministry of Health (MoH) hospitals and low bed capacity facilities (<50 beds), non-MoH governmental hospitals and high bed capacity facilities (>200 beds) were respectively associated with approximately 5.8- and 3.6-fold risk of COVID-19 infection. Likewise, emergency room, ICU and isolation ward were associated with a 2.2-fold risk of infection, independent from the other cofactors.

Other interesting findings from the present study support a strong intersection between professional and demographic factors, resulting in some specific risk profiles that are worth determining in an integrated strategy. Bivariate analysis showed that the prevalence of COVID-19 infection was significantly higher among HCWs aged 30-49 years (OR=1.38) as well as those from certain nationalities (OR=1.36). Such disparities are probably related to the elective distribution of healthcare professions across the demographic characteristics, which confound the level of exposure and the resulting risk of COVID-19.

In line with these observations, several local studies have reported single or multicenter data of COVID-19 infection among HCWs, and some of them have attempted to characterize the source of infection using various methods. A single-center study by Barry et al. that was conducted among 2,131 HCWs, from 2 March to 31 December 2020, showed a COVID-19 prevalence of 8.7% and nurses and therapists accounted for 60% of the cases (52). Another single-center study from Riyadh analyzed the levels of occupational exposure among 1,170 HCWs with confirmed COVID-19 infection, who were enrolled between March – July 2020. Result showed that working in highly exposed areas was associated with younger age and female gender, in addition to other professional factors such as the nursing profession, direct patient care and 12-hour working shift (53). Another seroprevalence study including 85 Saudi hospitals demonstrated that seropositivity rate was 3.6-fold higher among HCWs affiliated in COVID-19 referral hospitals compared with their counterparts (54). Internationally, a Mexican cohort of 500,920 HCWs who were involved between March to December 2020, concluded that the infection rates among COVID-19 teams versus other active healthcare workers were 20.1% versus 13.7% respectively (55). These studies agree in demonstrating that professional exposure to and risk of COVID-19 differs by type of setting and HCW's position, which may interact with the sociodemographic features. On the other hand, they suggest that the sole consideration of these factors would not enable determining a consistent risk profile throughout the settings and populations. This emphasizes the importance of analyzing local data for more accurate risk assessment and more efficient preventive strategies.

Community source of infection among HCWs

Although the present study findings support the significant contribution of occupational exposure in explaining the high prevalence of COVID-19 among HCWs, it does not undermine the significance of community risk. The study model showed that, for every 1-increment of the community exposure score that ranges between 0-10, the risk of COVID-19 is independently increased by 7%. Nevertheless, the weight of community-acquired COVID-19 among HCWs was estimated to be more important in several studies, using various methods. In the study by Barry et al., the use of contact tracing-based criteria to determine the mode of COVID-19 transmission among the 203 infected HCWs showed that community transmission accounted for 90.6% of the cases, while the remaining 9.4% were healthcare-associated (52). Another multiregional study from Switzerland, by Kahlert et al., analyzed the risk of COVID-19 infection associated with the levels of exposure to various non-occupational and occupational risk factors in 17 institutions. Results showed that having a COVID-19 positive person in the household was the strongest risk factor for infection with an adjusted OR of 59, while contact with an infected patient or coworker were associated with 2.7 and 1.9 OR (56).

To conclude, the characterization of the source of infection warrants more research that may require more advanced methods, such as phylogenetic research, which would enable better understanding of the nosocomial kinetics of the pandemic.

Limitations and strengths

The main limitations of the present study include: the voluntary participation that may induce selection bias; the self-reported exposure that exposes to high risk of recall bias; the self-assessed adherence to preventive measures, which lacks of reliability and comprises a risk of social acceptability bias; and the exclusion of mortality cases, which impacts the internal validity of the prevalence estimation. On the other hand, the study comprised of a comprehensive assessment of occupational and community exposure and risk situations, which enabled computing and testing different cumulative exposure scores.

Conclusion

The increased risk for COVID-19 infection among HCWs is a multifactorial and multifaceted issue with several epidemiological, clinical, public health and legal implications. The contribution of occupational exposure is likely to be substantial, notably among those working in high-risk areas and those who are frequently exposed to unintended high-risk care situations. It is of critical importance to enhance the baseline level of alertness and protection considering these unintended hazard situations, besides the specific measures for high-risk procedures or activities. Further measures and preventive protocols may be implemented in the care facilities to reduce the overall hazard level of the working environment regardless of the specific exposure to high-risk care situations. There is room for innovation in the design and conceptualization of personal protective equipment and in-hospital preventive strategies that enable better adherence and practicality while reducing mistakes attributable to the human factor.

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