Journal of Microbiology, Immunology and Infection 56 (2023) 537—546

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.e-jmii.com

Original Article

Risk categorization and outcomes among healthcare workers exposed to COVID-19: A cohort study from a Thai tertiary-care center

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Received 30 May 2022; received in revised form 29 December 2022; accepted 10 January 2023
Available online 20 January 2023

KEYWORDS
Risk categorization;
Exposure;
COVID-19;
Healthcare worker;
Thailand

Abstract *Background:* A risk categorization tool for healthcare workers (HCWs) exposed to COVID-19 is crucial for preventing COVID-19 transmission and requires validation and modification according to local context.
Methods: From January to December 2021, a prospective cohort study was conducted among Thai HCWs to evaluate the performance of the specifically-created risk categorization tool, which classified HCWs into low-risk (LR), intermediate-risk (IR), and high-risk (HR) groups based on types of activities, duration of exposure, and protective methods used during exposure. Subsequent measures were determined for the HCWs based on the risk categories.
Results: 1891 HCWs were included; 52%, 25% and 23% were LR, IR, and HR, respectively. COVID-19 was diagnosed in 1.3%, 5.1% and 27.3% of LR, IR and HR HCWs, respectively ($P < 0.001$). Independent factors associated with COVID-19 were household or community exposure [adjusted odds ratio (aOR), 1588.68; $P < 0.001$), being HR (aOR, 11.94; $P < 0.001$), working at outpatient departments (aOR, 2.54; $P < 0.001$), and no history of COVID-19 vaccination (aOR, 2.05; $P = 0.01$). The monthly rates of COVID-19 among LR, IR, and HR HCWs significantly decreased after the incremental rate of full vaccination. In-hospital transmission between HCWs occurred in 8% and was mainly due to eating at the same table.
Conclusion: The study risk categorization tool can differentiate risks of COVID-19 among the HCWs. Prevention of COVID-19 should be focused on HCWs with the identified risk factors and

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https://doi.org/10.1016/j.jmii.2023.01.011

behaviors associated with COVID-19 development and encouraging receipt of full vaccination.

Introduction

Healthcare workers (HCWs) are front-line workers in the coronavirus disease 2019 (COVID-19) pandemic and are at higher risk of severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) acquisition than general population. A systematic review and meta-analysis study has reported the global prevalence of COVID-19 among HCWs to be 11%,[1] while the prevalence among world population has been approximately 5%.[2] In Thailand, the alpha and delta variants of SARS-CoV-2 were the major causes of COVID-19 epidemics and affected more than 2 million people in 2021. The prevalence of COVID-19 among Thai HCWs was 7.75% which was higher than the prevalence of the country's general population (4.49%).[2] During the epidemics, COVID-19 had significant impacts not only on HCWs' health but also their work in regards to sick leave, being isolated if they get infected, being quarantined if they have high-risk contacts and increased workload to substitute other infected or quarantined HCWs.

Generally, HCWs can acquire COVID-19 from contact with SARS-CoV-2 infected individuals including household members, patients and other HCWs. Previous studies have identified risk factors for in-hospital transmission of COVID-19 among HCWs, which include prolonged periods of patient care, performing aerosol generating procedures, lack of adequate personal protective equipment (PPE) and inadequate compliance to infection prevention and control (IPC) policies.[3–5] To prevent in-hospital transmission of COVID-19, the United States Centers for Disease Control and Prevention (CDC) has published the guidance for risk assessment and public health management of HCWs with potential exposure to patients with COVID-19 in a healthcare setting and recommended appropriate monitoring and work restriction for HCWs based on duration of close contact, presence of source control, and PPE use.[6] The CDC's 3- level risk classification has been shown to differentiate COVID-19 risks among HCWs in the previous study.[7] However, outcomes in regards to in-hospital COVID-19 transmission after implementation of the risk classification and management have not been evaluated.

During the alpha and delta variant-dominant epidemics in Thailand, investigations and risk assessment have been conducted for a number of HCWs contacted with COVID-19 cases by our IPC nurses and physicians. Challenges included difficulties in categorizing HCWs to the different risk levels because the exposed HCWs reported characteristics and types of at-risk activities and behaviors different and more in detailed than those described and defined in the CDC's risk classification. Therefore, the IPC team had created a new COVID-19 risk categorization tool incorporating all relevant and detailed risk characteristics consistent with the hospital local context. This study aimed at evaluating the performance of the specifically-created risk categorization tool, determining factors associated with SARS-CoV-2 acquisition and assessing related outcomes and in-hospital transmission among HCWs.

Methods

Study design and setting

A prospective cohort study was conducted among all HCWs who exposed to persons with confirmed COVID-19 during the period from January 1st to December 31st, 2021, at Thammasat University Hospital in Pathumthani, Thailand. The hospital is a 734-bed tertiary-care medical center in central Thailand and employed a total of 5996 HCWs in 2021. This study was approved by the Human Research Ethics Committee of Thammasat University (Medicine). Consent was obtained from all participating HCWs.

Study protocol

According to our hospital IPC protocols during the COVID-19 epidemic, HCWs were required to report all of their COVID-19 exposures to the IPC department regardless of whether they had or did not have symptoms consistent with COVID-19. The exposures were subsequently investigated by trained infection control nurses and infectious disease specialists to categorize the HCWs into three-level risk groups; low-risk exposure (LR), intermediate-risk exposure (IR), and high-risk exposure (HR) based on the study risk categorization tool. The tool was created by the IPC team and modified from the CDC recommendations.[6] Additional risk characteristics and behaviors had been added to the tool as they were described in details by the HCWs during the investigations (Supplementary Table 1 and Supplementary Fig. 1). A HCW with any exposure characteristics with the high risk level will be regarded as being in the high-risk group. In case a HCW had exposure characteristics with more than one risk levels, he or she will be categorized to the highest risk level. All HCWs exposed to COVID-19 were required to follow the hospital IPC measures for monitoring and follow-up (Supplementary Fig. 2). These measures indicate the need for serial SARS-CoV-2 real-time polymerase chain reaction (RT-PCR) testing, quarantine, appropriate mask wearing, maintaining physical distancing ($\geq$2 m) while dining and when attending hospital activities, and performing hand hygiene according to the World Health Organization's 5 moments.[8] In addition, use of an N95 respirator, face shield/googles, gloves and gown were required when performing aerosol generating procedures. All of the HCWs with COVID-19 exposure were followed-up

for COVID-19 development during the 14-day observation period, clinical characteristics and outcomes of COVID-19, and subsequent in-hospital transmission.

Data collection and outcome measurement

The collected data included demographics, comorbidities, occupation, source of risk exposure, type of exposure, the use of PPE during exposure, COVID-19 vaccination history, subsequent RT-PCR test results, symptoms and clinical outcomes of COVID-19. The severity of COVID-19 was classified based on the World Health Organization's criteria.[9] The primary outcome was the difference in rates of COVID-19 development in the LR, IR and HR HCWs. The secondary outcomes included the factors associated with COVID-19 among HCWs, the rate of and factors associated with in-hospital COVID-19 transmission, and clinical manifestations and outcomes among HCWs.

Statistical analysis

All analyses were performed using IBM SSPS Statistics version 26 software (IBM Corp., Armonk, NY, USA). Descriptive data were described in numbers, percentages and a median with interquartile range (IQR). Categorical data were compared using a chi-square test or Fisher's exact test as appropriate while continuous data were compared using Mann Whiney U test. All *P* values were 2-tailed, and $P < 0.05$ was considered statistically significant. Variables that were significantly associated with COVID-19 development at a significance level of P less than 0.20 in univariable analyses or had been previously reported to be significant factors were entered into backward stepwise logistic regression models. Adjusted odd ratios (aORs) and 95% confidence interval (CI) were calculated in multivariable logistic regression analysis to determine factors associated with COVID-19 development among the HCWs.

Results

Characteristics of the study HCWs (Table 1)

During the study period, there were 1891 HCWs exposed to persons with confirmed COVID-19. Of these HCWs, 984 (52%), 467 (25%) and 440 (23%) were categorized into LR, IR, and HR groups, respectively. The median age of HCWs was 30 years (IQR, 26—36 years), female sex predominated (1485/1891; 79%), and the median body mass index was 22.8 kg/m^2 (IQR, 20.3—25.8 kg/m^2). Most of HCWs had no comorbidities (1455/1891; 77%), while 6% (107/1891) had hypertension, and 4% (78/1891) had diabetes mellitus. The majority of HCWs were nurses (625/1891; 33%), assistant nurses (438/1891; 23%), and physicians (347/1891; 18%) and worked in non-COVID-19 inpatient departments (912/1891; 48%). The most common source of risk exposure were HCWs (59%), and the three most common risk activities were being in the same room with closed space without wearing a mask (75%), sleeping in the same on-duty rooms without wearing a mask (29%) and poor adherence to hand hygiene (24%). Comparing between HR and LR HCWs, HR HCWs were younger (29 vs. 30 years) and had a higher proportion of HCWs who were physician (21% vs. 16%), worked in non-COVID-19 inpatient departments (50% vs. 42%) or outpatient departments (15% vs. 9%) and exposed COVID-19 in household (7% vs. 0%) or community sources (9% vs. 0%).

COVID-19 development among the study HCWs

During the 14-day observation period, 157 HCWs (8%) developed COVID-19. The rates of COVID-19 development were significantly different between each risk group ($P < 0.001$). The highest rate was in HR group (27.3%), followed by IR group (5.1%) and LR group (1.3%). Comparing characteristics between the HCWs with and without subsequent COVID-19 development (Table 2), those with COVID-19 were more-likely to be male (19% vs. 14%) and assistant nurse (30% vs. 23%), worked at outpatient departments (24% vs. 10%), had household exposure (22% vs. 0%) and community exposure (26% vs. 0%), and had no history of COVID-19 vaccination (15% vs. 4%). By multivariable logistic regression analysis, factors associated with COVID-19 among the HCWs included household or community exposure (aOR, 1588.68; $P < 0.001$), being HR (aOR, 11.94; $P < 0.001$), working at outpatient departments (aOR, 2.54; $P < 0.001$), and no history of COVID-19 vaccination (aOR, 2.05; $P = 0.01$) (Table 3). The aORs of low-, intermediate-, and high-risk groups for development of COVID-19 after adjusting for community/household exposure were 0.15 (95% CI 0.08—0.27; $P < 0.001$), 0.83 (95% CI 0.49—1.40; $P = 0.45$), and 7.12 (95% CI 4.50—11.27; $P < 0.001$), respectively. Among the high-risk HCWs, the rates of COVID-19 development among those who worked in COVID-19 inpatients departments (19.3%) and outpatient departments (13.8%) were significantly higher than the rates among those working in non-COVID-19 inpatient department (3.6%) and the emergency department (4.1%). The rates of COVID-19 development were also significantly higher among HCWs working in COVID-19 inpatients departments than those working in non-COVID-19 inpatient department for intermediate-risk groups (5.3% vs. 0.9%; $P = 0.02$) and high-risk groups (19.2% vs. 3.6%; $P < 0.001$), while the rates were comparable for low-risk groups (0% vs. 1.1%).

Of the 157 HCWs who developed COVID-19, 19 (12%) were asymptomatic, 126 (80%) had mild disease, and 12 (8%) had moderate disease. Among those with symptomatic COVID-19, common symptoms were fever (81%), cough (69%), sore throat (51%) and nasal congestion or rhinorrhea (44%). The median cycle threshold for RT-PCR test was significantly lower in symptomatic compared to asymptomatic HCWs with COVID-19 (18.8 vs. 22.6; $P = 0.007$). All of the HCWs with COVID-19 completely recovered by day 14 after the diagnosis. When analyzing the monthly data, the rate of COVID-19 among LR, IR, and HR HCWs significantly decreased after the incremental rate of full vaccination (at least 2 doses of viral vector or mRNA COVID-19 vaccines or 2 doses of inactivated vaccine with one booster dose of viral vector or mRNA vaccine) among the HCWs (Fig. 1). There were no cases of COVID-19 in any risk groups in the last trimester of 2021 as the rate of full vaccination went up to 27.17%.

Table 1 Characteristics and SAR-CoV-2 positivity rate of healthcare workers (HCWs) who exposed to persons with confirmed coronavirus diseases 2019 (COVID-19) stratified by risk category.

Characteristics	Total (n = 1891)	Risk categorization[a]			*P* value[b]
		LR (n = 984)	IR (n = 467)	HR (n = 440)	
Age, years, median (IQR)	30 (26–36)	30 (26–37)	29 (26–34)	29 (26–35)	0.003
Female,	1485 (78.5)	762 (77.4)	367 (78.6)	356 (80.9)	0.337
Comorbidities					
Previously healthy	1455 (76.9)	776 (78.9)	335 (71.7)	344 (78.2)	0.008
Diabetes Mellitus	78 (4.1)	35 (3.6)	26 (5.6)	17 (3.9)	0.189
Hypertension	107 (5.7)	41 (4.2)	40 (8.6)	26 (5.9)	0.003
Dyslipidemia	73 (3.9)	36 (3.7)	23 (4.9)	14 (3.2)	0.353
Pulmonary disease	29 (1.5)	9 (0.9)	10 (2.1)	10 (2.3)	0.073
Others[c]	267 (14.1)	142 (14.4)	74 (15.8)	51 (11.6)	0.170
Body Mass Index, kg/m^2, median (IQR)	22.8 (20.3–25.8)	22.7 (20.4–26.0)	22.4 (20.0–25.4)	23.1 (20.3–25.6)	0.425
Occupation					<0.001
Physician	347 (18.4)	154 (15.7)	100 (21.4)	93 (21.1)	
Nurse	625 (33.1)	352 (35.8)	160 (34.3)	113 (25.7)	
Assistant nurse	438 (23.2)	223 (22.7)	102 (21.8)	113 (25.7)	
Pharmacist or assistant pharmacist	56 (3)	39 (4)	5 (1.1)	12 (2.7)	
Laboratory technician	14 (0.7)	1 (0.1)	1 (0.2)	12(2.7)	
Medical or nursing student	78 (4.1)	45 (4.6)	21 (4.5)	12 (2.7)	
Other HCWs with patient contact[d]	126 (6.7)	53 (5.4)	37 (7.9)	36 (8.2)	
Other HCWs without patient contact[e]	206 (10.9)	117 (11.9)	41 (8.8)	48 (10.9)	
Working place					<0.001
COVID-19 inpatient department	57 (3)	18 (1.8)	8 (1.7)	31 (7)	
Non COVID-19 inpatient department	912 (48.2)	416 (42.3)	275 (58.9)	221 (50.2)	
Outpatient department	210 (11.1)	90 (9.1)	53 (11.3)	67 (15.2)	
Emergency department	217 (11.5)	180 (18.3)	26 (5.6)	11 (2.5)	
Laboratory department	14 (0.7)	1 (0.1)	1 (0.2)	12(2.7)	
Radiology department	63 (3.3)	28 (2.8)	27 (5.8)	8 (1.8)	
Operation room	135 (7.1)	74 (7.5)	22 (4.7)	39 (8.9)	
Others[f]	283 (15)	178 (18)	56 (12)	49 (11.1)	
Source of risk exposure[g]					<0.001
Patient	697(36.9)	346 (35.2)	229 (49)	122 (27.7)	
Healthcare worker	1119 (59.2)	638 (64.8)	232 (49.7)	249 (56.6)	
Household	35 (1.9)	0 (0)	4 (0.9)	31 (7)	
Community	40 (2.1)	0 (0)	2 (0.4)	38 (8.6)	
Risk exposure activities					
Eating at the same non-partitioned table	140 (7.4)	15 (1.5)	9 (1.9)	116 (26.4)	<0.001
Eating at the same partitioned table	135 (7.1)	9 (0.9)	21 (4.5)	105 (23.9)	<0.001
Sleeping in the same room (both did not wear a mask)	55 (29)	0 (0)	1 (0.1)	54 (12.3)	<0.001
Being in the same room (both did not wear a mask)					
Closed space (≤15 m^2)	658 (34.8)	130 (13.2)	264 (56.5)	264 (60)	<0.001
Closed space (>15 m^2)	768 (40.6)	575 (58.4)	131 (28.1)	62 (14.1)	<0.001
Open space	395 (20.9)	276 (28)	69 (14.8)	50 (11.4)	<0.001
Face-to-face contact within distance of <2 m (wearing mask)	1667 (88.2)	962 (97.8)	334 (71.5)	371 (84.3)	<0.001
Poor adherence to hand washing	459 (24.3)	180 (18.3)	161 (34.5)	118 (26.8)	<0.001
Performing aerosol generating procedures without wearing N95 mask	103 (5.4)	10 (1)	20 (4.3)	73 (16.6)	<0.001
Duration of risk exposure activities, minutes, median (IQR)	5 (5–10)	5 (3–5)	10 (10–10)	15 (15–30)	<0.001

Table 1 (*continued*)

Characteristics	Total (n = 1891)	Risk categorization[a]			*P* value[b]
		LR (n = 984)	IR (n = 467)	HR (n = 440)	
Protective method during exposure to COVID-19					
N95 mask with a covering surgical mask	70 (3.7)	67 (6.8)	0 (0)	3 (0.7)	<0.001
N95 mask only	64 (3.4)	45 (4.6)	19 (4.1)	0 (0)	<0.001
Surgical mask with a covering cloth mask	974 (51.5)	552 (56.1)	310 (66.4)	112 (25.5)	<0.001
Surgical mask only	343 (18.1)	296 (30.1)	41 (8.8)	6 (1.4)	<0.001
Face shield or goggles with a mask or two masks	576 (30.5)	523 (53.2)	50 (10.7)	3 (0.7)	<0.001
Gloves	422 (22.3)	229 (23.3)	120 (25.7)	73 (16.6)	0.003
Gown	177 (9.4)	93 (9.5)	80 (17.1)	4 (0.9)	<0.001
Medical hair cover	52 (2.7)	32 (3.3)	20 (4.3)	0 (0)	<0.001
RT-PCR for SAR-CoV-2 positivity	157 (8.3)	13 (1.3)	24 (5.1)	120 (27.3)	<0.001

NOTE.
IQR = interquartile range; RT-PCR = real-time polymerase chain reaction; SARS-CoV-2 = severe acute respiratory syndrome coronavirus-2.
Data are in numbers (%), unless indicated otherwise.
[a] Based on Thammasat University Hospital Infection Prevention and Control protocol for risk assessment and measures for HCWs with risk exposure to SARS-CoV-2.
[b] Comparison between HCWs who had low, intermediate, and high-risk exposure to persons with confirmed COVID-19.
[c] Included thyroid diseases, allergic rhinitis, chronic hepatitis B, gastroesophageal reflux disease, benign prostatic hyperplasia, obstructive sleep apnea, and systemic lupus erythematosus.
[d] Included physical therapists, radiologic technicians, maids, and patient transporters.
[e] Include clerks, security guards, and gardeners.
[f] Included nursing department, physical therapy department, planning and finance department, medical supplies department.
[g] Household acquired COVID-19 is defined as symptoms' onset or positive SAR-CoV-2 RT-PCR within 14 days after last contact with persons in the same household with COVID-19. Community acquired COVID-19 is defined as symptoms' onset or positive SAR-CoV-2 RT-PCR within 2 days after admission (or within 7 days with a strong suspicion of community transmission).

In-hospital COVID-19 transmission

Among the 157 HCWs with COVID-19, 12 (8%) developed COVID-19 after in-hospital HCW to HCW transmission. The transmission between HCWs mainly occurred when the HCWs ate together at the same tables (7/12; 58%) (Table 4). Mostly, each one of the index HCWs transmitted SARS-CoV-2 to only one of these 12 HCWs. However, there was one index HCW transmitted the virus to the other 2 HCWs of the 12 HCWs as he had worked in three different areas including an operating room, an intensive care unit, and an outpatient department.

Discussion

This study evaluates the performance of a specifically-created risk categorization tool for HCWs exposed to COVID-19 during the alpha and delta variant-dominant epidemics in Thailand. The main findings suggest that the study risk categorization tool can differentiate risks of COVID-19 among the HCWs with a clear dose–response relationship between exposure intensity and infection rates. These findings are consistent with those reported from a previous study which evaluated the performance of the Centers for Disease Control and Prevention (CDC)'s 3-level risk classification in the real-world setting.[7] However, in our risk categorization tool, several detailed risk characteristics and activities had been added to the tool to better categorize the risks and provide appropriate measures for the HCWs base on their risk levels. The modification included adding detailed risk characteristics, such as duration of exposure to, space of a room staying together with, distance and duration of taking with, use of partition when having food with, and use of double masking when contacting persons with COVID-19 to the tool. Among the high-risk group, the risk of developing COVID-19 is higher for high-risk HCWs working in COVID-19 inpatient departments and outpatient departments than those working in other departments. These indicate that the application of our risk categorization tool should be especially considered in these high-risk departments.

We have identified a number of factors associated with COVID-19 among the exposing HCWs. These included household or community exposure, being categorized in the HR group, working at outpatient departments, and no history of COVID-19 vaccination. The rate of household transmission among our HCWs was 22.3% in this study which was higher than the rate reported in a Turkish study of 5.9%.[10] This finding was likely due to the fact that most of Thai families are large (average of 3.5 people per household)[11] which increases the risk of SARS-CoV-2 transmission[12] and once one of the family members is infected, it is difficult for him or her to self-isolate at home. Household or community was the more common source of COVID-19 exposure than a healthcare setting for our HCWs, consistent with reports from other studies.[13–15] This was likely due to the more compliance to infection control

Table 2 Comparison of characteristics between exposing healthcare workers (HCWs) with and without subsequent coronavirus disease 2019 (COVID-19) development.

Characteristics	COVID-19 (n = 157)	No COVID-19 (n = 1734)	*P* value[a]
Age, years, median (IQR)	31 (26—40)	29 (26—36)	0.133
Female	135 (86)	1350 (90.9)	0.017
Occupation			<0.001
Physician	16 (10.2)	331 (19.1)	
Nurse	34 (21.7)	592 (34.1)	
Assistant nurse	47 (29.9)	391 (22.5)	
Pharmacist or assistant pharmacist	3 (1.9)	53 (3.1)	
Laboratory technician	4 (2.5)	10 (0.6)	
Medical or nursing practitioner	0 (0)	78 (4.5)	
Other HCWs with patient contact[b]	25 (15.9)	101 (5.8)	
Other HCWs without patient contact[c]	28 (17.8)	178 (10.3)	
Working place			<0.001
COVID-19 inpatient department	14 (8.9)	43 (2.5)	
Non COIVD-19 inpatient department	51 (32.5)	861 (49.7)	
Outpatient department	37 (23.6)	173 (10)	
Emergency department	10 (6.4)	207 (11.9)	
Laboratory department	4 (2.5)	10 (0.6)	
Radiology department	4 (2.5)	59 (3.4)	
Operation room	12 (7.6)	123 (7.1)	
Others[d]	25 (15.9)	258 (14.9)	
Source of risk exposure[e]			<0.001
Patient	70 (44.6)	627 (36.2)	
Healthcare worker	12 (7.6)	1107 (63.8)	
Household	35 (22.3)	0 (0)	
Community	40 (25.5)	0 (0)	
History of COVID-19 vaccination			<0.001
None	23 (14.6)	70 (4)	
At least one dose	15 (9.6)	82 (4.7)	
Two doses	101 (64.3)	1184 (68.3)	
Three doses	18 (11.5)	398 (23)	
One dose of vaccination			
CoronaVac	9 (5.7)	24 (1.4)	<0.001
ChAdOx1	6 (3.8)	58 (3.3)	0.752
Two doses of vaccination			
CoronaVac + CoronaVac	92 (58.6)	1091 (62.9)	0.284
ChAdOx1 + ChAdOx1	9 (5.7)	89 (5.1)	0.745
CoronaVac + ChAdOx1	0 (0)	2 (0.1)	0.670
CoronaVac + BNT162b2	0 (0)	1 (0.1)	0.763
ChAdOx1 + BNT162b2	0 (0)	1 (0.1)	0.763
Three doses of vaccination			
CoronaVac + CoronaVac + ChAdOx1	15 (9.6)	288 (16.6)	0.021
CoronaVac + CoronaVac + BNT162b2	3 (1.9)	110 (6.3)	0.025
Duration from the last dose of COVID vaccine and the time of risk exposure, days, median (IQR)	63 (35—90)	63 (26—36)	0.363
Duration of risk exposure activities, minutes, median (IQR)	15 (10—20)	5 (5—10)	<0.001
Risk categorization			<0.001
Low risk	13 (8.3)	971 (56)	
Intermediate risk	24 (15.3)	443 (25.5)	
High risk	120 (76.4)	320 (18.5)	

NOTE.
Data are in numbers (%), unless indicated otherwise.
[a] Comparison between at-risk HCWs with and without subsequent COVID-19 development.
[b] Included physical therapists, radiologic technicians, maids, and patient transporters.
[c] Include clerks, security guards, and gardeners.
[d] Included nursing department, physical therapy department, planning and finance department, medical supplies department.
[e] Household acquired COVID-19 is defined as symptoms' onset or positive SAR-CoV-2 RT-PCR within 14 days after last contact with persons in the same household with COVID-19. Community acquired COVID-19 is defined as symptoms' onset or positive SAR-CoV-2 RT-PCR within 2 days after admission (or within 7 days with a strong suspicion of community transmission).

Table 3 Multivariable logistic regression analysis for factors associated with coronavirus disease 2019 (COVID-19) development in the healthcare workers (HCWs).

Factors	Adjusted OR (95% CI)	*P* value
Household or community exposure	1588.68 (218.24–11564.84)	<0.001
High risk exposure	11.94 (7.69–18.53)	<0.001
Working at outpatient departments	2.54 (1.61–4.00)	<0.001
No history of COVID-19 vaccination	2.05 (1.17–3.61)	0.012
Assistant nurse	1.23 (0.82–1.85)	0.325
Duration of exposure	1.00 (0.99–1.03)	0.394
Male sex	0.60 (0.36–1.00)	0.053

NOTE: CI = confidence interval; OR = odds ratio.

measures for COVID-19 while the HCWs worked in healthcare settings than when they were at home or a community. Working at outpatient departments was at increased risk for acquiring SARS-CoV-2 than working in other departments in our study. This may be due to the higher number of patients whom the HCWs had to encounter and the difficulties to have all of these patients compliant with the hospital COVID-19 preventive measures in outpatient settings. Lastly, the HCWs who did not receive COVID-19 vaccination were at higher risk for COVID-19 development after exposure. This finding was consistent with those reported form other studies[16] and confirmed the effectiveness of COVID-19 vaccines.[17] In addition, our study also demonstrates that the rate of COVID-19 significantly decreased to 0% among LR, IR, and HR HCWs in the last trimester of 2021. This may be due to the fact that the rate of complete vaccination had increased among our HCWs during that period as well as the decrease in overall incidence of COVID-19 in the general Thai population. Our study reveals that HCWs who developed COVID-19 received 3-dose COVID-19 regimens (2 doses of CoronaVac + one dose of either ChAdOx1 or BNT162b2) in a significantly less proportion compared to those who did not develop COVID-19. These might indicate the requirement of at least 3 doses of vaccines (2 inactivated + 1 booster dose of viral vector or mRNA vaccine) to be effective in preventing COVID-19 as demonstrated in another study.[18] Altogether, these results suggest that prevention of COVID-19 among HCWs should focus on reducing risk behaviors, improving infection control compliance in household or community settings,[19,20] and while working at the high-risk areas such as outpatient departments. In addition, all HCWs are required to receive complete COVID-19 vaccination with at least one booster dose of viral vector or mRNA vaccine. Given the additional independent risk factors associated with COVID-19 identified in this study, further studies are needed to incorporate these factors into our original risk categorization tool and evaluate the performance of the revised tool in predicting COVID-19 and managing HCWs according to the risk level.

In this study, the rate of in-hospital HCW-to-HCW transmission was 7.6% which was lower than the reported rate from a systematic review and meta-analysis (51.7%).[21] The difference in the rates of transmission may be due to better compliance with the IPC measures after COVID-19 exposure of our HCWs than the other study's HCWs. We believe that the proposed infection control measures (shown in Supplementary Fig. 2) which include frequency of follow-up RT-PCR testing, duration of quarantine and

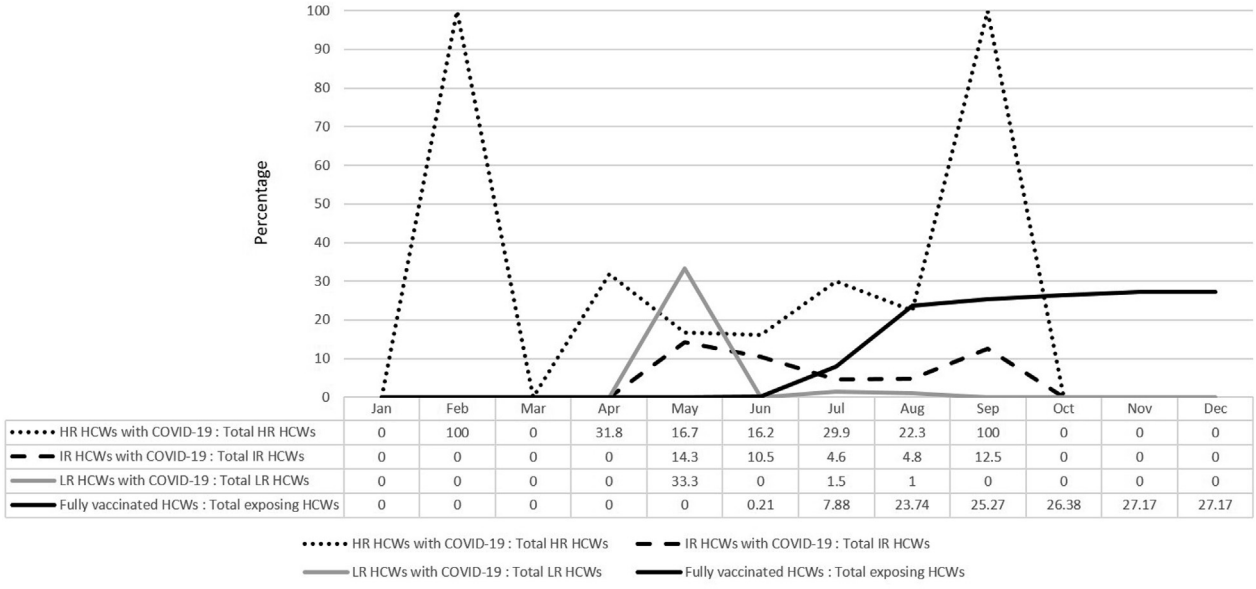

Figure 1. Monthly rates of full vaccination and COVID-19 development among healthcare workers (HCWs) with high-risk (HR), intermediate-risk (IR) and low-risk (LR) exposure. NOTE: Full vaccination was defined as HCW who received at least 2 doses of viral vector or mRNA COVID-19 vaccines or 2 doses of inactivated vaccine with one booster dose of viral vector or mRNA vaccine.

Table 4 Summary of the 12 healthcare workers (HCWs) who developed coronavirus disease 2019 (COVID-19) due to in-hospital transmission.

No.	Age	Sex	Occupation	Characteristics of risk exposure with another HCW with COVID-19	Duration of exposure (minute)	Location of exposure	PPE wearing	Risk level	Vaccination history	Severity of disease
1	37	Male	Physician	Eating at the same non-partitioned table	30	Common room	None	HR	CoronaVac, CoronaVac	Mild
2	37	Female	Assistant Nurse	Eating at the same non-partitioned table	30	Dining room	None	HR	CoronaVac, CoronaVac	Mild
3	42	Female	Assistant Nurse	Eating at the same non-partitioned table	30	Dining room	None	HR	CoronaVac, CoronaVac	Mild
4	24	Female	Assistant Nurse	Face-to-face contact within distance of <2 m	15	Ward	Surgical mask	IR	CoronaVac, CoronaVac	Mild
5	29	Female	Assistant Nurse	Being in the same room Closed space ≤ 15 m^2	30	Ward	Surgical mask	HR	CoronaVac, CoronaVac	Mild
6	42	Female	Assistant Pharmacist	Eating at the same non-partitioned table	30	Dining room	None	HR	CoronaVac, CoronaVac	Mild
7	28	Female	Assistant Nurse	Face-to-face contact within distance of <2 m	60	Ward	Double mask	IR	None	Mild
8	27	Female	Nurse	Eating at the same non-partitioned table	30	Dining room	None	HR	CoronaVac, CoronaVac	Mild
9	43	Female	Laboratory technician	Being in the same room Closed space ≤ 15 m^2	60	Laboratory	Surgical mask	HR	None	Mild
10	34	Female	Assistant Nurse	Eating at the same non-partitioned table	30	Dining room	None	HR	CoronaVac, CoronaVac	Mild
11	22	Female	Nurse	Eating at the same non-partitioned table	30	Dining room	None	HR	ChAdOx1	None
12	32	Female	Assistant Nurse	Being in the same room Closed space ≤ 15 m^2	30	Ward	Surgical mask	IR	CoronaVac, CoronaVac	None

duration of symptom observation for the different risk categories are appropriate since these measures were implemented based on the incubation period and natural history of COVID-19 caused by the current variants of SARS-CoV-2 at that time and were according to the national and international guidelines.[6] The activities mostly reported to be associated with the transmission in our study were eating at the same table and prolonged period of exposure in poorly ventilated rooms. These findings were similar to those reported in the previous study[22] and suggest that HCWs should have their meals at the different times, or keep distance for at least 2 m or use partitions if they need to have meals together, and avoid staying in the same room with poor ventilation (<1 L/s per person) for long period of time,[23] especially if a mask cannot be worn.

There are some recognizable limitations in this study. First, we used self-report and interviews to collect information in regards to at-risk activities and behaviors of the HCWs, which might lead to recall bias. However, the investigations that were conducted by a trained and experienced IPC team and used appropriate contact tracing questions and data collection technique should minimize this bias. Second, this was a single center study. The findings may not be generalizable to other settings with

differences in infection control measures and associated resources. Lastly, we did not assess SARS-CoV-2 variants, antibody levels against SARS-CoV-2 and other immunological responses after COVID-19 vaccination, which might impact the transmission and infection rates among the HCWs.

In conclusion, the study risk categorization tool, after modified according to the local context, has a good performance in differentiating risks of COVID-19 among the HCWs. The HCWs who are categorized as HR, expose COVID-19 in household or community settings, work in outpatient departments, and have not received or received incomplete vaccination should be monitored for compliance to infection control measures as they are at higher risk for COVID-19 development. The in-hospital HCW-to-HCW transmission can be prevented by avoidance of having meals at the same table and staying in the same room with poor ventilation for long period of time without wearing masks, in additional to the standard infection control measures.

Funding

None declared.

Declaration of competing interest

None declared.

Acknowledgement

We thank the personnel of Screening & Admissions unit, Infectious Control unit and Laboratory Department of Thammasat University Hospital for their contribution in data of this study.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jmii.2023.01.011.