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SOURCES OF HEALTHCARE WORKERS' COVID-19 INFECTIONS AND RELATED SAFETY GUIDELINES

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Abstract
Objectives: To evaluate the effectiveness of safety guidelines in the workplace, the authors analyzed the work-related exposure to SARS-CoV-2 and the source of COVID-19 infections among healthcare workers (HCWs), together with the use of personal protective equipment (PPE). **Material and Methods:** A cross-sectional prospective study was conducted in tertiary hospitals in the Uusimaa region, Finland, with 1072 volunteers being enrolled in the study from among the HCWs at the Helsinki University Hospital. Overall, 866 (80.8%) HCWs (including 588 nurses, 170 doctors, and 108 laboratory and medical imaging nurses) completed the questionnaire by July 15, 2020, with 52% of the participants taking care of COVID-19 patients. The participants answered a structured questionnaire regarding their use of PPE, the ability to follow safety guidelines, exposure to COVID-19, and the source of potential COVID-19 infections. The participants with COVID-19 symptoms were tested with the SARS-CoV-2 real-time polymerase chain reaction method. All infected participants were contacted, and their answers were confirmed regarding COVID-19 exposure. **Results:** In total, 41 (4.7%) participants tested positive for SARS-CoV-2, with 22 (53.6%) of infections being confirmed or likely occupational, and 12 (29.3%) originating from colleagues. In 14 cases (63.6%), occupational infections occurred while using a surgical mask, and all infections originating from patients occurred while using a surgical mask or no mask at all. No occupational infections were found while using an FFP2/3 respirator and following aerosol precautions. The combined odds ratio for working at an intensive care unit, an emergency department, or a ward was 3.4 (95% CI: 1.2–9.2, p = 0.016). **Conclusions:** A high infection rate was found among HCWs despite safety guidelines. Based on these findings, the authors recommend the use of FFP2/3 respirators in all patient contacts with confirmed or suspected COVID-19, along with the use of universal masking, also in personnel rooms. Int J Occup Med Environ Health. 2021;34(2):239–49

Key words:
occupational exposure, health personnel, COVID-19, masks, N95 respirators, infectious disease transmission

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INTRODUCTION

The spreading and infection rates of COVID-19 among healthcare workers

Generally, SARS-CoV-2 spreads mainly via droplets, secretions and direct contact [1]. Lately, the possibility of airborne transmission has been discussed even in the absence of aerosol-generating procedures (AGPs), especially indoors [2,3]. As SARS-CoV-2 appears to be more infectious than influenza, its reproductive number (R0) has been estimated to be as high as 2.3–5.7 [1,4–6]. Recent studies have shown that the infection rates among healthcare workers (HCWs) range 2.2–44% and exceed those of the general population, thus challenging healthcare providers to improve the safety of their personnel [7,8].

The first wave and restrictions in Finland

The COVID-19 infection reached the epidemic threshold in Finland in mid-March 2020, and the Finnish government declared a state of emergency which continued in the period of March 16–June 16, 2020. The primary focus was on social distancing with restrictions for travel, limitations of ≤10 persons at public gatherings, and recommendations to avoid spending time in public places. Additionally, visitors were banned from care institutions, healthcare units, and hospitals. The epicenter of the COVID-19 epidemic in Finland, the Uusimaa region, was isolated from the rest of the country between March 28–April 15, 2020. The Helsinki University Hospital (HUS) is an institution responsible for that region's specialized care, and its healthcare professionals are the focus of this article.

By July 15, 2020, Finland had recorded 7293 confirmed cases of COVID-19, 5223 of which were found in the HUS region, with a 0.3% infection rate [9]. In the HUS region, 794 (15.2%) of the infected persons were workers of social and healthcare organizations (as of July 15, 2020). According to the Finnish Institute for Health and Welfare, 349 (44.0%) of them had an occupational infection, 207 (26.1%) infections were non-occupational, and for 238 (30.0%) the source was unclear. As many as 153 (19.3%) of the infected HCWs were working at HUS, yielding a 0.9% infection rate at that institution [10–13].

Restrictions at HUS

Due to the crisis, HUS imposed several restrictions on its personnel to avoid spreading the virus in the hospital facilities; non-urgent patient contact was postponed, and personnel was instructed to:

- avoid all trips abroad,
- avoid all gatherings and favor digital meetings and remote patient contact,
- keep at least a 1-meter distance from other employees,
- maintain good hand hygiene,
- use the required personal protective equipment (PPE),
- self-isolate and get tested for COVID-19 (with the nasopharyngeal or oropharyngeal real-time polymerase chain reaction [RT-PCR] method) if they experienced any COVID-19-related symptoms.

Using masks and respirators to prevent COVID-19 infections

The World Health Organization (WHO) has advised that HCWs working with COVID-19 patients should use masks throughout their shift, and N95 or FFP2/FFP3 respirators during potential AGPs, as well as when staying at semi-intensive and intensive care units (ICUs) [14]. In HUS, cohort ward employees used surgical masks and followed droplet precautions, while ICU employees followed aerosol precautions. There was no recommendation for masks in the staff area.

The purpose of this study was to trace the source of COVID-19 infections in tertiary hospitals' HCWs while analyzing PPE use and HCWs' ability to maintain social distances, and to follow government's and hospitals' safety guidelines. The hypothesis was that the use of FFP2/3 respirators prevents workplace-related COVID-19 infections.

MATERIAL AND METHODS

A total of 17 740 nurses, midwives, and doctors work at HUS. The study was announced to employees by the HUS communication team with mass e-mails and messages posted on the intranet, asking for voluntary participation. The participation rates at various stages are seen in Figure 1. The number of participants exceeded the required minimum of 377 based on power calculation. To enable comparisons, the aim was to recruit a similar number of volunteer participants from 2 groups:

– the HCWs who treated COVID-19 patients,
– the HCWs who did not treat COVID-19 patients.

To meet this need, an additional e-mail was sent to head nurses at cohort and normal wards, asking them to bring up the study at their weekly meetings. To increase the participation rate among doctors, a similar request was sent to senior physicians. A printable information sheet about the study was also shared with them. The inclusion criteria were ≥18 years of age; education as a practical nurse, a paramedic, a nurse, a laboratorian, a radiological nurse, a midwife, or a doctor; and employment at HUS in March–July, 2020.

The participants filled out a questionnaire with 150 questions about their common health risks, leisure and working conditions during the COVID-19 pandemic (including PPE, potential infection symptoms, the ability to follow safety guidelines and exposure to COVID-19). The participants who presented any COVID-19-related symptoms were tested with the standard HUSLAB RT-PCR methods [15,16]. Additionally, some HCWs were tested with neutralizing antibodies as part of the employer's COVID-19 control strategy [17]. The participants' medical history was reviewed in July 2020 for COVID-19 RT-PCR and antibody results. Potential AGPs were listed according to the Finnish Institute for Health and Welfare as intubation, extubation, resuscitation, direct laryngoscopy, bronchoscopy, upper gastrointestinal endoscopy, non-invasive ventilation, the use of a nebulizer, high-flow nasal oxygen, open suction of the mucus from airways, as well as oral and ear, nose, throat surgery [18].

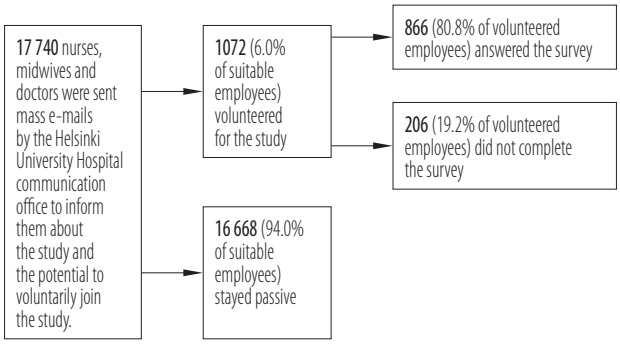


Figure 1. Sampling method and response rates of the survey participants

The number of COVID-19 infections in HCWs was calculated and compared to the general population in the same area. The use of PPE was compared between infected and non-infected HCWs. All infected participants were contacted, and their answers were confirmed regarding the tracing of the infection, the use of PPE and the ability to maintain social distance at the time of the assumed transmission. The infection was categorized as occupational if there were clear infection contacts (ICs) in the workplace and no possible IC outside the workplace; the infection was likely occupational if there were clear ICs in the workplace and some non-COVID-19-related contacts outside the workplace. Infections that were not traced successfully were marked as "unclear."

Statistical analysis

The statistical analysis was performed using statistical software (IBM SPSS Statistics v. 25, Chicago, USA). Before data collection, a power analysis was conducted to estimate the sample size required with a 0.95 confidence level. Differences between nominal variables were tested using a χ^2 test or Fischer's exact test with a $p < 0.05$ significance level. Odds ratios (ORs) and a 95% confidence interval (CI) were calculated using logistic regression with variance calculation. Some of the participants did not

answer all questions, leading to varying sample sizes from question to question. The number of answers per question is presented accordingly.

Ethical considerations

All procedures that involved human participants were conducted in accordance with the ethical standards of the institutional or national research committee and the 1964 Declaration of Helsinki, with its subsequent amendments, or comparable ethical standards. The Ethics Committee of HUS approved the study protocol (HUS/1450/2020). All the participants provided their written informed consent prior to their participation.

RESULTS

Characteristics, infection rates, and exposure among HUS personnel under study

Overall, 866 participants completed the questionnaire by July 15, 2020, and 820 (94.7%) of them said that they had followed all the safety guidelines imposed by the Finnish government. The characteristics of the participants are presented in Table 1.

In total, 41 (4.7%) participants were infected with SARS-CoV-2, representing 26.8% of all known infected HCWs at HUS. Of these COVID-19-positive participants, 28 (68.3%) said that they had knowingly taken care of COVID-19 patients (group 1, N = 451, 52.1% of the participants). Likewise, all infections originating from patients occurred in group 1. The overall infection rate in group 1 was 6.2%. The infection rates of COVID-19-positive participants are shown by location and source in Table 2.

As regards infections originating from patients, 80% happened either in the normal or cohort wards, and 12 (29.3%) of all infections originated from colleagues. Among ICU workers (N = 93), no clear workplace-related infections were found. Further information is seen in Table 3.

Additionally, 61 (7.4%) non-infected participants were quarantined by local infection doctors due to occupational COVID-19 exposure, 13 (1.6%) due to non-occupational exposure, and 1 (0.1%) due to both. Of the 62 occupational exposures, 37 (59.7%) were from colleagues, 13 (21.0%) from patients, and 12 (19.3%) were not stated.

The practical use of PPE and the ability to follow safety guidelines

Of the participants, 340 (39.5% of 861 participants) practiced donning and doffing (D&D) of PPE under supervision and only 77 (8.9%) reported that they did not know how to do D&D correctly. Among the participants with occupational infections, 10 (45.5%) said that they practiced D&D under supervision, and all 22 (100%) answered that they knew how to do it correctly. Only 13 participants (1.8%) told that they used an FFP2/3 respirator with non-infectious patients (Figure 2), the number increased to 169 (28.5%) with suspected COVID-19 patients, and with confirmed COVID-19 patients, fewer than half (210, 41.7%) used an FFP2/3 respirator.

Out of 22 HCWs with confirmed or likely occupational infections, 7 (31.8%) claimed that they were able to maintain at least a 1-meter distance from other staff members. One out of 7 participants (16.7%) infected by a colleague at the workplace was able to maintain a 1-meter distance at the time of the infection. In addition, 23 (2.8% of 824 participants) participants reported a complete shortage of PPE, but none of them was diagnosed with COVID-19. Some cases of partial shortages were reported by 224 (27.2% of 824 participants) other participants, with 7 confirmed or likely workplace-related infections. Finally, 14 (63.6%) occupational infections occurred while using a surgical mask. Detailed information on the participants' COVID-19 infection location, and mask and respirator use, is presented in Table 4.

DISCUSSION

The COVID-19 infection rate among HCWs compared to the general population

In total, 41 (4.7%) participants tested positive for COVID-19, which was more than among the overall HCWs

Table 1. The characteristics of the survey participants compared to personnel of the Helsinki University Hospital (HUS)*, Helsinki, Finland – infection status by the time of survey completion (June 12–July 15, 2020)

Variable	Participants (N = 866)				HUS nurses and doctors in 2019 (N = 17 740)***
	total	no COVID-19 infection (N = 825)	COVID-19 infection (N = 41)		
			total	confirmed or likely occupational COVID-19 infection (N = 22)	
Personnel [n (%)]					
nurses	588 (67.9)	553 (67.0)	35 (85.4)	20 (90.9)	12 008 (67.7)
doctors	170 (19.6)	164 (19.9)	6 (14.6)	2 (9.1)	3 430 (19.3)
laboratory and medical imaging nurses	108 (12.5)	108 (13.1)	0 (0)	0 (0)	2 302 (13.0)
Age [years] (M±SD)	42.4±11.0	42.2±11.0	45.6±10.9	41.5±9.8	43.8±n.a.****
Sex [n (%)]					
female	772 (89.0)	734 (89.0)	38 (92.7)	19 (86.4)	n.a. (83.9)****
male	94 (10.9)	91 (11.0)	3 (7.3)	3 (13.6)	n.a. (16.1)****
Existing risk factors [n (%)]**					n.a.
severe heart disease	2 (0.2)	2 (0.2)	0 (0)	0 (0)	
lung disease that is not clinically stabilized	22 (2.5)	20 (2.4)	2 (5.0)	1 (2.6)	
diabetes that involves organ damage	1 (0.1)	1 (0.1)	0 (0)	0 (0)	
diseases that weaken the immune system	8 (0.9)	8 (1.0)	0 (0)	0 (0)	
medication that significantly weakens the immune system	12 (1.4)	12 (1.5)	0 (0)	0 (0)	
none of the above	813 (94.8)	780 (94.8)	38 (95.0)	20 (90.9)	
Other potential risk factors [n (%)]					n.a.
daily smoking	80 (9.2)	76 (9.2)	4 (9.8)	2 (9.1)	
morbid obesity (BMI >40)	20 (2.3)	18 (2.2)	2 (4.9)	2 (9.1)	

n.a. – not available.
* Percentages may not add up to 100 because of rounding. Not all the participants answered all questions.
** COVID-19 risk factors based on the recommendations of the Finnish Institute for Health and Welfare. None of the participants had the risk factors ">70 years old" or "chronic liver or kidney disease," and thus those are not shown here.
*** Information about HUS personnel [13].
**** The whole personnel.

Table 2. The COVID-19 infection rate among the participants by infection location, and source of infection

Variable	Participants by infection location (N = 41)			
	confirmed workplace (N = 13)	likely workplace (N = 9)	unclear (N = 4)	outside workplace (N = 15)
Infection rate by infection location [%]	1.5	1.0	0.5	1.7
Source of infection [n (%)]				
colleague	5 (38.5)	0 (0.0)	0 (0.0)	5 (33.3)
likely colleague	0 (0.0)	2 (22.2)	0 (0.0)	0 (0.0)
business trip	0 (0.0)	0 (0.0)	0 (0.0)	2 (13.3)
patient	3 (23.1)	0 (0.0)	0 (0.0)	0 (0.0)
likely patient	1 (7.7)	1 (11.1)	0 (0.0)	0 (0.0)
unclear	4 (30.8)	6 (66.7)	4 (100.0)	1 (6.7)
non-occupational	0 (0.0)	0 (0.0)	0 (0.0)	7 (46.7)

at HUS (0.9%) and much higher than that of the general population in the HUS region (0.3%). This indicates that the infected HCWs were more eager to participate in the study. The healthcare workers' higher risk for COVID-19 infection had been reported earlier, and these findings were in line with earlier studies [8,14,19]. The confirmed or likely occupational infections represented 53.7% of the participants' infections, which is mainly in line with that of all HCWs in the HUS region (44.0%) [10].

The use of FFP2/3 respirators compared to surgical masks in occupational infections

To the best of the authors' knowledge, this is the first study that analyses the source of infections and compares the impact of using either a surgical mask or an FFP2/3 respirator on HCWs' COVID-19 infections, which aligns with an earlier meta-analysis indicating that respirators might have a stronger protective effect than surgical masks towards SARS-CoV-2 [19].

In this study, none of the ICU HCWs got infected while using the recommended PPE (a FFP3 respirator [or FFP2 if FFP3 was not available], a pair of gloves, a long-sleeved fluid repellent gown, hair protection and eye protection) although they spent the whole shift in the same room with COVID-19 patients. The OR for occupational COVID-19 infections was 3.4 (p = 0.016) when treating COVID-19-positive patients. All occupational infections that were traced from patients in the wards (N = 4, 20.0%) happened after instructions to HCWs early in the pandemic to reduce PPE to surgical masks. In an earlier study, surgical masks had been shown to reduce viral transmission of respiratory infections [20,21], but in this study, especially in the wards with high exposure, the surgical mask did not seem to provide enough protection against COVID-19.

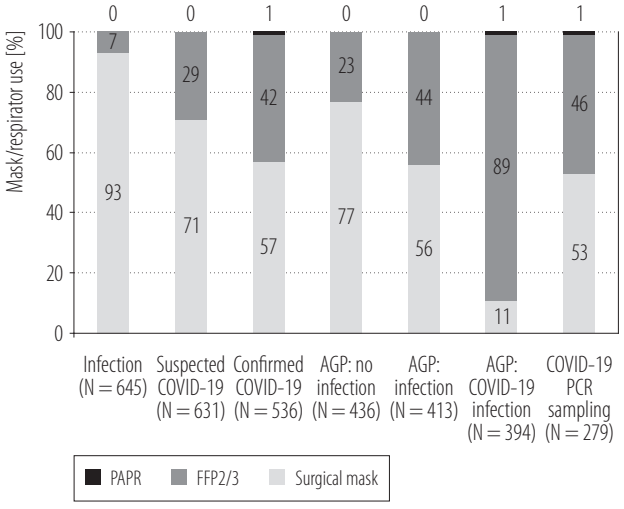
Although the practice of frequent doffing inside the patient area in the wards might increase the risk of infection, the UK guideline is to use the same mask for a session of work, and the infection rate for HCWs is even higher [8,22]. With other viral infections, contamination while doing D&D has been observed [23], marking the importance of assisted D&D and training [24]. Based on data presented by the authors, only <40% of the participants had been trained in D&D, thus the prevention of possible contamination during D&D needs more attention.

Out of the 413 participants who performed AGPs in infected patients, only 180 (43.6%) used FFP2/3 respirators. Fur-

Table 3. Working place, the ability to maintain a 1-meter distance and the infection odds ratio (OR) among the participants during the first wave of the COVID-19 epidemic

Working place[a]	Participants by working place[b] [n (%)]		COVID-19 infection								
	able to maintain a 1-meter distance[c]	infected	any			work-related					
			OR	95% CI	p	OR	95% CI	p	combined OR	95% CI	p
Cohort COVID-19 ward (N = 83)	23 (28.0)	5 (6.0)	1.3	0.5–3.5	0.583	2.9	1.0–8.0	0.051	3.4	1.2–9.2	0.016
Ward (N = 170)	58 (34.1)	15 (8.8)	2.5	1.3–4.8	0.008	2.0	0.8–4.9	0.170	3.4	1.2–9.2	0.016
Emergency department (N = 96)	26 (27.1)	6 (6.3)	1.4	0.6–3.4	0.443	2.4	0.9–6.8	0.086	3.4	1.2–9.2	0.016
Intensive care unit (N = 93)	29 (30.9)	2 (2.2)	0.4	0.1–1.7	0.214	n.a.	n.a.	0.099	3.4	1.2–9.2	0.016
Medical imaging (N = 55)	23 (41.8)	0 (0.0)	n.a.	n.a.	0.088	n.a.	n.a.	0.216	0.3	0.1–0.8	0.016
Outpatient appointment clinic (N = 175)	100 (57.1)	6 (3.4)	0.7	0.3–1.6	0.431	0.2	0.0–1.4	0.064	0.3	0.1–0.8	0.016
Researcher/administration/other non-patient (N = 50)	32 (64.0)	3 (6.0)	1.3	0.4–4.4	0.664	1.7	0.4–7.3	0.499	0.3	0.1–0.8	0.016
Sampling (N = 97)	40 (41.2)	2 (2.1)	0.4	0.1–1.7	0.188	0.8	0.2–3.4	0.751	0.3	0.1–0.8	0.016
Surgery (N = 47)	14 (29.8)	2 (4.3)	0.9	0.2–3.8	0.874	n.a.	n.a.	0.255	0.3	0.1–0.8	0.016
Total	345 (39.9)	41 (4.7)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

n.a. – not available.
[a] Participants number.
[b] The total N differs (866/865) as 1 person has not answered the "able to maintain a 1-meter distance" question.
[c] One missing value.



AGP – aerosol-generating procedure; PAPR – powered air-purifying respirator.
The figures may not add up to 100 because of rounding.

Figure 2. Minimum respirator or mask use during the first wave per selected patient group/procedure by all participants who had treated the patient group/performed the procedure

thermore, 42 (10.7%) participants were not using FFP2/3 respirators even while performing AGPs in COVID-19-positive patients. The WHO, international expert opinions and the Finnish Institute for Health and Welfare recommend always using FFP2/3 respirators during AGPs [14,18,25].

In the presented material, no occupational COVID-19 infections were found in laboratory workers. There are a few factors that could explain this. Firstly, out of 279 participants who performed COVID-19 PCR sampling, 148 (53.0%) used FFP2/3 respirators, marking a higher figure than those who cared for the confirmed COVID-19 patients. Secondly, extensive safety measures in PCR sampling, such as drive-in sampling stations and reducing exposure time to <15 min during the sampling process, are likely to explain the absence of COVID-19 infections in laboratory workers.

Occupational infections between co-workers

Overall, 29.3% of identified infections were traced back to colleagues both at the workplace (N = 7) and outside (N = 5). The use of surgical masks in employees' facilities could reduce transmissions and prevent infections between colleagues, and the WHO recommends using medical masks continuously throughout a shift, apart from eating and drinking. The mask should be changed after caring for a patient requiring droplet/contact precautions for other reasons (e.g., influenza) to avoid any possibility of cross-transmission [14]. At HUS, the guideline has been

Table 4. The use of masks and respirators among COVID-19-positive participants, as well as safety distance and source of infection by infection location groups

Variable	Participants by infection location (N = 41) [n (%)]			
	workplace (N = 13)	likely workplace (N = 9)	unclear (N = 4)	outside the workplace (N = 15)
Using a mask/a respirator at the estimated infection time				
FFP2/3 respirator	0 (0.0)	0 (0.0)	1 (25.0)	0 (0.0)
surgical mask	9 (69.2)	5 (55.6)	1 (25.0)	0 (0.0)
none	4 (30.8)	4 (44.4)	2 (50.0)	15 (100.0)
Ability to maintain a 1-meter safety distance at the estimated infection time	2 (15.4)	5 (55.6)	1 (25.0)	4 (26.7)

to use surgical masks only during patient contact, to avoid any personal gatherings, and to keep at least a 1-meter distance from co-workers. A recent systematic review [19] has shown a clear association in the reduction of infections by having at least a 1-meter social distance, and this study supports the importance of social distance also for HCWs. Despite the safety guidelines, 83.3% of those who got (confirmed or likely) the infection from a colleague at the workplace, and 60.1% of all participants, were not able to main the instructed 1-meter radius from other people. This highlights the difficulty of following this instruction in a crowded hospital setting and urges hospitals to find additional ways of reducing transmission between colleagues.

Strengths and weaknesses of this study

This is the first study to analyze the source of infections and the impact of using surgical masks compared to FFP2/3 respirators in the moment of assumed transmission. The positive COVID-19 infections were proven by COVID-19 RT-PCR and antibody tests, which are the gold standard in COVID-19 diagnostics [26]. The study was conducted prospectively during the first wave of the COVID-19 pandemic in Finland, and all of the nurses and doctors working at HUS were informed about the study. Of those that opted to participate, 95% stated that they had followed the state safety guidelines which reduced all non-occupational social interactions during this study. These factors, combined with the low population density of 176/km^2 in the Uusimaa region, greatly reduce the likelihood of non-occupational infections among HCWs and hence increase the reliability of the analysis of workplace-related infections.

This study, however, has several potential limitations; the overall number of infected HCWs was relatively low and the possibility of not recognizing asymptomatic infections was very likely. In fact, HCWs were prioritized in RT-PCR testing, even though the testing capacity was considered sufficient during most of the first wave, and the guideline was to test all with COVID-19 symptoms. The characteristics of the participants reflect the overall personnel although females are slightly overrepresented in this study. As usual, the people related to the topic participate more frequently, as was evidenced by the number of COVID-19-infected participants. The sampling method of sending general e-mails to the whole staff could reduce the participation of those employees who do not frequently follow their e-mails. Also, the beginning of the summer holiday season likely reduced the participation rate. However, the fact that a significant proportion of infected HCWs at HUS participated in the study provided an opportunity to look more reliably at the sources of their infection.

CONCLUSIONS

Generally, HCWs have a higher risk of contracting a COVID-19 infection compared to the general population. Despite the high exposure to SARS-CoV-2, none of the ICU workers got a clear occupational COVID-19 infection, whereas working in a cohort COVID-19 ward or a normal ward with COVID-19 patients seems to have a high-risk association for occupational COVID-19 infections. All ICU workers and most laboratory workers used FFP2/3 respirators and aerosol precautions when working with COVID-19 patients, whereas the PPE used in the wards followed droplet precautions with surgical masks. Notably, 29.3% of the infections were from colleagues, thus also requiring special attention for social distances and infection control measures between co-workers.

As practical implications, the use of FFP2/3 respirators in all patient contacts with confirmed or suspected COVID-19 patients is recommended. Also, as a high number of COVID-19 infections and exposures among HCWs are from colleagues, the authors recommend the use of universal masking during the shift, also in personnel rooms. Safety distances and other means of infection control in the hospital environment need more research and implementation in the workplace to ensure HCWs' safety during pandemics.

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