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# Estimating the risk of incident SARS-CoV-2 infection among healthcare workers in quarantine hospitals: the Egyptian example

Sofía Jijón, Ahmad Al Shafie, Essam Hassan, Laura Temime, Kévin Jean, Mohamed El-Kassas

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1        **Estimating the risk of incident SARS-CoV-2 infection among healthcare**  
2        **workers in quarantine hospitals: the Egyptian example**

3  
4        *Sofía Jijón<sup>1,2†</sup> (PhD), Ahmad Al Shafie<sup>3†</sup> (MSc), Essam Hassan<sup>4</sup>(MD), EMAE-MESuRS*  
5        *working group on nosocomial SARS-CoV-2 modeling, Laura Temime<sup>1,2</sup> (PhD), Kévin*  
6        *Jean<sup>1,2,5\*</sup> (PhD), Mohamed El-Kassas<sup>3\*</sup> (MD)*

7  
8        <sup>1</sup> Laboratoire Modélisation, épidémiologie et surveillance des risques sanitaires (MESuRS),  
9        Conservatoire national des Arts et Métiers, Paris, France

10        <sup>2</sup> Unité PACRI, Institut Pasteur, Conservatoire national des Arts et Métiers, Paris, France

11        <sup>3</sup> Endemic Medicine Department, Faculty of Medicine, Helwan University, Cairo, Egypt

12        <sup>4</sup> Tropical Medicine Department, Faculty of Medicine, Fayoum University, Fayoum, Egypt

13        <sup>5</sup> MRC Centre for Global Infectious Disease Analysis, Department of Infectious Disease  
14        Epidemiology, Imperial College London, United Kingdom

15  
16        <sup>†</sup> *Contributed equally to the work*

17        <sup>\*</sup>*Contributed equally to the work*

18  
19        **Corresponding author:**

20        Sofía Jijón, [sofia.jijon\\_alban@sorbonne-universite.fr](mailto:sofia.jijon_alban@sorbonne-universite.fr)

21        Current address: Sorbonne Université, Campus Pierre et Marie Curie, 4 Place Jussieu, 75005  
22        Paris, France.

23        **Running title:** SARS-CoV-2 infection risk among HCW in quarantine hospitals

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25 **ABSTRACT**

26 In response to the COVID-19 epidemic, Egypt established a unique care model based on  
27 quarantine hospitals where only externally-referred confirmed COVID-19 patients were  
28 admitted, and healthcare workers resided continuously over 1- to 2-week working shifts.  
29 While the COVID-19 risk for HCWs has been widely reported in standard healthcare settings,  
30 it has not been evaluated yet in quarantine hospitals.

31 Here, we relied on longitudinal data, including results of routine RT-PCR tests, collected  
32 within three quarantine hospitals located in Cairo and Fayoum, Egypt. Using a model-based  
33 approach that accounts for the time-since-exposure variation in false-negative rates of RT-  
34 PCR tests, we computed the incidence of SARS-CoV-2 infection among HCWs. Over a total  
35 follow-up of 6,064 person-days (PD), we estimated an incidence rate (per 100 PD) of 1.05  
36 (95% CrI: 0.58–1.65) at Hospital 1, 1.92 (95% CrI: 0.93–3.28) at Hospital 2 and 7.62 (95%  
37 CrI: 3.47–13.70) at Hospital 3. The probability for an HCW to be infected at the end of a  
38 shift was 13.7% (95% CrI: 7.8%–20.8%) and 23.8% (95% CrI: 12.2%–37.3%) for a 2-week  
39 shift at Hospital 1 and Hospital 2, respectively, which lies within the range of risk levels  
40 previously documented in standard healthcare settings, whereas it was >3-fold higher for a 7-  
41 day shift at Hospital 2 (42.6%, 95%CrI: 21.9%–64.4%). Our model-based estimates unveil a  
42 proportion of undiagnosed infections among HCWs of 46.4% (95% CrI: 18.8%–66.7%),  
43 45.0% (95% CrI: 5.6%–70.8%) and 59.2% (95% CrI: 34.8%–78.8%), for Hospitals 1 to 3,  
44 respectively.

45 The large variation in SARS-CoV-2 incidence we document here suggests that HCWs from  
46 quarantine hospitals may face a high occupational risk of infection, but that, with sufficient  
47 anticipation and infection control measures, this risk can be brought down to levels similar to  
48 those observed in standard healthcare settings.

49

50 **Keywords.** COVID-19; SARS-CoV-2; Nosocomial infection; Healthcare workers;  
51 Quarantine hospitals.

52 **WHAT THIS PAPER ADDS**

53 **What is already known on this topic**

54 Previous studies conducted in standard care settings have documented that frontline  
55 healthcare workers (HCWs) face high risk of COVID-19. Whether risk levels differ in  
56 alternative care models, such as COVID-19 quarantine hospitals in Egypt where HCWs  
57 resided in the hospital days and nights for various durations, is unknown.

58 **What this study adds**

59 COVID-19 risk for HCWs in quarantine hospitals varies substantially between facilities, from  
60 risk levels that are in the range of those documented in standard healthcare settings to levels  
61 that were approximatively 3 times higher.

62 **How this study might affect research, practice or policy**

63 With sufficient anticipation and infection control measures, occupational COVID-19 risk for  
64 HCWs working in quarantine hospitals can be brought down to levels similar to those  
65 observed in standard healthcare settings.

## 66 INTRODUCTION

67 Healthcare settings have faced multiple challenges related to the currently ongoing severe  
68 acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic. They have notably had  
69 to deal with influxes of infected patients across successive epidemic waves while controlling  
70 the risk of nosocomial spread to other patients and staff. As a result, healthcare workers  
71 (HCWs) have been a population of interest in terms of risk assessment and control measure  
72 implementation [1].

73 At early stages of the pandemic, Egypt was identified as one of the African countries most  
74 vulnerable to SARS-CoV-2 importation [2]. On February 14, 2020, Egypt reported the first  
75 confirmed case of coronavirus disease 2019 (COVID-19) in Africa and remained among the  
76 five African countries most assigned by the COVID-19 epidemic up to the end of 2020 [3].  
77 From February 14 to August 31, 2020 (the period to which we refer to as the first wave), the  
78 COVID-19 epidemic in Egypt resulted in about 9,700 confirmed infections and 5,500 deaths  
79 reported nationally [4]. These numbers most certainly reflect underreporting of the real  
80 number of infections, due to the high proportion of asymptomatic SARS-CoV-2 infection  
81 [5,6] and limited testing.

82 To mitigate the high risk of SARS-CoV-2 spreading, Egypt established a unique care model  
83 under supervision from the World Health Organization, whereby specific hospitals were  
84 assigned as quarantine hospitals for patients with COVID-19, and where dedicated medical  
85 teams stayed in the hospital days and nights during working shifts of various durations [7].

86 While the quarantine-hospital strategy has the potential to be highly efficient in terms of  
87 patient care, as well as in limiting the potential spread of the virus from hospitals into the  
88 community, its impact on infection risk for HCWs remains understudied. One theoretical  
89 modelling study assessing healthcare working force organization found that alternating HCW  
90 teams by 1-week periods may reduce the overall number of infected HCWs [8]. On the other  
91 hand, to the best of our knowledge, previous epidemiological studies focusing on the infection  
92 risk faced by Egyptian HCWs have been conducted in non-quarantine settings exclusively [9–  
93 11]. Yet, the quarantine strategy was adopted again to face the second wave of the COVID-19  
94 epidemic at the national level, and could be adopted for future epidemic waves in Egypt  
95 and/or in other countries [12].

96 Here, we used mathematical modelling to estimate the risk of SARS-CoV-2 infection among  
97 HCWs participating in quarantine-hospital interventions, relying on detailed longitudinal data  
98 collected in three Egyptian healthcare facilities during the first wave of the COVID-19  
99 epidemic.

## 100 **METHODS**

### 101 *Study settings*

102 Data was collected within three Egyptian hospitals (hereafter denoted by Hosp1, Hosp2 and  
103 Hosp3) located in Cairo (Hosp1 and Hosp3), and Fayoum (middle Egypt, Hosp2), that were  
104 temporarily transformed into quarantine hospitals during the first COVID-19 wave. During  
105 the quarantine-organization period (Hosp1: March 14th to August 1st, 2020; Hosp2: April 1st  
106 to July 31th; Hosp3: June 6th to July 11th, 2020), only externally-referred COVID-19  
107 confirmed patients were admitted to these hospitals for medical care. Multidisciplinary  
108 medical teams fully dedicated to COVID-19 patient management worked in total isolation,  
109 organized by shifts (Hosp1: 2-week shifts; Hosp2: 1 to 2-week shifts; Hosp3: 1-week shifts).  
110 During their shift, HCWs were assigned either to intensive care units (ICU) or non-ICU.  
111 HCWs were screened for SARS-CoV-2 infection before starting a working shift using rapid  
112 serological IgM/IgG antibody tests (Artron laboratories Burnaby, Canada; sensitivity: 83.3%,  
113 specificity: 100% [13]). Only HCWs with no SARS-CoV-2 antibodies were allowed to start  
114 working in the hospital; except for the last shift in Hosp3, where staff recruitment relied  
115 exclusively on HCWs who had been previously infected (positive serological tests), and were  
116 additionally tested using reverse transcription-polymerase chain reaction (RT-PCR) on  
117 nasopharyngeal swabs, obtaining negative results. During the working shifts, HCWs were  
118 tested for SARS-CoV-2 infection using RT-PCR tests: i) routinely at the end of the shift, ii)  
119 upon symptoms, and iii) in case of outbreak suspicion (>2 positive tests among HCWs).  
120 HCWs testing negative at the end of the shift were then released for self-isolation at home for  
121 two weeks. HCWs testing positive before or during their shift self-isolated at home in the case  
122 of presenting no or mild symptoms, or were admitted to the same quarantine hospital for  
123 medical care in the case of presenting moderate to severe symptoms.

### 124 *Observed risk of SARS-CoV-2 infection*

125 Crude incidence rates were obtained from the number of incident SARS-CoV-2 infections  
126 observed (ie, diagnosed during or at the end of a shift) among HCWs screened as seronegative  
127 for SARS-CoV-2 before their working shift. Incidence rate ratios were obtained through a  
128 Poisson regression adjusted by hospital and by type of care unit (ICU/ non-ICU). In addition,  
129 we computed the attack rates over each working shift, based on the observed infections  
130 among HCWs having a negative screening test at the beginning of the working shift.

131 Observed per-shift attack rates of were considered to be healthcare-associated outbreaks  
132 among HCWs.

133 *Model-based estimates of the incidence rate of SARS-CoV-2 infection*

134 An important feature arising from COVID-19 surveillance within quarantine hospitals is  
135 potential right-truncation of data: HCWs infected a short time before the end of a shift are  
136 likely to remain undiagnosed despite the systematic testing at the end of shifts, especially if  
137 the test is performed early in the incubation period. We thus developed the following  
138 mathematical model to estimate the incidence rate of both diagnosed and undiagnosed SARS-  
139 CoV-2 infections.

140 We simulated the daily number of incident infections among HCWs,  $X_{k,i}^A$  based on an  
141 unobserved binomial process:

$$X_{k,i}^A \sim \text{Bin}(n = S_{k,i}^A, p = \lambda)$$

142 where  $k$  denotes the working shift,  $i$  denotes the day within the shift,  $A$  is the hospital unit of  
143 HCWs' assignments ( $A \in \{\text{ICU}, \text{Non-ICU}\}$ ),  $S_{k,i}^A$  denotes the number of susceptible HCWs  
144 assigned to  $A$ , at the beginning of the  $i$ -th day of shift  $k$  and  $\lambda$  denotes the constant daily  
145 probability of SARS-CoV-2 infection faced by HCWs. The number of susceptible HCWs was  
146 updated on a daily basis:

$$S_{k,i+1}^A = S_{k,i}^A - X_{k,i}^A$$

147 To model right-truncation in the surveillance data, we simulated an observation process  
148 representing the systematic RT-PCR testing of HCWs at the end of each shift, accounting for  
149 documented variation in test sensitivity as a function of time since infection [14]. The period  
150 of time since infection was computed as  $j_k - i$ , where  $j_k$  denotes the day at the end of shift  $k$   
151 (i.e., the day when testing was performed) and  $i$  denotes the day of infection. Then, the daily  
152 number of incident infections eventually diagnosed at the end of the -th shift was given by

$$I_{k,i}^A = X_{k,i}^A \theta_{j_k - i}$$

153 where  $\theta_{j_k - i}$  denotes the probability of testing positive to RT-PCR,  $j_k - i$  days after  
 154 infection.

155 We used a Bayesian Markov Chain Monte-Carlo (MCMC) approach to estimate the  
 156 parameter  $\lambda$  that best fitted the observed number of infections. We assumed that  $\lambda$  was  
 157 constant over the study period. We considered a non-informative uniform prior distribution  
 158  $\sim U(0,1)$  for  $\lambda$  and the following binomial likelihood function:

$$L(\lambda | \text{data}) = \prod_A \left( \frac{\sum_{k,i} N_{k,i}^{S,A}}{\sum_{k,i} N_{k,i}^{I,A}} \right) \left( \frac{\sum_{k,i} I_{k,i}^A}{\sum_{k,i} S_{k,i}^A} \right)^{\sum_{k,i} N_{k,i}^{I,A}} \left( 1 - \frac{\sum_{k,i} I_{k,i}^A}{\sum_{k,i} S_{k,i}^A} \right)^{\sum_{k,i} N_{k,i}^{S,A} - \sum_{k,i} N_{k,i}^{I,A}},$$

159 where  $\sum_{k,i} N_{k,i}^{S,A}$  and  $\sum_{k,i} N_{k,i}^{I,A}$  denote the total number of susceptible HCWs (denoted by the  
 160 superscript  $S$ ) and the total number of HCW infected and diagnosed with COVID-19  
 161 (denoted by the superscript  $I$ ), observed in hospital unit  $A$ , during the study period,  
 162 respectively. The model was thus fitted to the total number of observed infections in each  
 163 hospital unit.

164 Medians and 95% credibility intervals (CrI) for  $\lambda$  were computed from posterior samples  
 165 obtained after 10,000 model runs. The chains were visually inspected for convergence. For  
 166 each hospital, we further estimated the probability for a susceptible HCW to be infected at the  
 167 end of a shift as

168 
$$P(\text{Infected at shift end}) = 1 - (1 - \lambda)^d,$$

169 where  $d$  is the length of the working shift, in days.

170 Finally, to assess the proportion of undetected infections among HCWs, we ran our model on  
 171 each hospital, using the posterior distributions for  $\lambda$ , to obtain an estimate for the real number  
 172 of SARS-CoV-2 infections in each hospital (both diagnosed and undiagnosed), over the study  
 173 period.

174 The numeric implementation of the model was coded in R 4.0.3 [15], using the FME package  
 175 [16] for parameter estimation.

176

177 *Ethical approval*

178 This study was approved by the Research Ethics Committee (REC) of the Central Directorate  
179 of Research and Health Development and Reviews at the Egyptian Ministry of Health and  
180 Population (Serial: 25-2020/16), and by REC for human subject research at the Faculty of  
181 Medicine, Helwan University (Serial: 50-2020).

182

183 **RESULTS**

184 The study period covered ten 2-week shifts in Hosp1, nine ~2-week shifts in Hosp2 and five  
185 1-week shifts in Hosp3. The mean (min–max) number of HCWs per shift was 46 (34–63) in  
186 Hosp1, 15 (5–26) in Hosp2 and 19 (16–20) in Hosp3 (Table 1). Over a total follow-up of  
187 8,733 person-days (PD), 54 SARS-CoV-2 infections were observed (ie., diagnosed by RT-  
188 PCR) among 722 HCWs showing no evidence of SARS-CoV-2 antibodies at the beginning of  
189 their shifts, across the three hospitals. This represented an overall incidence rate of 0.62 (95%  
190 CI: 0.45–0.78) diagnosed SARS-Cov-2 infections per 100 PD (Table 2). A significantly  
191 higher incidence rate was observed for HCWs working at Hosp3 as compared to the other two  
192 hospitals; and HCWs working in non-ICU units tended to be more at risk than HCWs  
193 working in ICU, though this difference was not statistically significant (Table 2).

194

195 **Table 1. Hospital characteristics.**

196 Quarantine organization period, location and mean number of HCWs and patients by hospital (Hosp1, Hosp2  
197 and Hosp3). Abbreviations: HCWs = Healthcare workers, PD = person-days.

	<b>Hosp1</b>	<b>Hosp2</b>	<b>Hosp3</b>
<b>Quarantine organization period</b>	March 14 – August 1	April 1 – July 31	June 6 – July 11
<b>Location</b>	Cairo	Fayoum	Cairo
<b>Mean daily number of patients (min–max)</b>	62 (0–108)	37 (0–103)	8 (0–20)
<b>Mean number of HCWs per shift (min–max)</b>	46 (34–63)	15 (5–26)	19 (16–20)
<b>Shift duration</b>	14 days	7–14 days	7 days

198

199

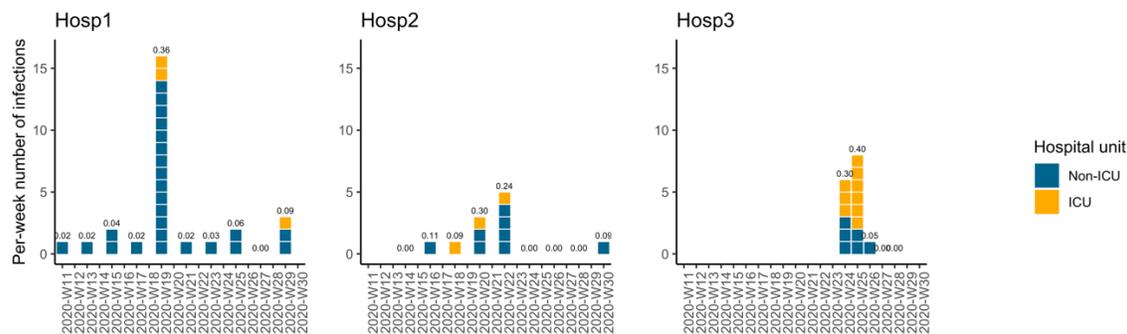
200

201 **Table 2. Observed risk of SARS-CoV-2 infection among HCWs, by hospital and by hospital unit.**  
 202 A total of 54 infections were observed (ie., diagnosed before or at the end of a shift) over 8,733 person-days, in  
 203 the three hospitals (Hosp1, Hosp1 and Hosp3). Crude rates of SARS-CoV-2 infection among HCWs by hospital  
 204 and by hospital unit: intensive and non-intensive care units and 95% confidence intervals. A Poisson regression  
 205 adjusted by hospital and by hospital unit was performed on the observed infections to obtain the incidence rate  
 206 ratios and 95% confidence intervals. Abbreviations: CI = confidence interval, ICU = intensive care unit, IRR =  
 207 incidence rate ratio, PD = person-days.

		Observations		Crude rates		Adjusted Poisson Regression		
		Events	PD	Rate per 100 PD	95% CI	IRR	95% CI	<i>p</i>
<b>Hospital</b>	<b>Hosp1</b>	28	6258	0.45	0.28–0.61	1	ref	–
	<b>Hosp2</b>	11	1808	0.61	0.25–0.97	1.49	0.74–2.87	0.28
	<b>Hosp3</b>	15	667	2.25	1.1–3.39	5.59	3.13–10.01	<0.001
<b>Hospital Unit</b>	<b>ICU</b>	15	2628	0.57	0.28–0.86	1	ref	–
	<b>Non-ICU</b>	39	6105	0.64	0.44–0.84	1.49	0.85–2.59	0.16

208

209 Healthcare-associated outbreaks among HCWs (observed attack rates of ) represented ~70%  
 210 (38/54) of all SARS-CoV-2 infections observed over the study period (Figure 1). Two of  
 211 these outbreaks occurred in Hosp2 with 30% (3/10) and 24% (5/21) of HCWs being infected  
 212 over two different working shifts. An outbreak where 36% of HCWs were infected (16/44)  
 213 occurred in Hosp1 around the same time period. Two outbreaks took place later on in Hosp3,  
 214 leading to, respectively, 30% (6/20) and 40% (8/20) of susceptible HCWs being infected over  
 215 two different shifts. Of note, each outbreak resulted in infections in both ICU and non-ICU.  
 216 For the last shift in Hosp3, staff recruitment relied exclusively on HCWs who had been  
 217 infected during the first or the second shifts. This likely prevented HCWs in Hosp3 from  
 218 becoming infected during the last shift (cf. Figure 1).



**Figure 1. Per-week number of infections by hospital unit.**

For a given working shift, healthcare workers were assigned to either the intensive care unit (ICU, yellow) or a non-ICU (blue). Dates are given in weeks, denoted by the prefix W followed by the week number of year 2020. Hosp1 was established as a quarantine hospital from March 14th to August 1st (W11 to W31), Hosp2 from April 1st to July 31st (W14 to W31) and Hosp3 from June 6th to July 11th (W23 to W28). In Hosp1 and Hosp2, most infections occurred in non-ICU units. Per-shift attack rates are shown above the bars. Of note, only previously infected HCWs worked during the last two shifts (W27 and W28) in Hosp3.

219  
220

To estimate the mean incidence rate of both observed and unobserved infections in each

221

hospital, we ran our model considering a constant risk,  $\lambda$ , over the whole study period, in each

222

hospital unit. The chains for  $\lambda$ , for the three hospitals, are depicted in the Supplementary

223

Figure 1. We estimated significantly different risk levels between the three hospitals

224

(Kolmogorov-Smirnov test; p-value  $< 0.001$ ), with an incidence rate of 1.05 (95% CrI: 0.58–1.65) per

225

100 PD in Hosp1, 1.92 (95% CrI: 0.93–3.28) per 100 PD in Hosp2 and 7.62 (95% CrI: 3.47–

226

13.70) per 100 PD in Hosp3.

227

The probability for a HCW to be infected at the end of a working shift was estimated at

228

13.7% (95% CrI: 7.8%–20.8%) and 23.8% (95% CrI: 12.2%–37.3%) for 2-week shifts at

229

Hosp1 and Hosp2, respectively, whereas a much higher probability of 42.6% (95% CrI:

230

21.9%–64.4%) was found for a 7-day shift at Hosp3 (see Table 3). These probabilities

231

become 7.1% (95% CrI: 4.0%–11.0%) and 12.7% (95% CrI: 6.3%–20.8%), for Hosp1 and

232

Hosp2, respectively, if 7-day shifts are considered as well, for easier comparison (Table 3).

233

Given the notable differences between hospitals (Figure 1), we did not assess infection risk by

234

care unit across hospitals, but within each hospital.

235

The posterior distributions for the incidence rate  $\lambda$  yield the following model-based median

236

numbers of total SARS-CoV-2 infections: 59 (95% CrI: 45–74) at Hosp1, 31 (95% CrI: 14–

237

52) at Hosp2 and 41 (95% CrI: 19–63) at Hosp3 (Table 3), which unveils a proportion of

238

undiagnosed infections among HCWs of 46.4% (95% CrI: 18.8%–66.7%), 45.0% (95% CrI:

239

5.6%–70.8%) and 59.2% (95% CrI: 34.8%–78.8%), respectively.

240 We further ran our model on each hospital unit, on each hospital, which confirmed a notable  
 241 difference between Hosp1–2 and Hosp3: our results suggest that HCWs working in Hosp1  
 242 and Hosp2 face a higher risk when assigned to non-ICU, as compared to those assigned to the  
 243 ICU; whereas HCWs in the ICU of Hosp3 face higher risk (see Fig. 1 and Table 3).

244 **Table 3. Model-based estimates of all SARS-CoV-2 infections**

245 The model-based estimates of the incidence rate, the probability of infection for a 7-day working shift and the  
 246 estimated number of SARS-CoV-2 infections in each hospital, over the study period. Running our model for  
 247 each type of care unit (ICU and non-ICU) in each hospital unveils the difference in the risk faced by HCWs  
 248 between the three hospitals of our study. Indeed, HCWs working in Hosp1 and Hosp2 face a higher risk when  
 249 assigned to non-ICU, as compared with those working in the ICU; whereas HCWs in Hosp3 face a slightly  
 250 higher risk when assigned to the ICU. All estimates concern both diagnosed and undiagnosed infections (all),  
 251 unless otherwise stated (diagnosed). Abbreviations: CrI = credibility interval, ICU = intensive care unit, PD =  
 252 person-days.

	Median estimated incidence rate per 100 PD (95% CrI)			Probability of infection for a 7- day shift (95% CrI)	Median number of SARS-CoV-2 infections (95% CrI)		
	ICU	Non-ICU	Overall		All	Diagnosed	Proportion of undiagnosed infections
<b>Hosp1</b>	0.59 (0.11–1.61)	1.27 (0.68–2.01)	1.05 (0.58–1.65)	7.1% (4.0%–11.0%)	59 (45–74)	31 (15-51)	46.4% (18.8%–66.7%)
<b>Hosp2</b>	1.33 (0.33–3.33)	2.75 (1.12–5.02)	1.92 (0.93–3.28)	12.7% (6.3%–20.8%)	31 (14–52)	17 (7-31)	45.0% (5.6%–70.8%)
<b>Hosp3</b>	9.37 (3.48–19.66)	7.12 (2.06–18.71)	7.62 (3.47–13.70)	42.6% (21.9%–64.4%)	41 (19–63)	16 (6-30)	59.2% (34.8%–78.8%)

253

254

## 255 **DISCUSSION**

256 Here, we studied the risk of incident SARS-CoV-2 infection among HCWs residing days and  
257 nights in quarantine hospitals, relying on detailed longitudinal data collected during the first  
258 wave of COVID-19 in Egypt. We found that most diagnosed infections (70%) occurred  
259 during what we defined as healthcare-associated outbreaks (as compared to isolated  
260 infections). We observed high variability in nosocomial incidence, ranging from 0.45 to 2.25  
261 infections per 100 PD across the three hospitals. Using a model-based approach, we  
262 estimated the risk of both diagnosed and undiagnosed SARS-CoV-2 infections among HCWs,  
263 by hospital and by hospital unit (ICU and non-ICU). We further estimated that a substantial  
264 proportion of infections may have remained undetected, ranging from 45.0% to 59.2% across  
265 the three hospitals.

266 Our study design has several limitations. First, screening HCWs using serological tests before  
267 starting their working shifts may not detect active infections at the time of testing. Indeed,  
268 antibodies may be detected by serological tests in less than 40% of infected individuals within  
269 7 days since symptoms onset, reaching higher detection levels at day 16 after symptom onset  
270 [17]. Hence, serological screening may allow recently infected HCWs –who are probably  
271 infectious– to start a working shift. However, the Egyptian public health authorities' choice of  
272 a protocol relying on serological tests before working shifts was mainly driven by material  
273 constraints. Indeed, the use of rapid serological tests as a diagnostic tool was and remains of  
274 particular interest in limited-resource contexts due to their lower cost, the minimal equipment  
275 required, and faster results, as compared with RT-PCR tests [18]. Second, the assumption of a  
276 constant overall risk of infection among HCWs disregards dynamic fluctuations in risk driven  
277 by variation in the number of HCWs and/or patients in the hospitals, as well as the frequency  
278 and nature of HCWs' contacts during their working shifts. This simplification was made in  
279 order to estimate average transmission rate first; fine reproduction of transmission dynamics  
280 were left for future work. Third, despite the quarantine strategy being adopted nationally, the  
281 differences between the organizations of each of the three hospitals (working shifts lengths,  
282 quarantine-organization period) resulted in some difficulties in comparing the risk estimations  
283 across the three hospitals. Data from other hospitals that have adopted a quarantine strategy  
284 will be beneficial to better understand occupational risks and eventually study the  
285 performance of such a strategy in comparison to standard care settings.

286 We found a ~5-fold higher observed risk for Hosp3 as compared with the risk found in  
287 Hosp1; whereas the risk of infection at Hosp2 was just slightly higher. The higher risk of  
288 SARS-CoV-2 infection we report for Hosp3 and the higher risk faced by HCWs assigned to  
289 the ICU of Hosp3 may be partly explained by the short period over which this hospital  
290 adopted the quarantine organization, which coincided with the country's highest epidemic  
291 activity of the first wave [4]. This may have led to a high proportion of severe and thus highly  
292 contagious COVID-19 patients referred to quarantine hospitals together with a higher  
293 workload for HCWs. Contrarily, Hosp1 adopted the quarantine organization in mid-March  
294 2020, and thus experienced several weeks of lower epidemic intensity that may have  
295 improved preparedness for intense COVID-19 activity and implementation of infection  
296 control measures for invasive procedures (e.g., intubation in the ICU).

297 Our model-based approach, accounting for false-negativity rates of testing, as well as the  
298 right-truncation of our data, allowed us to estimate the risk of both diagnosed and  
299 undiagnosed SARS-CoV-2 infection among HCWs, by hospital and by hospital care unit. We  
300 estimated that a rigorous quarantine organization with systematic testing of HCWs at the end  
301 of their working shifts captures only about half of all HCW infections (depending on the  
302 length of the working shift). Of note, the higher proportion of infections that remained  
303 undetected in Hosp3 (59.2%, versus 46.4% and 45.0% in Hosp1 and Hosp2, respectively)  
304 may be explained by the shorter duration of the working shifts (7 days), which may result in  
305 false-negative tests for HCWs infected a short time before the end of their shift. Moreover,  
306 these results suggest that, in the absence of the quarantine-hospital organization and, more  
307 specifically, in the absence of systematic testing at the end of quarantine working shifts, an  
308 even larger proportion of infections among HCWs may remain undetected, thus putting  
309 HCWs' close contacts at risk of infection [19] and, consequently, putting themselves at risk  
310 for adverse psychological symptoms [20].

311 The model-based estimates we found for the SARS-CoV-2 infection risk in Hosp1 and Hosp2  
312 are consistent with infection point-prevalence reported in earlier studies performed in non-  
313 quarantine Egyptian hospitals (varying from 4.2% to 14.3%) and with incidence estimates  
314 reported among front-line HCWs in the UK (13% infection rate after one month) [10,11,21].  
315 For comparison, a summary of previous results obtained early in the Covid-19 pandemic  
316 and/or specifically in the Egyptian context is presented in Table 4. Moreover, our results  
317 suggest that HCWs assigned to non-ICU face a higher risk than those assigned to the ICU, in

318 Hosp1 and Hosp2, which is in line with what was observed in previous studies addressing the  
319 occupational risk of SARS-CoV-2 infection for HCWs in non-quarantine settings [22].  
320 Overall, our findings on Hosp1 and Hosp2 suggest that, providing sufficient preparedness,  
321 HCWs working in quarantine hospitals may not face a higher infection risk, and thus  
322 highlight the benefits of implementing a quarantine-hospital strategy.

323

324 **Table 4. Our results in a context.**

325 Our estimation of the per-shift probability of infection in Hosp1–3, along with estimates of the point-prevalence  
326 in other Egyptian studies and the observed cumulative incidence rate among HCWs in an English study.

Indicator	Estimate (%)	Context	Study
Per-shift probability of infection (95% CrI)	12.8 (7.6–19.5)	Hosp1 (14-days shift)	Our results
	17.3 (7.5–30.7)	Hosp2 (14-days shift)	
	48.2 (23.8–74.5)	Hosp3 (7-days shift)	
Point-prevalence	4.2	Symptomatic and asymptomatic HCWs in 12 healthcare facilities (N=4040).	[23]
Point-prevalence	14.3	Asymptomatic HCWs in emergency departments of tertiary care facility (N=203).	[10]
Incidence rate	13.0	Front-line HCWs testing negative at enrollment.	[21]

327

328 A notable strength of our study lies in the specific nature of the quarantine hospital set-up:  
329 because HCWs resided continuously in the hospitals over their entire working shifts, we were  
330 able to exclude risk of infection in the community and specifically quantify the nosocomial  
331 risk for HCWs. Conversely, results reported from non-quarantine hospitals worldwide are  
332 generally unable to distinguish between the nosocomial vs. community risk of infection.  
333 However, as most studies conducted in healthcare settings, we were unable to distinguish  
334 between patient-to-HCW and HCW-to-HCW routes of transmission. A previous study on  
335 several nosocomial Covid-19 healthcare-associated outbreaks in Germany reported that  
336 HCW-to-HCW transmission could represent an outsized risk as compared to the one due to  
337 infected patients [24]. Still, assessing the relative contribution between patient-to-HCW  
338 versus HCW-to-HCW SARS-Cov-2 transmission was left for future work. However, it is  
339 worth noting that during the outbreaks observed in our study, infections occurred in different  
340 care units, which may prime HCW-to-HCW transmission, rather than simultaneous  
341 independent events of patient-to-HCW transmission. In early stages of the pandemic, personal  
342 protective equipment (PPE) placed a focus on the risk induced by patients, but could have

343 contributes to underestimate the risk of infection from –infected and undiagnosed–  
344 colleagues. This may be especially true for quarantine hospitals in which HCWs share resting  
345 and conviviality rooms for longer times than in standard care settings. Adapting the use of  
346 PPE and social distancing between colleagues while ensuring sufficient social interaction and  
347 support to maintain HCWs’ mental health thus constitutes a specific challenge for quarantine  
348 hospitals [20].

349 Preventing nosocomial SARS-CoV-2 infection remains an urgent need, especially in settings  
350 where preparedness does not match the risk faced by HCWs. The large variation in infection  
351 risk we found between hospitals suggests that HCWs from quarantine hospitals may face a  
352 high risk of infection, but that, with sufficient anticipation and infection control measures, this  
353 risk can be brought down to levels similar to those observed in standard COVID-19 care  
354 settings. A comprehensive assessment of quarantine hospital care models should also include  
355 their impact on HCWs’ mental health as well as the potential benefits of earlier infection  
356 diagnosis, which is likely to reduce further hospital, household and community transmission  
357 [20].

358

359 **EMAE-MESuRS working group on nosocomial SARS-CoV-2 modeling**

360 Audrey Duval<sup>6,7,8</sup>, Kenza Hamzi<sup>1</sup>, Niels Hendrickx<sup>6</sup>, Kévin Jean<sup>1,2,5</sup>, Sofía Jijón<sup>1,2</sup>, Ajmal

361 Oodally<sup>6,7,1</sup>, Lulla Opatowski<sup>6,7</sup>, George Shirreff<sup>6,7,8</sup>, David RM Smith<sup>6,7,1</sup>, Cynthia

362 Tamandjou<sup>7</sup> and Laura Temime<sup>1,2</sup>

363 <sup>6</sup> Institut Pasteur, Epidemiology and Modelling of Antibiotic Evasion (EMAE), Paris, France

364 <sup>7</sup> Université Paris-Saclay, UVSQ, Inserm, CESP, Anti-infective evasion and

365 pharmacoepidemiology team, Montigny-Le-Bretonneux, France

366 <sup>8</sup> IAME, UMR 1137, Université Paris 13, Sorbonne Paris Cité, France

367

368 **Declaration of interest**

369 The authors declare no conflicts of interest.

370

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374

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