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1 **Covid-19 outbreak and health care worker behavioral change toward hand hygiene**
2 **practices.**

3 Running title: Covid-19 and hand hygiene practices.

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16

17 **Keywords:** Covid-19, real-time measurement, compliance, automated hand hygiene
18 monitoring, cross-transmission, infection control.

19

20 **Abstract**

21 **Background:** The coronavirus disease (COVID-19) pandemic has affected healthcare
22 workers (HCW) in their clinical practice. HCW were challenged with new guidelines and
23 practices to protect themselves from occupational risks. We wished to observe if hand
24 hygiene behavior by real-time measurement was related to the dynamic of the epidemic, and
25 the type of patient being cared for in France.

26 **Methods:** This study used an automated hand hygiene recording system to measure HCW
27 hand hygiene on entry to and exit from patient rooms throughout the COVID-19 pandemic.
28 We analyzed the correlation between hand hygiene compliance and COVID-19
29 epidemiological data. Analysis of variance was performed to compare compliance rate during
30 the different periods of the epidemic.

31 **Findings:** HCW hand hygiene rate on room entry decreased over time; on room exit, it
32 increased by 13.73% during the first wave of COVID-19, decreased by 9.87% during the
33 post-lockdown period, then rebounded by 2.82% during the second wave of the epidemic.
34 Hand hygiene during patient care and hand hygiene on room exit had a positive relationship
35 with the local COVID-19 epidemic; conversely, hand hygiene on room entry did not depend
36 on the trend of the epidemic, nor on nursing of COVID-19 patients, and it decreased over
37 time.

38 **Conclusion:** HCW modified their behaviors to face the risk propensity of the pandemic.
39 However, to improve the poor compliance at room entry, reducing confusion between the
40 hand hygiene recommendation and glove recommendation may be necessary; disinfection of
41 gloving hands might solve this issue.

42 **Introduction**

43 Since the 2000's, coronaviruses (CoVs) have been associated with significant disease
44 outbreaks in East Asia (SarS-CoV-1) and the Middle East (MERS-CoV). The spread of the
45 novel coronavirus (SARS-CoV-2), initially identified in the Hubei province of China in
46 December 2019, was declared by the World Health Organization (WHO) as the pandemic of
47 coronavirus disease (COVID-19) in March 2020 [1]. At the time of writing there had been
48 91,938,218 cases and 1,967,655 deaths globally, including 2,806,590 cases and 68,802 deaths
49 in France [2]. Healthcare workers worldwide, who have been regularly trained to avoid
50 hospital-acquired infection by following guidelines, particularly hand hygiene, to reduce cross
51 transmission and protect their patients are currently facing another objective: to protect
52 themselves from SARS-CoV-2 infection using prevention protocols to which they are less
53 commonly accustomed (self-protection). These new sanitary guidelines directed toward health
54 care worker protection rather than toward patient protection is a new challenge for this
55 community. With personal protection equipment (PPE), hand hygiene has been shown to be
56 the cornerstone of protection from respiratory viruses [4,5], and hand hygiene remains a main
57 way to limit cross-transmission, as recommended by the WHO [5].

58 Since 2012, we have developed an automated hand hygiene monitoring system and used it as
59 a part of the management of healthcare-associated-infections at the University Hospital
60 Institute Méditerranée Infection (IHU-MI) [6–9]. The changing paradigm of hand hygiene
61 practice imposed by this new ongoing epidemic seemed interesting to monitor with our
62 system, to evaluate if HCW had (or not) easily adjusted to this new approach of infection
63 prevention and changed their behaviour. Since we have observed two epidemic waves, we
64 were interested in monitoring HCW in between the two waves to evaluate if their hand
65 hygiene behavior correlated with the outbreak amplitude and with the type of patient being
66 cared for.

67 This study aims to observe if hand hygiene practices on entry and exit of the patient's room
68 and during patient care were correlated with the dynamic of the epidemic, and the type of
69 patient being cared for (COVID-19 cases or not) throughout the two waves of the COVID-19
70 pandemic.

71 **Methods**

72 Automated hand hygiene recording systems

73 Since the end of 2017, an automatic hand hygiene monitoring device (MediHandTrace©) has
74 been in place in the infectious diseases unit, which contains 25 single bedrooms. This system
75 measures HCW utilization of alcohol-based hand rubs (AHR) on entry and exit from patient
76 rooms (hand hygiene opportunity). Thanks to voluntary HCW who gave their consent, a
77 unique ID tag is inserted in their shoes and when entering or exiting the bedroom of each
78 patient's room, this ID tag, a door sensor and a sensor on the hand sanitizer, communicate
79 through a server and allow identification of who entered or exited the room, and if AHR was
80 performed on entry and exit, with a very good accuracy in experimental settings [7–10].
81 However, in the real-life environment, the system does not tend to perform as well, especially
82 when several HCW enter the room at the same time. Indeed, sensor events like “the door is
83 opening” and “the door is closing” are not associated with an ID tag, and therefore cannot be
84 directly linked to a particular HCW, leaving issues such as whether or not the person whose
85 behavior is being evaluated truly exited the room.

86 To optimize the accuracy of interpretation of HCW activities, we developed an algorithm
87 written in C++ programming language that identifies each activity by analysis of short
88 sequences of consecutive events from raw sensor data. Sensor events were grouped in
89 sequences defined as a serial of signals traducing an event (the door is opening, an identified

90 HCW puts their shoes on the carpet, he/she uses hydroalcoholic solution, etc.) associated with
91 its corresponding time of occurrence.

92 Such event grouping enabled us to accurately pair entry and exit events with unique ID tags in
93 the single bedroom / multiple HCW scenario. It was thus possible to follow the nursing staff's
94 activities in a bedroom on an individual basis, for instance, for each HCW, to know whether
95 they washed their hands when they entered and when they left the room. To assess the
96 accuracy of the optimization algorithm, we compared its interpretation to a human-based
97 video analysis from cameras set up in patients' rooms. Level of correspondence was excellent.

98 Piloting of the automated system

99 In order to assess accuracy of data capture, we examined 33 randomly selected HCW events
100 occurring between 26th November to 29th November 2019 and compared video and
101 interpretations from the algorithm. Eighteen room entries were correctly interpreted as such
102 by the algorithm; for room exits, 13 were interpreted correctly but 2 interpretations were
103 erroneous due to several HCW exiting at the same time. As a result, 93.9% of entries and
104 exits were interpreted correctly by the algorithm and the kappa coefficient between the videos
105 and interpretations from the algorithm was 0.88 (Supplementary material).

106 Infection control procedures

107 During the COVID-19 pandemic, HCW were trained and encouraged to adhere to the
108 principles of WHO evidence-based guidelines for PPE use and hand hygiene practice [11,12].
109 HCW were asked to wear PPE (gown, FFP2 mask and gloves) before entering patient rooms.
110 Hand sanitizers containing alcohol (75–85% v/v) effectively reduce the infectivity of
111 coronaviruses *in vitro* [13]. Disinfection of gloved hands has been demonstrated as efficient
112 and feasible during patient care for multiple activities, and a recent study shows that alcohol-
113 based solution did not affect elongation at breakage of the nitrile gloves [14–16]. Thus, we

114 promoted the use of gloved AHR upon entry to the room, upon exit of the room and as often
115 as necessary during patient care.

116 Definitions

117 Daily hand hygiene compliance rate on room entry and exit was computed by the daily
118 number of AHR utilizations on entry and exit, divided by the total daily number of entries and
119 exits. AHR during care were computed by the number of AHR recorded by our system after
120 18 seconds (grace delay period) from entering divided by the total daily number of room
121 entries. AHR consumption was computed by the total volume (1 application of AHR=3ml) of
122 AHR by each HCW each day.

123 The epidemiological COVID-19 data of our hospital was based on the monthly number of
124 patients screened and the number of patients diagnosed positive for SARS-CoV-2, obtained
125 from the hospital information system. To calculate nursing care of the COVID-19 patient, the
126 bed-day total was calculated as the daily number of beds occupied by either a COVID-19 or a
127 non-COVID-19 patient admitted as an inpatient each month. We then separated the study into
128 four periods: (1) pre-COVID-19, from September 2019 to the end of February 2020; (2) the
129 first wave of COVID-19, from March 2020 to the end of May 2020; (3) post-lockdown, from
130 June 2020 to the end of August; (4) the second wave of COVID-19, from September 2020 to
131 the end of November 2020.

132 Statistical analysis

133 Data analysis included descriptive analyses. The assumption of normality was assessed by
134 analysis of skewness and kurtosis. First, to evaluate the relation between the local COVID-19
135 epidemic and hand hygiene behaviors, the Pearson correlation coefficient was used to
136 evaluate the strength of the relationship between the compliance with AHR (on entry and
137 exit), the number of patients screened, the number of patients diagnosed as positive for

138 SARS-CoV-2 and the total bed-day of care of each COVID-19 patient. Second, comparing
139 any differences in compliance with AHR between the four COVID-19 periods, analysis of
140 variance (ANOVA) was used to compare the mean of compliance with AHR (on entry, during
141 care and on exit) and AHR consumption between these periods. Time series analysis using
142 autoregressive integrated moving average (ARIMA) model was performed to analyze the
143 trend of hand hygiene compliance over time. Results were considered statistically significant
144 at p-values less than 0.05. All the collected data were entered into an Excel file and the
145 statistical tests were performed with SPSS 25.

146 Ethics

147 The study protocol was approved by the Review Board of our institution and available under
148 N° 2016-018; all participating HCW were informed about the automatic monitoring
149 procedure and the guarantee of anonymity and confidentiality. Video was recorded and
150 visualized for accuracy evaluation of the algorithm by two researchers not involved in patient
151 care (MA and FH). Once the content was analyzed and anonymized, the recording video was
152 destroyed. All HCW are protected by the French National Commission on Informatics and
153 Liberty.

154 **Results**

155 Evolution of compliance with hand hygiene

156 From September 2019 to November 2020 (over 15 months of real-time observation), a total of
157 162 334 entries and exits were recorded by the automatic monitoring system. The mean of
158 compliance with AHR use on entry to a patient's room within this period of observation was
159 21.02% (SD= 8.91) and on exit from a patient's room was 55.03% (SD= 11.9). During care,
160 mean incidence of AHR use by HCW was 4.32% (SD=2.34). Mean AHR consumption was

161 61.63(SD= 22.45) mL/HCW/day. Figure 1 shows the evolution of compliance with AHR use
162 on room entry, during patient care and on room exit.

163 Epidemiological data

164 From December 2019 to November 2020, 253547 new patients were screened at IHU-MI and
165 21938 patients were diagnosed as SARS-CoV-2 positive. A total of 1319 patients were
166 admitted to our unit including 834 COVID-19 patients. Each month, the average number of
167 patients screened was 16903 (SD= 18654) and the average number of COVID-19 patients was
168 1466 (SD= 2058) (Supplementary material). The average number of bed-days was 730
169 (SD=123) per month, including 313 (SD=265) bed-days for non-COVID-19 patients and 417
170 (SD= 330) bed-days for COVID-19 patients (Figure 2).

171 Compliance with AHR use on room exit had a positive correlation with the number of patients
172 screened ($r=0.66$, $p=0.004$), the number of patients diagnosed ($r=0.53$, $p=0.021$) and the total
173 number of bed-days of COVID-19 patients ($r=0.68$, $p=0.011$). Use of AHR during care had a
174 strong positive correlation with the number of patients screened ($r=0.84$, $p<0.001$), the
175 number of patients diagnosed ($r=0.77$, $p<0.001$), the number of bed-days of COVID-19
176 patients ($r=0.88$, $p<0.001$) and the moderate positive relation with total number of bed-days of
177 care ($r=0.57$, $p=0.033$). AHR consumption had a positive correlation with the number of bed-
178 days of COVID-19 patients ($r=0.63$, $p=0.019$) and total bed-days of care ($r=0.61$, $p=0.023$).
179 Compliance with AHR use on room exit and AHR use during patient care increased as the
180 epidemic of COVID-19 increased or the nursing of COVID-19 in the unit increased, and vice
181 versa. AHR consumption increased when the total number of bed-days or the nursing of
182 COVID-19 patients increased. However, compliance with AHR use on room entry was not
183 associated with the COVID-19 epidemic or the nursing of COVID-19 in the unit (Table I).

184 The mean of compliance with AHR use on room entry was 23.88% (SD=7.56) during the pre-
185 COVID-19 period. For the first wave of COVID-19 this was 27.31% (SD=6.45), for the post-
186 lockdown period 17.3% (SD=6.77) and for the second wave was 13.3% (SD=6.27) ($F(3,435)$
187 $= 77.93$, $p < 0.001$). This low compliance rate on room entry could be explained by the fact
188 that HCW were gloved before entering the room and staff were not used to disinfecting
189 gloved hands. The mean rate of AHR use during patient care was 3.21% (SD=1.43) at the pre-
190 COVID-19 period; for the first wave of COVID-19 this was 5.37% (SD=2.11), for the post-
191 lockdown period 4.41% (SD=2.15) and for the second wave 5.17% (SD=1.83) ($F(3,435) =$
192 37.36 , $p < 0.001$). The mean of compliance with AHR use on room exit was 50.63%
193 (SD=8.28) for the pre-COVID-19 period; for the first wave of COVID-19 this was 64.37%
194 (SD=8.27), for the post-lockdown period 54.5% (SD=8.52) and for the second wave 57.32%
195 (SD=9.93) ($F(3,435) = 51.57$, $p < .001$). Mean AHR consumption was 60.28 (SD=22.75)
196 mL/HCW/day for the pre-COVID-19 period; for the first wave of COVID-19 this was 69.42
197 (SD=18.74) mL/HCW/day, for the post-lockdown period 54.94 (SD=15.97) mL/HCW/day
198 and for the second wave, 66.98 (SD=21.83) mL/HCW/day ($F(3,435) = 9.578$, $p < .001$)
199 (fig.3).

200 Mean rate of AHR use on room entry increased by 3.43% during the first wave of COVID-19
201 but got lower over time. Mean rate of AHR use during patient care increased by 2.15% during
202 the first wave of COVID-19, decreased by 0.95% during the post-lockdown period, and then
203 rebounded by 0.76% during the second wave of the epidemic. Mean rate of AHR use on room
204 exit increased by 13.73% during the first wave of COVID-19, decreased by 9.87% during the
205 post-lockdown period, then rebounded by 2.82% during the second wave of the epidemic.
206 Concerning AHR consumption, this increased by 9.14 mL/HCW/day during the first wave of
207 COVID-19, decreased by 14.48 mL/HCW/day post-lockdown and then rebounded by 12.05
208 mL/HCW/day during the second wave of the epidemic. Time series analysis confirmed that

209 there was a decrease of compliance with AHR use on room entry over time ($P < 0.001$) and an
210 increase of compliance with AHR use on room exit over time ($p = 0.013$)

211 **Discussion**

212 This long-term hand hygiene observation using data from an automated monitoring system
213 shows that HCW use of AHR during patient care and on room exit were positively correlated
214 with the dynamics of the local COVID-19 epidemic and the nursing of COVID-19 patients.
215 Total AHR consumption appeared to be related to the nursing of COVID-19 patients and the
216 total number of bed-days of care. Conversely, AHR use on room entry did not depend on the
217 trend of the epidemic nor nursing of COVID-19 patients. As a result, rates of AHR use on
218 both room entry and room exit increased during the first wave of the epidemic and both
219 decreased during the post-lockdown period, while AHR use on room exit and during care
220 tended to follow the trend of the epidemic; AHR use on room entry decreased over time.

221 Four recent studies found that HCW hand hygiene compliance improved during the early
222 pandemic (first quarter of 2020); however, three of these studies were observed by audit
223 without comparing with any remarkable events in national COVID-19 control [17–20]. One
224 study which was based on an automated monitoring system obtained a similar result to ours.
225 The authors found decreased hand hygiene performance after school closures, and concluded
226 that even during the global crisis, it seemed difficult to maintain improved hand hygiene
227 performance [20].

228 Automated monitoring does afford some advantages during the pandemic, such as reducing
229 the human cost for audit, continued measurement and reducing the Hawthorne effect [13].
230 Our finding shows the different evolution of four hand hygiene indicators: compliance with
231 AHR use on room entry, AHR use during patient care, AHR use on room exit and total AHR
232 consumption. AHR use on room entry and during patient care are mainly related to patient

233 protection whereas AHR use on room exit is related to self-protection of HCW. At the
234 beginning of the epidemic, the improvement of both self-protection and patient-protection
235 measures could be explained by HCW fear of the crisis, to avoid transmitting the virus to their
236 family, to themselves or to their patients. A recent psychology study showed that fear of
237 pandemic encouraged recommended public health behaviors due to the negative emotions that
238 reduce motivation for risky behaviors [22]. It could be also explained by respect of the
239 protocol. Among all required PPE within the COVID-19 protocol, our observations show a
240 correlation between AHR use and the hospitalization of COVID-19 patients in the unit, with
241 hand hygiene being performed frequently as recommended by the WHO [23].

242 The second observation was the different evolution of compliance with AHR use at room
243 entry and room exit. It seems that the COVID-19 outbreak had more impact on compliance
244 with AHR use on room exit and during care, and on total AHR consumption. HCW were
245 asked to wear PPE before entering a patient's room and then to remove gloves and apply
246 AHR before leaving a patient's room; this protocol was respected. Thus, even with the drop in
247 compliance during the post-lockdown period, the AHR use on room exit and during patient
248 care remained higher during the second wave of the epidemic than during the pre-COVID-19
249 period.

250 Under those circumstances, it seems that gloving hands cause the reduction of compliance at
251 entry. After the first wave of the epidemic, HCWs disinfected their hands less and less on
252 room entry. The low compliance rates on entry could be explained by the gloved hand which
253 has been reported to reduce hand hygiene [24]. Moreover, one can imagine that HCW better
254 perceived the risk to be exposed to the virus for themselves than to protect the patients.
255 However, several recent studies showed the benefit of disinfection of gloved hands [25–27];
256 alcohol-based disinfectants may slightly affect the breaking load of nitrile gloves, but it does
257 not affect its extensibility [15]. It seems our HCW were not aware on such evidence on room

258 entry. As noticed by Allegranzi et al. hand hygiene appears neglected when the emergent
259 virus seems to disappear with compliance rates becoming lower, which ties in with our
260 observations. The studies of Maltezou et al. shows there are gaps in infection control in non-
261 COVID-19 referral hospitals; it is possible that adherence to recommendations could be even
262 lower in non- COVID-19 hospitals [28].

263 **Conclusion**

264 In conclusion, HCW respected the protocol and modified their behaviors during the outbreak;
265 however, improvements of compliance with AHR on both room entry and exit were not
266 sustained throughout the epidemic especially for entry. This pandemic has led HCW to adapt
267 their hand hygiene behavior to the visible risk (the epidemic's curve) to protect themselves;
268 according to our finding, we enforce the importance of hand hygiene monitoring even during
269 the pandemic, especially before patient contact. To reduce potential confusion between the
270 hand hygiene recommendation and glove recommendation, disinfection of gloving hands
271 might improve poor compliance at entry.

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277 **Contributors**

278 Conceived and designed the experiments: PB, FH, SB. Performed the experiments: FH, OF.
279 Algorithm developed: SD and MA. Analysed the data: FH. Wrote the paper: FH, PB, SB,
280 MA.

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285 **Conflict of Interest**

286 P Brouqui was a former advisor of the Medihandtrace® Company.

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374

Figure Legends:

Fig.1: The evolution of the compliance to AHR use on room entry, during patient care and on room exit; 95% confidence interval.

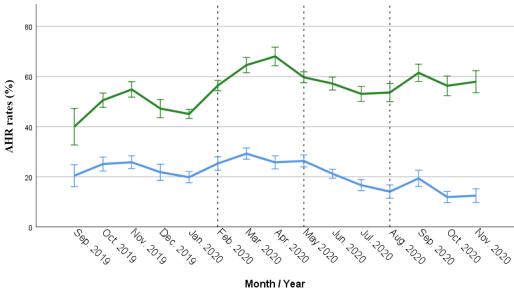
The green line represents AHR rates of use on room exit; the blue line represents AHR rates of use on room entry. The vertical dashed lines represent the different periods of the epidemic.

Fig.2: The evolution of bed-days of care

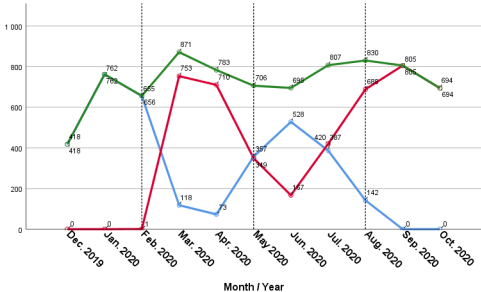
The green line represents the total number of bed-days of care, the red line represents the bed-days of care of COVID-19 patients and the blue line represents the bed-days of care of non-COVID-19 patients. The vertical dashed lines represent the different periods of the epidemic.

Fig.3: Boxplots and mean plots

(a.) AHR use on room entry (%), (b.) AHR use during patient care (%), (c.) AHR use on room exit and (%), (d.) AHR consumption (mL/HCW/day) in four periods of the COVID-19 epidemic.



Count



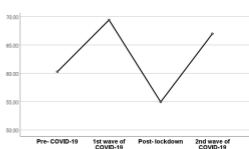
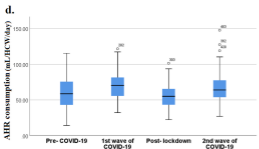
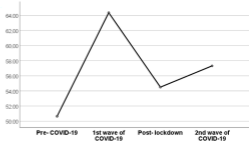
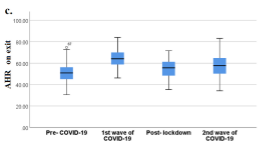
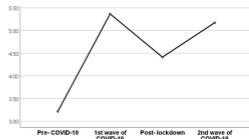
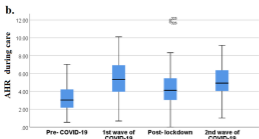
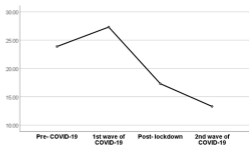
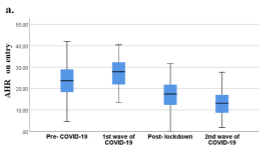


Table I.

Correlations between the monthly data of AHR use on room entry, AHR use during patient care, AHR use on room exit, number of patients screened, number of patients diagnosed, bed-days of COVID-19 patients and total bed-days of care.

		AHR on entry	AHR on exit	AHR during care	AHR consumption	Patients screened	Patients diagnosed	COVID patients
AHR on exit	Pearson Correlation	,211	1					
	(p values)	,226						
	N	15	15					
AHR during Care	Pearson Correlation	-,307	,782**	1				
	(p values)	,133	,000					
	N	15	15	15				
AHR consumption	Pearson Correlation	,203	,561*	,298	1			
	(p values)	,234	,015	,140				
	N	15	15	15	15			
Patients screened	Pearson Correlation	-,310	,656**	,842**	,290	1		
	(p values)	,131	,004	,000	,147			
	N	15	15	15	15	15		
Patients diagnosed	Pearson Correlation	-,360	,529*	,769**	,329	,915**	1	
	(p values)	,093	,021	,000	,116	,000		
	N	15	15	15	15	15	15	
COVID patients	Pearson Correlation	-,165	,676*	,882**	,628*	,932**	,848**	1
	(p values)	,314	,011	,000	,019	,000	,000	
	N	11	11	11	11	11	11	11
Bed-days of care	Pearson Correlation	-,022	,465	,573*	,612*	,493	,393	,659*
	(p values)	,475	,075	,033	,023	,062	,116	,014
	N	11	11	11	11	11	11	11