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COVID-19

Analysing different exposures identifies that wearing masks and establishing COVID-19 areas reduce secondary-attack risk in aged-care facilities

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Abstract

Background: The COVID-19 epidemic has spread rapidly within aged-care facilities (ACFs), where the infection-fatality ratio is high. It is therefore urgent to evaluate the efficiency of infection prevention and control (IPC) measures in reducing SARS-CoV-2 transmission.
Methods: We analysed the COVID-19 outbreaks that took place between March and May 2020 in 12 ACFs using reverse transcription–polymerase chain reaction (RT–PCR) and serological tests for SARS-CoV-2 infection. Using maximum-likelihood approaches and generalized linear mixed models, we analysed the proportion of infected residents in ACFs and identified covariates associated with the proportion of infected residents.
Results: The secondary-attack risk was estimated at 4.1%, suggesting a high efficiency of the IPC measures implemented in the region. Mask wearing and the establishment of COVID-19 zones for infected residents were the two main covariates associated with lower secondary-attack risks.
Conclusions: Wearing masks and isolating potentially infected residents appear to be associated with a more limited spread of SARS-CoV-2 in ACFs.

Key words: COVID-19, aged-care facilities, mask wearing, generalized linear mixed models, secondary-attack risk

Key Messages

- The number of COVID-19 cases has increased in aged-care facilities (ACFs) with the delay in wearing masks.
- Isolating residents infected or exposed to COVID-19 is associated with lower secondary-attack rates.
- Accounting for the structure of ACFs is important for the understanding of outbreak sizes.

Introduction

COVID-19 spreads rapidly within aged-care facilities (ACFs)[1–3] and recommendations have been issued to reduce new cases once an outbreak has been identified.[4] Guidelines from the European Geriatric Medicine Society (EuGMS) mention a variety of interventions based on testing, mask wearing or the isolation of people with established or suspected infection (as well as their contacts).[5] The relative impact of the different interventions on the magnitude of potential COVID-19 outbreaks in ACFs remains unclear and requires testing.

In France, the first COVID-19 epidemic wave is estimated to have started in mid-January 2020.[6] The first COVID-19 cases in a French ACF were detected in the Hérault department (France) on 10 March. This first outbreak triggered an immediate response from the Regional Health Authority (ARS Occitanie). Infection prevention and control (IPC) guidelines were implemented and included (i) mask wearing, (ii) the establishment of 'COVID-19 units' to isolate exposed or infected residents (Table 1) and (iii) repeated testing for SARS-CoV-2.[2] Several studies have assessed the secondary-attack risk of SARS-CoV-2, showing, for instance, that mask wearing reduces virus transmission in households.[7–9] However, we are not aware of similar studies in ACFs. These are all the more necessary, given (i) that ACFs have very specific features regarding the average infection-fatality ratio,[10] (ii) the variety of SARS-CoV-2 symptoms exhibited by the residents[11] and (iii) the difficulty in implementing certain IPC measures such as mask wearing.[4] Furthermore, in France, during the early stages of the epidemic, the wearing of surgical masks was still associated with clinical settings. Since ACF management and staff insist on not being seen as a hospital setting, this may have limited the implementation of mask wearing in these facilities, despite its strong potential to decrease epidemic spread.[12] The need for more data is also illustrated by a recent review on the clinical-practice guidelines of various agencies, associations and organizations to control COVID-19 epidemics in ACFs and these guidelines do not include mask wearing.[13]

The goal of this study was to investigate the efficiency of the IPC measures implemented in the Hérault department (Occitanie region, France) in reducing the spread of SARS-CoV-2 in ACFs when a patient tested positive. We first estimated the secondary-attack risk, defined as the proportion of residents infected [positive reverse transcription–polymerase chain reaction (RT–PCR)] in an ACF after an outbreak.[14,15] We further analysed the data using maximum-likelihood and generalized linear models to better understand the relative role of specific exposures among ACF residents on the total outbreak size.

Methods

Survey

In the Hérault department (France), an observational retrospective longitudinal study was carried out in 12 public and private ACFs that experienced a COVID-19 outbreak between March and May 2020. The exposure period lasted from early March to the end of April. Epidemic spread was monitored in each ACF by RT–PCR testing on a weekly basis. The follow-up of an ACF ended when there was a full week without any of the residents testing positive for SARS-CoV-2, which was interpreted as the end of the outbreak. The primary endpoint was the number of infected residents in the ACF at the end of an outbreak.

After the clinical identification of a COVID-19 case in any ACF, all residents and staff were tested weekly via RT–PCR on nasopharyngeal swabs. COVID-19 IPC measures were applied to all residents who were clinically followed up for 6 weeks and who underwent repeated RT–PCR testing. Contact patients were treated as positive patients but were not moved to COVID units. Positive or contact patients were considered as uninfected only after a full week of negative testing. After the end of the last infection in an ACF, serum antibodies were assessed by two clinical laboratories that performed the analyses. Blood testing for IgG antibodies directed against the SARS-CoV-2 nucleocapsid protein used an enzyme-linked immunosorbent assay CE-IVD marked kit (ID screen SARS-CoV-2-N

Table 1 Details of the aged-care facilities (ACFs) included in the study.

Facility[a]	Number of residents	Number of infections	Number of floors	Date of first case (2020)	Staff per resident	Days between mask wearing and first case	COVID unit	Report having enough masks	% single rooms	Part-time workers	Nurses per resident	Nursing assistants per resident	Hospital service agents per resident
AI	79	41	4	March 10	0.29	0	No	Yes	0.93	No	0.03	0.15	0.11
AU	62	1	3	April 4	0.48	–20	Yes	No	1	No	0.08	0.30	0.10
CH	125	10	4	March 17	0.34	–1	Yes	No	1	No	0.03	0.15	0.15
CO	46	12	1	March 27	0.46	–9	Yes	No	0.86	No	0.04	0.30	0.11
LA	101	21	4	March 25	0.37	–4	Yes	Yes	0.95	Yes	0.05	0.18	0.14
MD	64	13	2	March 25	0.23	–16	No	Yes	0.84	No	0.03	0.13	0.08
ML	83	11	3	April 21	0.36	–28	Yes	Yes	0.96	Yes	0.06	0.16	0.15
MN	80	44	4	March 19	0.49	–3	No	Yes	0.98	Yes	0.06	0.25	0.18
MF	81	21	3	March 17	0.46	0	No	Yes	1	No	0.05	0.25	0.16
PP	85	11	4	April 12	0.39	–38	Yes	Yes	1	No	0.06	0.21	0.12
LQ	63	10	3	April 1	0.34	–23	Yes	Yes	0.65	Yes	0.04	0.19	0.11
RO	61	18	5	March 25	0.51	–2	Yes	Yes	1	Yes	0.05	0.26	0.20

[a]For the purposes of anonymity, each ACF is listed by a two-letter identifier.

IgG indirect from IDvet, Montpellier, France). In the following analyses, positivity was based on RT–PCR tests. As reported earlier, there was a 95% match between RT–PCR and the serological result.[2]

When a COVID-19 outbreak was detected in an ACF, all residents and/or their relatives were informed that the residents' anonymized clinical and biological data would be used for research purposes. None of them disagreed. In the present analysis, the data were further anonymized by being aggregated at the facility floor level. This observational study was approved by the Institutional Review Board of the Montpellier University Hospital (IRB-MTP_2020_06_202000534).

Seven main exposures associated with each ACF were extracted from a survey carried out among the directors of the 12 ACFs:

- number of floors;
- number of days between the first COVID-19 case and the generalization of mask wearing;
- number of medical staff per resident;
- presence or not of a 'COVID unit', i.e. isolation of infected patients;
- ACF director reporting sufficient or lack of mask availability after the detection of the first case;
- proportion of single rooms;
- presence or not of temporary agency workers before the detection of the first case.

The masks used were all surgical facial masks (NF EN 14683 norm) and were worn by all people entering the ACF (residents, staff and potential visitors). Floors refer to the actual physical floor in the facility, which may overlap with the 'COVID unit' exposure in some of the establishments. The medical staff includes nurses, nursing assistants and hospital service agents (Table 1). All exposures were defined at the facility level and were reported by ACF directors. The data were aggregated by ACF floor and are provided in Supplementary data file, along with the Supplementary R-code file, available as Supplementary data at *IJE* online.

Statistical analyses

The response variable in our analyses was the number of residents infected during each outbreak. We first estimated the secondary-attack risk of the selected outcomes using a model-based approach described by Bailey.[14] Formally, the probability that j persons have been infected among n susceptible persons, knowing there were a introduction events in the household during the outbreak, is given by the formula:

$$\begin{cases} \pi_{jn}^{a} = \binom{n-a}{j-a} \pi_{jj}^{a} (1 - \mathrm{SAR})^{j(n-j)}, if\ a \leqslant j < n, \\ \pi_{nn}^{a} = 1 - \sum_{j=a}^{n-1} \pi_{jn}^{a} \end{cases} \quad (1)$$

Where SAR denotes the secondary attack risk.

Here, the 'household' is assumed to be the floor of an ACF. The value of the secondary-attack risk was estimated using a maximum-likelihood approach.

By treating the proportion of infected residents in each ACF after the outbreak (f) as a final epidemic size, we estimated the basic reproduction number (denoted R_0) in these ACFs by solving the following classical equation:[16]

$$R_0 = \frac{-log(1-f)}{f} \quad (2)$$

To study the effect of the seven main exposures on the proportion of infected residents, we used generalized linear models (GLMs) with a binomial distribution for the response variable weighted by the total number of residents. In these models, the unit of analysis (the 'household' in the secondary-attack-risk model) is the ACF.

To avoid arbitrarily selecting some of the exposures or using only univariate models, we performed GLMs with all possible combinations of our seven covariates (i.e. $2^7 = 128$ models) and performed model selection using the Akaike Information Criterion (AIC). An AIC difference of 2 between models was considered to be significant following classical statistical practice.[17] This means that the models eventually selected may only include some of the exposures.

To improve the statistical power, we also performed the analysis at the level of the ACF floors. The rationale for accounting for such a structure within ACFs is that activities between groups of residents were cancelled and that French national guidelines incited ACFs to separate different structures and staff. To partly correct for non-independence issues, we used a nested structure with the floors being associated with an ACF, which was itself treated as a random effect in the model. This was done using generalized linear mixed models (GLMMs) with a binomial distribution for the response variable and a normal distribution for the random effect.[18] As for GLMs, the model comparison was performed using the AIC. Analyses were performed using the lme4 package (glmer function)[19] in R version 4.0.2.

Results

The study involved 930 residents and 360 medical staff spread over 40 floors from 12 ACFs, with an average of 3.3 floors per ACF. Details regarding the ACF and the number of infected residents can be found in Table 1. The first RT–PCR-positive cases were detected on 10 March 2020, whereas the last ACF of the area to be affected by the first wave reported its first case on 21 April 2020.

Assuming a single virus introduction per ACF floor and independence between floors, we estimated a secondary-attack risk of 0.041 [95% confidence interval (CI): 0.036, 0. 047] among the residents. Assuming two virus introductions instead of one per ACF floor decreased the estimate to 0.033 (95% CI: 0.028, 0.038). Based on the final outbreak size, i.e. the total number of residents infected per ACF floor, we found that the estimate for the basic reproduction number (R_0), assuming a single introduction per ACF, was 1.021 (95% CI: 1.018, 1.024).

We then used GLMMs to identify the covariates associated with ACF outbreak size. The GLMM with the lowest AIC, shown in Supplementary Table S1, available as Supplementary data at *IJE* online, contained two covariates: the delay in mask wearing (in days) and the reported mask availability. These exposures were both significantly associated with larger outbreaks, as shown in Figure 1. When analysing the 11 GLMMs that were comparable from a statistical point of view (their difference in AIC with the best model was <2), we found consistent results. Table 2 shows that the two covariates identified in the best model were often the most significant in the 11 models. Another significant covariate was the presence of a 'COVID unit', which decreases the outbreak size. Finally, in some of the models, the presence of temporary agency workers before the first case was associated with larger outbreaks. In terms of associations between covariates, we have identified two classes of models. In the first class, the significant covariates are the two related to mask wearing. In the second class, the significant covariates are the presence of a COVID unit and the presence of temporary agency workers.

When assuming a less detailed model without any structure at the floor level, we identified 11 generalized GLMs that performed comparatively well from a statistical point of view (their AIC difference with the best model was <2). The presence of a COVID unit had a significant effect in all 11 models. The next significant effects were (i) the presence of temporary agency workers before the first case (10 models out of 11), (ii) the delay in mask wearing (6 models out of 11) and, for 2 of the models, (iii) the number of floors in the ACF. The effect of the covariates on outbreak size was the same as for the GLMMs.

Discussion

First, we estimated the secondary-attack risk of COVID-19 outbreaks in ACFs. We found values of <5%, which is

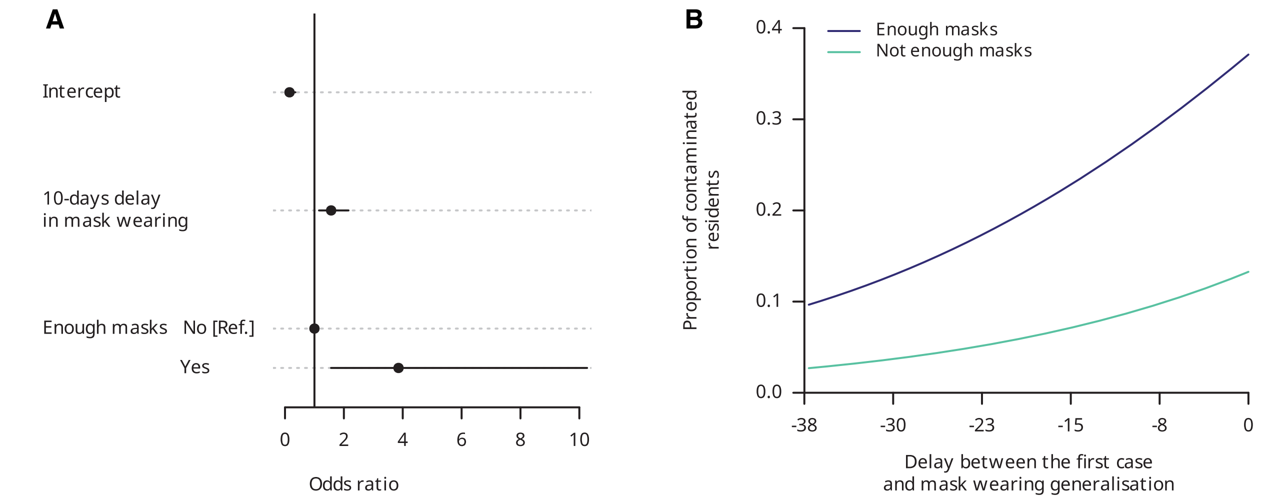

Figure 1 Effect of delay in mask wearing and mask availability on the risk of infection of aged-care facility (ACF) residents. (A) Odds ratio from the generalized linear mixed model shown in Supplementary Table S1, available as Supplementary data at *IJE* online. (B) Predicted proportion of infected residents in ACFs that reported an adequate supply of masks are in blue (darker colour) and the others are in green (lighter colour) based on the same model.

Table 2 Covariates identified in the 11 best generalized linear mixed models (GLMMs)

Covariate	Proportion	Proportion significant	Effect
Days until mask wearing	0.91	0.73	+
Report enough masks	0.82	0.73	+
COVID unit	0.55	0.18	−
Part-time workers	0.36	0.18	+
Medical staff	0.18	0	NA
Proportion single room	0.18	0	NA
Floors	0.09	0	NA

We show the proportion of models that contain each covariate, the proportion of models in which it is significant (p-value < 0.05 in the GLMM) and its effect on the total number of infections if significant.

much lower than the earlier estimates that ranged from 13.8% to 19.3%,[8] 23%[9] or even 35%.[7] This is consistent with the strict IPC measures implemented after the first outbreak that was detected on 10 March 2020. These were also most likely helped by the implementation of the national lockdown in France, which began on 17 March 2020. However, by the end of June 2020, <34 370 of the 726 410 residents in French ACFs had been infected by SARS-CoV-2,[20] i.e. <4.8%. Since our secondary-attack risk by definition only includes facilities that suffered an outbreak, its magnitude is low compared with the national average. This is consistent with other analyses that underline the importance of virus testing and cooperation from all stakeholders.[21]

Second, we conducted statistical modelling analyses to identify the relevant exposures that best explain the observed heterogeneity in COVID-19 transmission. GLMs were used because the response variable was not continuous (number of infected residents per ACF), making classic linear regression—such as analysis of variance (ANOVA) or analysis of covariance (ANCOVA)—inadequate. The structure of the data allowed us to gain even more insight by working at the floor level. However, this raises non-independence issues between the same floor of an ACF. To address this, we used GLMMs, also known as hierarchical generalized linear models, which are commonly used in clinical research.[18] In these models, the ACF had a 'random' effect, thereby partly correcting for the non-independence issue. However, care had to be taken in model interpretation.[19]

Our main approach was to analyse epidemics at the level of an ACF floor using GLMMs. This was motivated by the fact that early guidelines led to limiting contacts in ACFs (e.g. cancelling group events or assigning staff members to specific floors). We found that two exposures affected the epidemic spread within the ACFs: the delay in mask wearing and the reported mask availability. The earlier the mask wearing was generalized in the ACF, the smaller the outbreak. Unexpectedly, models where this covariate was significant also found that reporting a lower mask availability was associated with fewer outbreaks. Whereas this effect should be handled with care—due to the subjective dimension of the covariate—an explanation could be that a (reported) shortage of masks occurred in the ACFs that were using more masks. Indeed, there was a national shortage of mask availability in France and regional health authorities (the ARS) constituted a stock of masks in order to ensure a fair distribution between facilities. Therefore, it is possible that variations in adherence to the ARS guidelines (which are known to occur given the variations in the date of generalization of mask wearing) could have affected mask availability in the facility, especially since masks were supposed to be worn by residents, staff and potential visitors. Another hypothesis to explain the lower secondary-attack risk of ACFs reporting insufficient masks could be that the shortage of masks led to the local implementation of stricter guidelines that help control the outbreaks.

It is important to stress that ACFs differ from hospitals, especially in the context of an epidemic. For instance, training on how to use personal protective equipment is important and studies have shown that in hospitals, the workers who were not assigned to the care of COVID-19 patients were those most affected by the virus.[22] Furthermore, residents may display a variety of symptoms in response to SARS-CoV-2 infection[11] and can also refuse to wear masks.

Interestingly, when using less detailed statistical models that ignored the floor structure (i.e. GLMs), therefore assuming that cases occurred homogeneously within the ACF, the main effect we found was the setting-up of a 'COVID unit', which was associated with smaller outbreaks. This further strengthens our choice to use a detailed GLMM model to analyse the data. The presence of temporary agency workers before the first case was also associated with larger outbreaks in some of the GLMs.

Although this study includes 12 ACFs, which makes it one of the largest conducted to date, the statistical power is still limited. However, increasing the number of facilities could introduce additional biases, especially if they depend on different regional health authorities that may implement different guidelines.

From a statistical standpoint, the potential presence of overdispersion in the data deserves further investigation. When correcting for this potential bias, only 9 of the 127 potential GLMMs had a significant covariate: the presence of a COVID unit in the ACF. Unfortunately, correcting for overdispersion requires the use of quasi-likelihoods, therefore precluding AIC-based model comparison.

Another major limitation of this study is that it was conducted retrospectively, which constrained the design and variable choices. In particular, some of the exposures are subjective, which can generate unexpected correlations. However, this work can be considered as a pilot and will help to design further prospective studies with improved statistical power and the possibility to potentially include additional covariates. For instance, understanding the origin of the introduction of the virus into the facilities as well as the potential superspreading events could help to prevent such outbreaks.[23]

Overall, these results confirm the efficiency of the measures implemented in the south of France to prevent SARS-CoV-2 epidemics in ACFs. They reveal the importance of the within-ACF structure. They also show that delays in the generalization of mask wearing before the first case are strongly associated with the magnitude of the outbreaks. Finally, they support the USA's Centers for Disease Control and European guidelines, which both recommend that ACFs facing a COVID-19 outbreak should dedicate an area of the facility—with specific staffing and IPC measures—for the care of residents with suspected or confirmed COVID-19 infection.[2,4]

Supplementary data

Supplementary data are available at *IJE* online.

Ethics approval

This observational study was approved by the Institutional Review Board of the Montpellier University Hospital (IRB-MTP_2020_06_202000534).

Data availability

The data used for the analysis are available in the Appendix.

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Author contributions

S.A., M.T.S., C.S., H.B. and J.B. conceived of the study; H.B. and S.M. collected the data from the ACFs; E.T. and A.P. performed the biological analyses; B.R. performed the statistical analyses; S.A. wrote the first version of the manuscript, which was greatly improved by J.B.'s edits. All authors contributed to the final version of the manuscript.

Conflict of interest

None declared.

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