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Staff rostering, split team arrangement, social distancing (physical distancing) and use of personal protective equipment to minimize risk of workplace transmission during the COVID-19 pandemic: A simulation study

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ABSTRACT

Background: The recent global survey promoted by the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) Taskforce on COVID-19 (coronavirus disease 2019) described staff rostering and organization as significant operational challenges during the COVID-19 pandemic.

Method: A discrete event simulation was used to explore the impact of different permutations of staff roster, including the number of shifts per day, the number of staff on duty per shift, overall number of staff accessible to work in the laboratory (i.e. overall staff pool), the frequency of shift changes (i.e. number of consecutive days worked), fixed work-rest days and split team arrangement on workplace transmission of COVID-19 by a simulated index staff who acquired the infection from the community over 21 days. Additionally, the impact of workplace social distancing (physical distancing) and use of personal protective equipment (PPE) were investigated.

Results: A higher rate of transmission was associated with smaller overall staff pool (expressed as multiples of the number of staff per shift), higher number of shifts per day, higher number of staff per shift, and longer consecutive days worked. Having fixed work-rest arrangement did not significantly reduce the transmission rate unless the workplace outbreak was prolonged. Social distancing and PPE use significantly reduced the transmission rate.

Conclusion: Laboratories should consider organizing the staff into smaller teams/shift and reduce the number of consecutive days worked. Additionally, our observation aligns with the IFCC biosafety recommendation of monitoring staff health (to detect early infection), split team arrangement, workplace social distancing and use of PPE.

1. Introduction

The coronavirus disease 2019 (COVID-19), caused by a novel betacoronavirus called severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), is a highly infectious outbreak that has been declared a pandemic by the World health Organization (WHO) [1]. The International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) has recently formed a Taskforce on COVID-19 to provide guidance to laboratory practitioners in managing this challenge. The Task Force has already published biosafety recommendations, which outlined the steps that laboratories operating at biosafety level 1 and level 2 shall or may use to lower the risk of workplace transmission of the virus. These included the use of personal protective equipment (PPE), temperature and symptom monitoring, split team work arrangements and workplace social distancing [2].

A global survey by the Taskforce has then revealed that clinical

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laboratories have used PPE variably [3]. The laboratories also found it challenging to manage staff rostering, split team arrangement and maintain workplace social distancing (physical distancing) [4]. In part, this may be due to uncertainty surrounding the impact of different measures in reducing the risk of viral transmission. Therefore, this simulation study was conducted to explore the relative impact of staff rostering, split team arrangement, social distancing and use of PPE on the potential risk of transmission within the laboratory environment. From the results of this simulation, several recommendations are developed to further assist laboratories in planning their workplace in order to minimize the risk of transmission of SARS-Cov-2 infection.

2. Material and methods

A simulation model based on discrete event simulation approach [5] was constructed to compare the transmission of SARS-CoV-2 among staff under various roster arrangements and workplace measures. The entities in the simulation are laboratory staff assigned to work in a particular shift. In this simple model, each staff can only assume one of the two states, namely staying at home or working in the laboratory. The state of working in the laboratory is further divided into sub-states, representing each work shift, for rosters with more than 1 shift per day. The model only simulates the transition of the state of the staff in discrete time, i.e. when the staff goes to work and returns to home.

Each staff carries an attribute that describes whether they are susceptible to COVID-19 or infected. Staff who are working in the same shift with an index staff might contract the virus through a stochastic transmission process (the details of transmission will be described in the section below). In conventional agent-based models [6], the movement of the simulated staff is modeled and tracked continuously through time. This requires the setting of the number and duration of interaction between the simulated staff in the model. This simulation simplifies the parameters and models the transition of the staff from susceptible to infected upon a “successful contact” with an infected colleague.

2.1. Workplace assumptions

The workplace assumptions are arbitrarily determined to represent a wide range of laboratory scenarios.

2.1.1. Number of staff per shift and number of shifts

In this model, a laboratory is simulated to have a number of non-overlapping shifts per day (n = 1, 2, 3) with a number staff working in each shift (n = 5, 10, 20, 30). For simulated laboratories with more than 1 shift, it is assumed that the number of staff is reduced to 40% (i.e. n = 2, 4, 8, 12, respectively) after the first shift.

2.1.2. Overall number of staff accessible to work in the laboratory (i.e. Overall staff pool)

The overall number of staff accessible to work in the simulated laboratory was assumed to be 2, 4, 6 times the number of staff on the first shift. For example, for a laboratory with 5 staff working on the first shift, an overall staff pool of 10, 20, and 30 persons were examined. The expression of overall staff pool as multiples of the number of staff working per shift was designed to allow comparison between simulation scenarios.

2.1.3. Shift arrangement

The staff was assumed to change shift after a single day (shift), as well as after working 3, 7, 14, 21 consecutive days [4]. After each shift, the simulated staff is assumed to return and stay at home for at least the same number of days as the shift before being randomly assigned to a new shift with the other off-duty colleagues. For example, if a simulated staff works for 3 consecutive days, the staff will be off duty for at least the 3 following days. Additionally, the scenario where the simulated staff are randomly assigned a new shift without fixed rest days are also examined in laboratories with a single shift. The above two scenarios represent an alternating shift roster and a random roster arrangement, respectively.

2.1.4. Split team arrangement

Additionally, we also examined the impact of splitting the laboratory staff into 2 mutually exclusive teams. Under this assumption, the staff remains permanently assigned in a team and never interacts with members of another team. Within each team, the staff will continue to work in similar shift arrangements as above. The teams are assumed to change shift after a single day (shift), as well as after working 3, 7, 14, 21 consecutive days. The key workplace simulation parameters are summarized in Supplemental Table 1.

2.2. Transmission assumptions

The simulation assumes that an index staff contracts SARS-CoV-2 from the community and transmits the disease within the laboratory. The index staff is always assigned to the first shift in the staff roster at the beginning of each cycle of simulation to initiate the infection process. All the laboratory staff are assumed to have no prior immunity and thus being equally susceptible to infection. The staff within each shift are assumed to interact with one another (i.e. they interact within the same work environment).

Due to the stochastic nature of virus transmission, not all contacts lead to successful virus transmissions. Therefore, the probabilistic factor of p is applied to the average contact rate parameter c in a modified Poisson distribution for the number of “successful” contacts, which refers to contacts that lead to successful viral transmission, per work shift [7]. Mathematically, it is described by:

$$P(k) = \frac{(pc)^k}{k!}e^{-pc}$$

where P(k) represents the probability for k successful contact in a work shift, with k being a non-negative integer, p is the probability of transmission while c is the average contact rate (i.e. average number of unique contacts in a shift). From this Poisson distribution k is drawn randomly when susceptible staff are assigned to a shift with at least one infected staff. Subsequently, k staff are randomly drawn from other staff in the same shift to be infected to propagate the infection. Of note, P is a function of R_0 (the basic reproduction number), contact rate and length of infection period for an entire population [7]. The probabilistic model adopted in this study allows the simulation of virus transmission in a micro-environment, where there is a limited number of people an index case can infect (i.e. people in the same shift only), instead of an entire population.

Each newly infected staff further transmits the virus to other susceptible persons through the same process, leading to an eventual exponential increase of infection. It is assumed that the newly infected staff will only be able to transmit the virus in the subsequent shifts. In view of the stochastic nature of virus transmission and roster allocation, simulations with the same parameters are repeated 100 times and the median of the proportion of staff infected are recorded. The simulation model is visually represented in Fig. 1.

Throughout the simulation, it is assumed that the infected staff are not quarantined, and the staff remain equally infectious throughout the duration of simulation (i.e. 21 days), either being symptomatic or asymptomatic. Furthermore, the simulation assumes that the staff will only be infected at the workplace as this study focuses on the effect of roster arrangement on disease transmission. There are now reports of asymptomatic transmission of SARS-CoV-2 in the literature [8,9] with varying transmission rates compared to symptomatic patients [10,11]. These parameters have been explored in a pilot simulation but not included in the final model since they did not change the trend of the results nor the conclusions of the analysis.

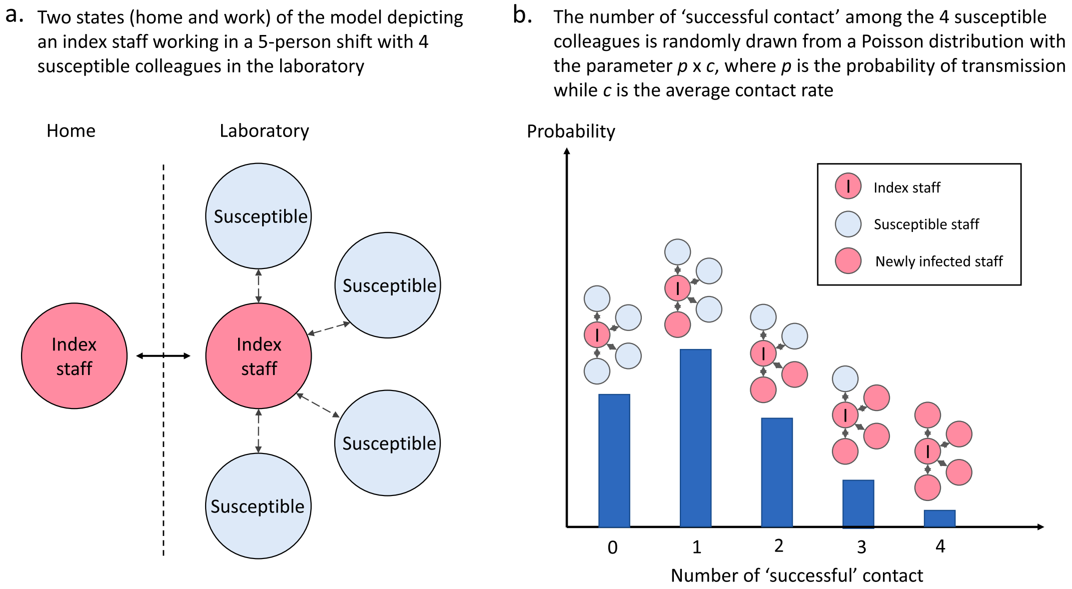

Fig. 1. Visual representation of the simulation model. Panel a shows the two states a simulated staff can be in, namely staying at home or working in the laboratory with 4 colleagues (5-staff shift). Panel b shows the Poisson distribution from which the susceptible colleagues are drawn from.

2.3. Secondary attack rate

The virus is assumed to be transmitted through contact between an infected staff and a susceptible staff with a probability (p), which is the secondary attack rate and is set as 15% for the base case scenario. Secondary attack rates of 5% and 30% were also simulated. These secondary attack rates are commensurate with the household secondary attack rates that have been reported in 6 publications to range from 4.6% to 32.4% with an average of 15.8% [12–17].

2.4. Impact of personal protective equipment

Additional simulations are performed to examine the effect of protective measures such as frequent hand washing and wearing various PPE that reduce the probability of infection. The odds ratios adopted for the reduction of p in the simulation are shown in Supplemental Table 1 [18].

2.5. Impact of social distancing

The number of distinct persons each staff comes into contact with over the duration of the working time is assumed to follow a Poisson distribution with an average contract rate of c. In general, the value of c increases as more staff are assigned to a single shift. In the baseline study, c assumes the value of [0.4 × number of staff on the shift]. In other words, it is assumed that a staff has contact with 40% of her colleagues who are on the same shift. To simulate the effect of workplace social distancing, c is arbitrarily reduced by halve.

2.6. Outcome

The outcome measure of the simulation is the proportion of simulated staff infected by the index staff at the end of the simulation period. The outcome of the simulation was examined after 7, 14 and 21 simulated days. In order to fully examine the impact of different staffing strategy, the simulation assumed that the infected staff continued to work throughout the simulation period.

2.7. Simulation package

This simulation was performed with codes written in Python 3 on a desktop computer (Intel Core i5 3.5 GHz, 8 GB RAM). Standard libraries such as NumPy and pandas are employed. The simulation codes used in this study are provided here (https://github.com/chaose5/COVID-roster-simulation) and in the Supplemental Material.

3. Results

3.1. General staff roster arrangement

The results of the base scenario simulation of a 15% secondary attack rate with fixed alternating workdays (i.e. fixed consecutive days on, and fixed minimum consecutive days off) is summarized in Supplemental Table 2. The simulation results for 5% and 30% secondary attack rates are summarized in Supplemental Tables 3 and 4. The trend of the results of the baseline scenario (15% secondary attach rate) were reproduced in the sensitivity analysis using different secondary attack rates of 5% and 30%.

By day 7 of simulation, the proportion of staff infected by the index colleague generally increased with:

1. Number of simulated days progressed (Fig. 2).
2. Lower overall number of staff accessible to work in the laboratory (i.e., the overall staff pool, expressed as multiples of the number of staff per shift) (Fig. 3).
3. Higher number of shifts per day (Fig. 3).
4. Higher number of staff per shift (Fig. 3).
5. Longer consecutive days worked (Fig. 4).

Initially, the proportion of simulated staff infected is higher for lower number of staff per shift due to the lower denominator (i.e. lower overall number of staff) and grows gradually in a stepwise manner. However, the rates of infection for higher number of staff per shift grow exponentially such that by day 5, roster arrangements with higher number of staff per shift has higher proportion of staff infected. This observation is due to the higher number of secondary infected staff in larger shift arrangements that can seed the cross-infection more rapidly. Of note, the simulation day when this intersection occurs is earlier when the overall number of staff accessible to work in the laboratory (overall staff pool) is lower.

On the other hand, there is a trade-off in having staff working in the same team for longer consecutive days, where it increases the

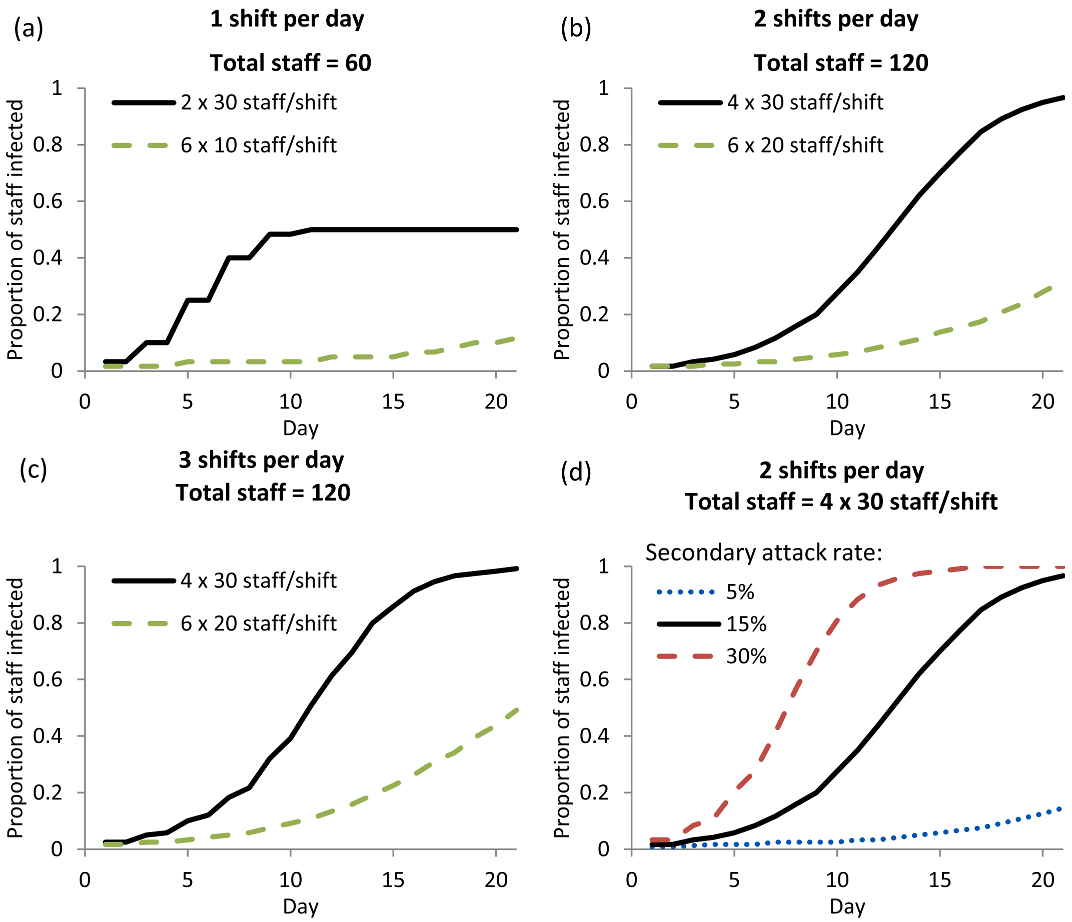

Fig. 2. Panels a, b and c show impact of different roster arrangements (number of shifts, number of staff per shift, total staff pool) on the proportion of staff infected by workplace transmission. The secondary attack rate is set at 15% with the stimulated staff working non-consecutive days. Panel d shows the effect of different secondary attack rates on proportion of staff infected.

likelihood of cross-infection within the team due to the prolonged interaction. However, this arrangement insulates the infected staff from those on other teams.

When the simulated staff do not have fixed alternating workdays (i.e. they are randomly assigned a new shift), they have generally similar proportion of cross infection at day 7 of the simulated workplace outbreak (Supplemental Table 5). The proportion of cross-infection is higher in the random workday cohort by day 14 and 21 of the simulations.

3.2. Split team arrangement

The split team arrangement is represented by the simulated scenarios where the laboratory has a single shift per day, an overall staff pool of twice the number of staff per shift and has fixed alternating workday. When this compared to the equivalent scenarios but with randomly allocated workday cohorts, the split team arrangement is associated with lower cross infection rates at all times (Fig. 5).

3.3. Social distancing and personal protective equipment

The results of the additional workplace measures, including social distancing and use of PPE at day 14 of the simulations, are summarized in Supplemental Table 6.

The contact rate, *c*, of the model is reduced to simulate the impact of workplace social distancing. This resulted in a significant reduction in the proportion of cross-infections across all roster arrangements and duration of simulation compared to the base model (Fig. 5). Similarly, the use of PPE reduced the rate of transmission proportional to the odds ratio adopted in the simulations (Fig. 5). The strongest protective effect is seen with the N95 masks (nearly equivalent to a FFP2 mask), which has the effect of reducing the odds of transmission by 0.09.

4. Discussions

There are several important limitations in this study. The simulation is a highly simplified model with many assumptions. It considers only two states (work and home) for the simulated staff. In reality, more states are expected to exist, for example, personal outing in the community. However, given the general adoption of lockdown and movement restriction in many parts of the world, this assumption may be reasonable. Nevertheless, the risk of additional laboratory staff acquiring the infection from the community may be increased in communities where the infection is widespread, as well as for those with some important predisposing factors (i.e., age ≥40 years, male sex, overweight) [19]. In such scenarios, the rate of transmission will be significantly increased [11]. Additionally, an important function of the laboratory is to support point-of-care testing, including the blood gas machines in the clinical areas. This may increase the risk of nosocomial infection, which may be seen as an additional risk for intra-hospital transmission.

The secondary attack rate of 15% also likely represents a high estimate for intra-laboratory transmission when PPE and disinfection is well practiced. However, the selection of this attack rate allows separate examination of the impact of PPE on the transmission rate.

The simulation also assumes that the infected staff is equally

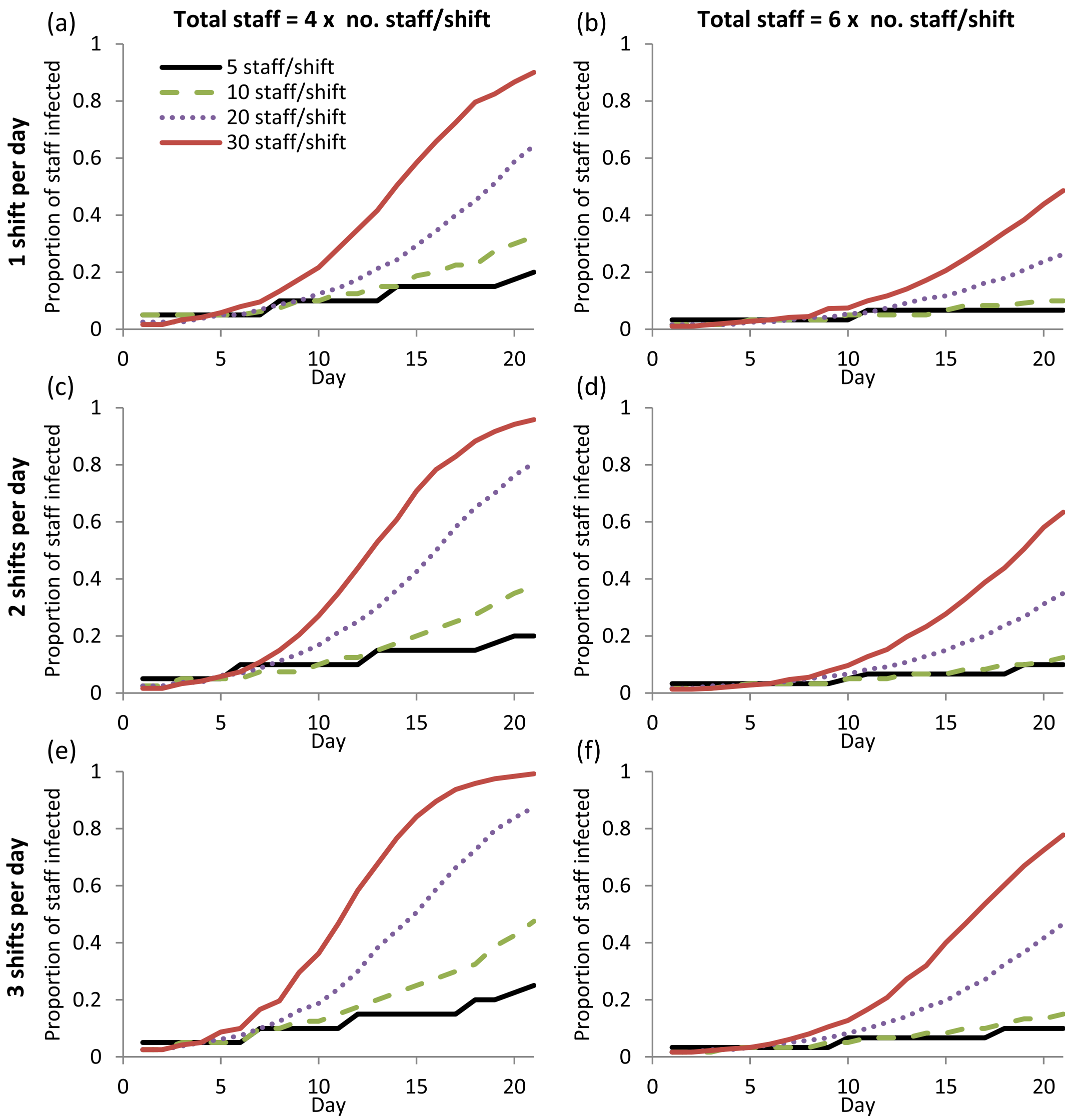

Fig. 3. Effect of number of staff per shift and of the number of shifts per day on the proportion of staff infected by workplace transmission. The secondary attack rate is set at 15% with the stimulated staff working non-consecutive days.

infectious throughout the simulation period (21 days), which likely represents an extreme scenario for infectious period as the average infectious period is 7–14 days and changes dynamically during the infection [20]. In reality, the infected staff is likely to display symptoms after an incubation period of 5–6 days [11], following which the staff should refrain from physically attending to work. Additionally, recovery from the illness is also ignored in this model [21]. These assumptions were necessary as this is a simulation that focuses on a relatively small population and a closed environment over a relatively short period of time. Without the assumptions, the simulation will fail to progress as there will not be sufficient simulated staff to be allocated into the shifts, or the impact of the different roster permutations and workplace interventions will be dampened and difficult to observe. The results obtained at day 7 of the simulation are likely to provide the most realistic representation of a workplace outbreak. Nonetheless, the results of the simulation are meant to show the relative effects of various staff arrangements and interventions. Owing to the assumptions above, they should not be considered predictive of workplace outbreaks.

The roster design in this simulation has also been simplified to contain the potential simulation permutations and allow convergence of simulation results. In practice, the roster design is likely to be more complex than what is represented here as it needs to take into account issues such as staff availability, operational requirements, staff preferences, leave entitlements, labor law and union requirements.

Despite the limitations outlined above, several broad recommendations can be made from the results of this simulations. In a laboratory that has staff working in rotating shifts/ section, there is a risk of an infected staff seeding new infections to other colleagues. The key consideration in minimizing the risk of workplace transmission is minimizing the opportunity for contact.

4.1. *Recommendation 1. Having less staff per shift is preferred*

For a given overall number of staff accessible to work in the laboratory (staff pool), it is preferable to organize smaller number of staff per shift than larger ones (Figs. 2 and 3). This may require the consolidation of certain laboratory function or sections. Having less staff at work reduces the opportunity of cross infection. Should there be excess manpower, staff can work from home.

4.2. *Recommendation 2. Frequent staff change is preferred*

Increase the frequency of shift change by having staff work less hours per day (i.e. increasing the number of shifts per day) or avoid

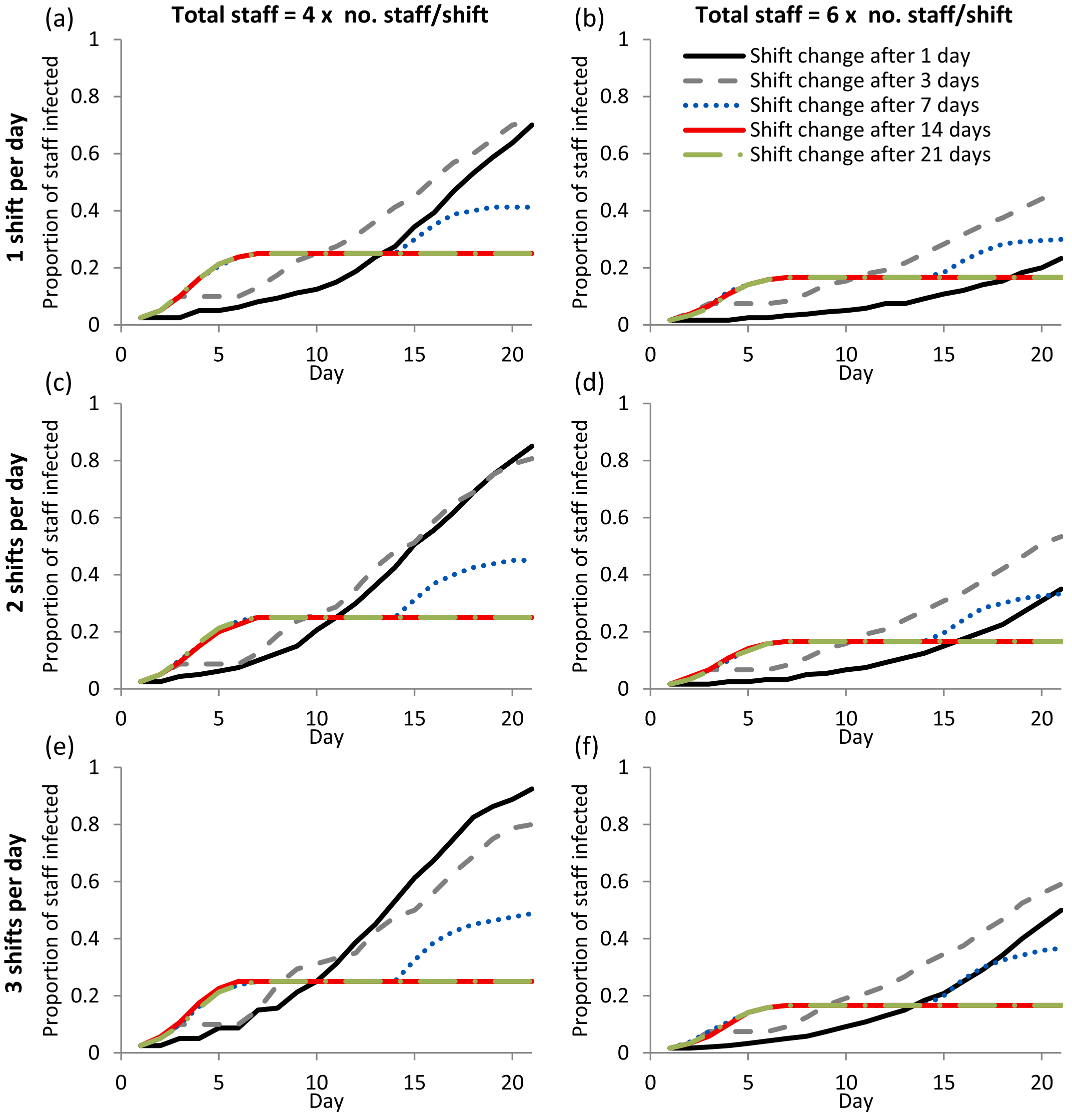

Fig. 4. Effect of frequency of shift change (i.e. number of consecutive days worked) on the proportion of staff infected by workplace transmission. The secondary attack rate is set at 15% with 20 staff per shift.

having staff work several days consecutively. These measures have the effect of reducing the probability of staff contact in the laboratory, as they stay at home more frequently. This is illustrated in Fig. 4, where the initial plateau appearance of graphs for the frequent shift change arrangements (after 1 day, after 3 consecutive days) is due to the index staff staying at home waiting on the next shift. On the other hand, longer consecutive workdays can ultimately limit the number of staff infected in a prolonged workplace outbreak.

4.3. Other observations

It is important to monitor the health of the staff. This is to isolate any infected staff early and prevent workplace transmission to grow exponentially (Fig. 2). This can be achieved by using temperature monitoring or asking the staff to self-report symptoms or illness as recommended in the IFCC biosafety recommendations [2], especially those most frequently associated with the initial stage of COVID-19 (cough, myalgia, headache, loss of smell and taste, gastrointestinal disturbances). The temperature and symptom monitoring can be performed by the staff themselves, or at the workplace (e.g. at the entrance to laboratory or building) and is already in practice in some laboratories [4]. Nevertheless, an infected staff may be minimally symptomatic yet infectious [9,22,23]. When staff are symptomatic, they should refrain from attending to work and self-isolate for a period of time according to local guidelines, but not less than for 2 weeks [20]. Detailed appraisal of the laboratory modalities available for diagnosis and monitoring of COVID-19 has been published by the IFCC COVID-19 Taskforce [24].

Splitting the staff into mutually exclusive teams has similar effects as having smaller number of staff working per shift. It limits the risk of workplace transmission to a smaller subgroup of operators (Fig. 5). This observation aligns with the recommendation by Lippi et al. However, split team arrangement often requires a larger buffer of manpower. Of note, the split team arrangement should include auxiliary staff, such as the cleaners, to ensure no intermediary transmission agents [4]. Where this is unfeasible, the laboratory may consider the recommendations in point 1.

Social distancing within the laboratory should be implemented, as the risk of transmission is directly proportional to the rate of contact (Fig. 5). This can be achieved by physical measures (where the laboratory staff keeps a safe distance of not less than 1 m, but preferably 2 m) or by policy (e.g. limiting social interaction such as disallowing lunch gathering, minimizing face-to-face meetings, coffee breaks, and so forth). Rest and mealtime gathering among staff is considered an at-

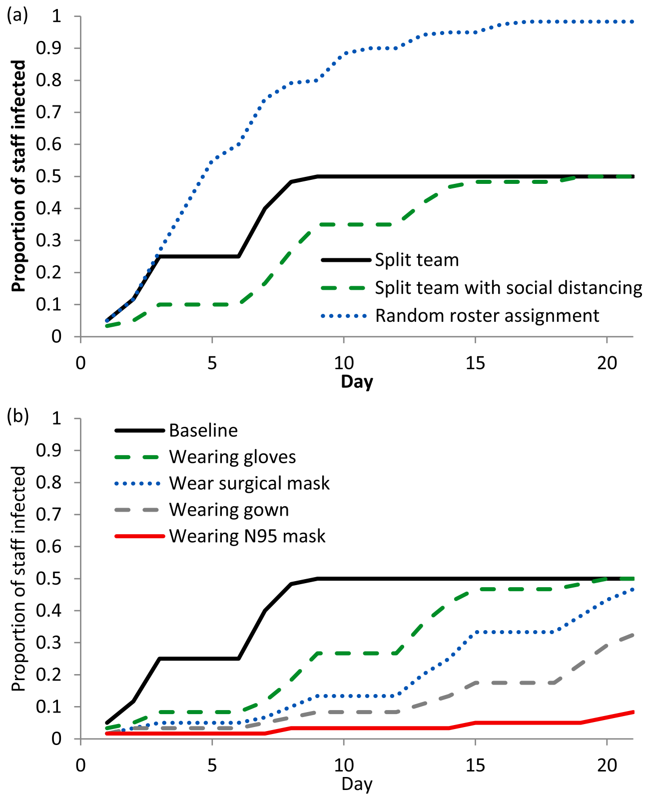

Fig. 5. Effect of a) split team arrangement, social distancing and b) personal protective equipment on the proportion of staff infected by workplace transmission. The data represents the impact of the individual interventions.

risk activity as they may not be wearing any PPE, and social distancing practices should be maintained. Nevertheless, physical space constraints often make it challenging to maintain a safe distance, and face-to-face workplace communication is often unavoidable in the laboratory.

In terms of PPE, the N95 face mask confers the highest protection against workplace transmission (Fig. 5), but it is not often used/or available in the laboratory during the current COVID-19 pandemic [4]. This is followed by gown, surgical mask and gloves. These data on protective effects of PPE are obtained from a *meta*-analysis of 6 case-control studies related to severe acute respiratory syndrome (SARS) [17], but should be broadly applicable to the current COVID-19 situation. Nevertheless, it is noted from the IFCC global survey that shortage of PPE is the biggest operational worldwide challenge in the current pandemic [4]. At a minimum, laboratory staff should wear gloves at all times. If available, the surgical mask should also be worn routinely and not only when handling specimens, particularly when the rate of community infection is high.

5. Conclusion

In conclusion, this study examined a wide range of measures on the risk of workplace transmission of COVID-19 using a simulation approach. The several broad recommendations are drawn from the results of the simulations. The recommendations are not meant to be prescriptive. Each laboratory operates in a unique environment and should tailor their practices to best suit their priorities within the available resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clinbiochem.2020.09.003.

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