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Original Article

Predictors of SARS-CoV-2 transmission in congregate living settings: a multicenter prospective study

Jerome A. Leis MD[1,2,3,4], Christina K. Chan MPH[2], Charlie Tan MD[2], James Callahan BScN[5], Victoria Serapion HBSc[5], Brigitte Pascual RPN[5], Wayne Lee BSc[5], Jaclyn O'Brien RN[2], Neethu R. Thomas RN[2], Heather Candon MSc[2], Matthew Crittenden TAB Eng[6], Alex Kiss PhD[3], Adrienne K Chan MD[1,2,3], Marianna Ofner PhD[2] and Jeff E. Powis MD[1,4,5]

[1]Division of Infectious Diseases, Department of Medicine, University of Toronto, Toronto, ON, Canada, [2]Sunnybrook Health Sciences Centre, Toronto, ON, Canada, [3]Sunnybrook Research Institute and Institute of Health Policy, Management and Evaluation, University of Toronto, Toronto, ON, Canada, [4]Centre for Quality Improvement and Patient Safety, University of Toronto, Toronto, ON, Canada, [5]Michael Garron Hospital, Toronto, ON, Canada and [6]Air and Water Precision Balancing Incorporated, Toronto, ON, Canada

Abstract

Background: Older adults residing in congregate living settings (CLS) such as nursing homes and independent living facilities remain at increased risk of morbidity and mortality from coronavirus disease 2019. We performed a prospective multicenter study of consecutive severe acute respiratory coronavirus virus 2 (SARS-CoV-2) exposures to identify predictors of transmission in this setting.

Methods: Consecutive resident SARS-CoV-2 exposures across 17 CLS were prospectively characterized from 1 September 2022 to 1 March 2023, including factors related to environment, source, and exposed resident. Room size, humidity, and ventilation were measured in locations where exposures occurred. Predictors were incorporated in a generalized estimating equation model adjusting for the correlation within CLS.

Results: Among 670 consecutive exposures to SARS-CoV-2 across 17 CLS, transmission occurred among 328 (49.0%). Increased risk was associated with nursing homes (odds ratio (OR) = 90.8; 95% CI, 7.8–1047.4), Jack and Jill rooms (OR = 2.2; 95% CI, 1.3–3.6), from source who was pre-symptomatic (OR = 11.2; 95% CI, 4.1–30.9), symptomatic (OR = 6.5; 95% CI, 1.4–29.9), or rapid antigen test positive (OR = 35.6; 95% CI, 5.6–225.6), and in the presence of secondary exposure (OR = 6.3; 95% CI, 1.6–24.0). Exposure in dining room was associated with reduced risk (OR = 0.02; 95% CI, 0.005–0.08) as was medium room size (OR = 0.3; 95% CI, 0.2–0.6). Recent vaccination of exposed resident (OR = 0.5; 95% CI, 0.3–1.0) and increased ventilation of room (OR = 0.9; 95% CI, 0.8–1.0) were marginally associated with reduced risk.

Conclusion: Prospective assessment of SARS-CoV-2 exposures in CLS suggests that source characteristics and location of exposure are most predictive of resident transmission. These findings can inform risk assessment and further opportunities to prevent transmission in CLS.

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Background

Older adults residing in congregate living settings (CLS) such as nursing homes (NH) and independent living facilities remain at increased risk of morbidity and mortality from coronavirus disease 2019 (COVID-19).[1–3] Despite measures like universal masking, heightened syndromic surveillance, accessible molecular testing, and immunization, the burden of severe acute respiratory coronavirus virus 2 (SARS-CoV-2) transmission in CLS remains substantial since the emergence of the Omicron variant.[4–6]

The physical environment can modulate the risk of SARS-CoV-2 transmission, especially when engineering controls in CLS are lacking.[7] How best to routinely incorporate factors such as humidity, ventilation, and room size in the risk assessment of resident exposures to SARS-CoV-2 remains unclear due to the lack of systematically designed studies in CLS assessing the role of these in transmission. A prior meta-analysis of SARS-CoV-2 attack rates in NH found that the majority were outbreak investigations with <15% of studies including any measure regarding ventilation.[8] We performed a prospective multicenter study of consecutive exposures of SARS-CoV-2 to assess the relative importance of such factors in the risk of transmission in CLS.

Methods

Since October 2020, CLS in Toronto, Canada, are supported by hospital Infection Prevention and Control (IPAC) programs, referred to as IPAC hubs.[4] Our two IPAC hubs support a total of 30 CLS, including 14 NHs and 16 independent living facilities across north-east Toronto. According to provincial guidelines during the

Corresponding author: Jerome A. Leis; Email: jerome.leis@sunnybrook.ca
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2022–2023 viral respiratory season, residents of CLS with confirmed SARS-CoV-2 were required to self-isolate, although contacts underwent risk assessment to determine whether to quarantine in their room pending nasopharyngeal polymerase chain reaction (PCR) test on day 5 post-exposure.[9] Contacts were defined as any resident who interacted with a source at close proximity within 48 hours of onset of infection (symptom onset or test positivity, whichever was first) and up to 10 days following. All exposed residents underwent nasopharyngeal PCR testing upon the development of symptoms or by day 5 if asymptomatic. Universal masking using medical mask or N95-equivalent masks was required for healthcare workers and most visitors and caregivers, but most residents were unmasked. N95 masks were required for providing care to any resident isolated for droplet precautions. Rapid antigen testing (RAT) was available and used in some homes to provide an early diagnosis of SARS-CoV-2 infection, although all residents underwent PCR confirmation regardless of RAT results, which was performed at one of four different off-site reference laboratories in the region.

For quality improvement purposes, consecutive resident SARS-CoV-2 exposures were prospectively characterized from 1 September 2022 to 1 March 2023, from all 30 CLS supported by IPAC hubs. During this period, Omicron variant was dominant including BA.1, BA.2, BA.3, BA.4, and BA.5 and their associated sub-lineages including BQ.1/BQ1.1.[10] The data did not include any identifying resident information because the goal was to analyze exposure characteristics routinely collected by IPAC hubs to improve risk assessment. Environmental variables included the type of CLS (NH and independent living facility), exposure on memory care unit, room type (private room, shared room, shared washroom known as Jack and Jill room, common room, and dining room), the presence of outbreak, ventilation (air change per hour, ACH), humidity (<30%, 30%–60%), and room size (small, medium, and large). Source characteristics included source type (resident, healthcare worker/caregiver, visitor, and others), symptom status (asymptomatic, pre-symptomatic, and symptomatic), day of infection (<1 day and ≥1 day), positive RAT, and cycle threshold (CT) of PCR test. Resident contact characteristics included estimated cumulative exposure (<15 minutes, 15 minutes–1 hour, 1–2 hours, and >2 hours), level of care (independent, minimal-to-moderate assistance, and bedbound), vaccination within previous 3 months, and whether or not a secondary exposure occurred within the incubation period.

We defined a pre-symptomatic source when completely asymptomatic at the time of exposure and developing symptoms within 48 hours. Physical characteristics of all rooms were measured between 27 February and 28 April 2023. The volume of every room with a known exposure was measured using a laser measuring tool. Rooms were further categorized (small, medium, and large) based on size distribution of resident and common rooms within each facility. This assessment involved creating a histogram of room volume distribution within each home and visually categorizing both resident rooms and common areas in relative size categories. ACH and percent humidity were measured for all different room sizes, using balometer capture hood (digital micromanometer with a flow hood kit), digital vane anemometer, and indoor air quality meter (TSI probe, IAQ-Calc Meter 7545). Further description of variable definitions and measurements is available in Appendix A.

The primary outcome was the occurrence of SARS-CoV-2 transmission, defined by whether PCR testing of exposed resident was positive by day 5 post-exposure. Bivariate analysis of predictors was assessed with χ^2 and logistic regression for categorical and continuous variables, respectively. Prior to multivariate modeling, predictors of interest were assessed for multicollinearity (tolerance statistic <0.4). All tolerance values were >0.4. Predictors were incorporated in a generalized estimating equation (GEE) model with a logit link function, adjusting for the correlation within different CLS. Odds ratios (OR) for each predictor were calculated compared with reference, and $P < .05$ was considered statistically significant. A sensitivity analysis was performed where continuous variables were dichotomized or categorical variables regrouped into fewer categories (Appendix B). All analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC, USA). Research ethics review was not required because the study met institutional criteria at both IPAC hubs for exemption as quality improvement research.

Results

During the study period, there were 670 exposures to SARS-CoV-2 arising from 130 different sources across 9 NHs (median 44 exposures per home, IQR 65), 8 independent living facilities (median 21 exposures per home, IQR 17.5), and 17 CLS facilities overall (median 28 exposures per home, IQR 38). The remaining 13 CLS without exposure events were excluded.

Transmission occurred among 328 (49.0%) residents. The secondary attack rate within sources was 38.5% (95% CI 31.6–45.4) and within facilities was 41.2% (95% CI 27.0–55.7). Exposure characteristics and their unadjusted association with transmission are described in Table 1. Significant unadjusted predictors included CLS type, location, outbreak status, ventilation, humidity, type of source, cumulative duration, symptom status, level of care, and vaccination.

Table 2 summarizes the results of the GEE model. After adjusting for correlation within facilities, the most predictive factors of SARS-CoV-2 transmission were exposures arising in NHs (OR = 90.8; 95% CI, 7.8–1047.4), in Jack and Jill rooms (OR = 2.2; 95% CI, 1.3–3.6), from source who was pre-symptomatic (OR = 11.2; 95% CI, 4.1–30.9), symptomatic (OR = 6.5; 95% CI, 1.4–29.9), or RAT positive (OR = 35.6; 95% CI, 5.6–225.6), and in the presence of secondary exposure (OR = 6.3; 95% CI, 1.6–24.0). Exposure in dining room was associated with lower risk of transmission (OR = 0.02; 95% CI, 0.005–0.08) as was medium room size as compared with small rooms (OR = 0.3; 95% CI, 0.2–0.6). Recent vaccination of exposed resident (OR = 0.5; 95% CI, 0.3–1.0) and increased ventilation (total ACH) of room (OR = 0.9; 95% CI, 0.8–1.0) were marginally associated with reduced transmission risk.

Results of sensitivity analysis are described in Appendix B. Duration of exposure (>15 min) was marginally associated with increased risk (OR = 2.9; 95% CI, 1.0–8.8; $P = .05$). CT cut-off of <28 was not associated with increased risk (OR = 1.8; 95% CI, 0.7–5.1; $P = .23$) nor was ventilation not meeting ≥6 total ACH for dining room or ≥ 4 total ACH for resident room (OR = 0.5; 95% CI, 0.2–1.3; $P = .15$).

Discussion

In this prospective multicenter study, nearly half of SARS-CoV-2 exposures resulted in transmission to residents of CLS, with greatest risk in NHs. Transmission was multifactorial as expected, yet source characteristics and location of exposure were most predictive of resident transmission. These findings can inform risk assessment of resident contacts and the application of control

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Table 1. SARS-CoV-2 exposure characteristics and unadjusted bivariate analysis of resident transmission in congregate living settings (CLS)

CLS characteristics (n = 670)	N (%), unless specified	N (% transmission), unless specified	*P*-value[a]
Type of CLS			<.001
Nursing home	434 (64.8)	281 (64.8)	
Independent living facility	236 (35.2)	47 (19.9)	
Memory care unit	72 (10.8)	47 (65.3)	.003
Location of exposure			<.001
Private room	155 (23.1)	98 (63.2)	
Shared room	148 (22.1)	107 (72.3)	
Jack and Jill room (shared washroom only)	7 (1.0)	4 (57.1)	
Common room	146 (21.8)	72 (49.3)	
Dining room	214 (31.9)	47 (22.0)	
Presence of outbreak on unit	462 (69.0)	254 (55.0)	<.001
Ventilation			
Total ACH (median, IQR)	4.6 (6.7)	4.6 (5.6)[b]	<.001
Fresh ACH (n = 444) (median, IQR)	2.0 (4.9)	3.0 (5.4)[b]	.07
Humidity			<.001
<30%	571 (85.2)	297 (52.0)	
30%–60%	99 (14.8)	31 (31.3)	
Room size			.02
Small	213 (31.8)	116 (54.5)	
Medium	116 (17.3)	63 (54.3)	
Large	341 (50.9)	149 (43.7)	
Type of source			<.001
Resident	293 (43.7)	156 (53.2)	
Healthcare worker/caregiver	100 (14.9)	63 (63.0)	
Visitor	114 (17.0)	40 (35.1)	
Others	163 (24.3)	69 (42.3)	
Symptom status			<.001
Asymptomatic	38 (5.7)	13 (34.2)	
Pre-symptomatic	242 (36.1)	71 (29.3)	
Symptomatic	390 (58.2)	244 (62.6)	
Day from onset of infection (≥1 day)	37 (5.5)	20 (54.1)	.52
Cycle threshold (n = 541, median, IQR)	21.4 (6.0)	20.7 (5.8)[b]	.21
Rapid antigen test positive	487 (72.7)	235 (48.3)	.55
Cumulative duration of resident exposure			<.001
<15 min	116 (17.3)	63 (54.3)	
15 min–1 h	175 (26.1)	105 (60.0)	
1–2 h	171 (25.5)	82 (48.0)	
>2 h	208 (31.0)	78 (37.5)	
Exposed resident level of care			<.001
Independent	233 (34.8)	61 (26.2)	
Minimal to moderate assistance	278 (41.5)	154 (55.4)	
Bedbound	159 (23.7)	113 (71.1)	
Exposed resident vaccination within 3 months	322 (48.1)	140 (43.5)	.006
Occurrence of secondary exposure	127 (19.0)	62 (48.8)	.97

[a]Unadjusted bivariate analysis.
[b]Median, IQR of exposures with SARS-CoV-2 transmission; ACH = air changes per hour.

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Table 2. Predictors of SARS-CoV-2 transmission among residents of congregate living settings (CLS) based on multivariate generalized estimating equation model adjusting for correlation within facilities

Predictor[a]	Odds ratio (OR), 95% confidence interval	*P*-value[b]
Type of CLS		**.0003**
Independent living facility		
Nursing home	**90.8, 95% CI, 7.8–1047.3**	
Memory care unit	0.5, 95% CI, 0.09–3.1	.48
Location of exposure		< **.0001**
Private room		
Shared room	0.6, 95% CI, 0.3–1.5	
Jack and Jill room (shared washroom only)	**2.2, 95% CI, 1.3–3.6**	
Common room	0.3, 95% CI, 0.06–1.3	
Dining room	**0.02, 95% CI, 0.005–0.08**	
Presence of outbreak on unit	1.7, 95% CI, 0.9–3.2	.08
Total air change per hour (median, IQR)	0.9, 95% CI, 0.8–1.0	.05
Fresh air change per hour (median, IQR)	1.0, 95% CI, 0.7–1.2	.74
Humidity		
<30%		
30%–60%	1.0, 95% CI 0.2–5.5	.99
Room size		**.006**
Small		
Medium	**0.3, 95% CI, 0.2–0.6**	
Large	0.5, 95% CI, 0.2–1.4	
Type of source	1.1, 95% CI, 0.8–1.3	.62
Symptom status		< **.0001**
Asymptomatic		
Pre-symptomatic	**11.2, 95% CI, 4.1–30.9**	
Symptomatic	**6.5, 95% CI, 1.4–29.9**	
Day from onset of infection (≥1 day)	1.4, 95% CI, 0.4–4.3	.57
Cycle threshold	1.0, 95% CI, 0.9–1.1	.74
Rapid antigen test positive (if available)	**35.6, 95% CI, 5.6–225.8**	**.0001**
Cumulative duration		.16
<15 min		
15 min–1 h	3.1, 95% CI, 0.9–10.2	
1–2 h	7.8, 95% CI, 0.6–103.9	
>2 h	2.9, 95% CI, 0.8–10.9	
Exposed resident level of care		.13
Independent		
Minimal to moderate assistance	0.8, 95% CI, 0.4–1.6	
Bedbound	1.3, 95% CI, 0.5–3.7	
Exposed resident vaccination within 3 months	0.5, 95% CI, 0.3–1.0	.06
Occurrence of secondary exposure	**6.3, 95% CI, 1.6–24.0**	**.007**

[a]First in category is reference.
[b]Bold considered significant, $P < .05$.

measures to ensure these are commensurate with burdens imposed on affected residents.[11]

Previous studies describing the role of the physical environment on SARS-CoV-2 transmission in CLS include outbreak investigations and retrospective cohort studies using administrative data sets.[7,8,12–16] A cross-sectional, nationwide study that combined multiple data sets for NHs found that architectural design has significant impact on COVID-19 risk.[16] Increased

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number of private rooms and larger living areas were associated with decreased risk, but these authors did not have data on indoor air quality and ventilation.

Our study's prospective longitudinal assessment of consecutive SARS-CoV-2 exposures aimed to systematically combine epidemiological factors with contemporaneous measurements of the physical environment. We found that some of the strongest predictors of SARS-CoV-2 transmission were clinical characteristics of the source, including symptom status and RAT positivity. Our findings mirror what is known about SARS-CoV-2 transmission risk based on the symptom status including a previous meta-analysis of contact studies.[17,18] We did not identify timing of infection as an important predictor for transmission likely because nearly all exposures in our study occurred within 24 hours of symptom onset due to the surveillance present in these CLS. Similarly, we did not identify CT to predict transmission risk like in other studies,[19,20] which may have been due to heterogeneity of PCR across the different laboratories performing this testing.

Our study helps to inform how the physical environment modulates transmission risk and should be included in risk assessment. Increased room size and specifically dining rooms were associated with lower risk. Shared rooms are already known to be a risk to increased transmission throughout health care,[20,21] yet our study additionally found increased risk in rooms with a Jack and Jill design. This observation is consistent with a prior outbreak investigation involving a shared washroom.[22] Although our study was not specifically designed to identify the reasons for this increased risk, the presence of a single exhaust located in washroom of these rooms may explain this difference, especially if exhaust is non-functioning.

We found significant variation in ventilation across CLS, with ACH of many rooms falling below standards.[23,24] Yet our analysis found only a marginal association between ACH and transmission risk. One potential explanation is that significantly greater ventilation is needed to mitigate transmission risk than was present in these exposures. Fresh air changes could only be determined for two-thirds of rooms, which may have underpowered this assessment.

Vaccination strongly protects residents from severe COVID-19-related outcomes, but the reduced immunogenicity in older populations may explain the marginal protection observed against transmission.[25,26] Confounding by indication may also have been present given that some of the highest-risk residents were more likely to receive additional boosters during the study period.

An interesting finding in our study is the lack of increased risk of transmission on memory care units. These types of units are recognized to be associated with higher secondary attack rates and longer outbreak duration due to increased number of exposures resulting from the inherent challenges implementing control measures.[27] One way to reconcile this finding is that although memory care units generate increased resident contacts due to the wandering behaviors of the residents, the risk of discrete exposure events is not necessarily higher after adjusting for other factors.

Another surprising finding of our study was the marginal role of exposure duration, which is traditionally considered important in risk assessment.[28] Our study does not support application of a minimum time-based rule because the duration of exposure needed to increase the risk of SARS-CoV-2 transmission is likely situational, based on the other factors identified.[29]

Our study has several limitations. First, the observational study design cannot exclude other unmeasured confounders. The types of interactions, compliance with masking, deployment of HEPA filters, and source vaccination rates were among factors not measured. Second, we could not adjust for correlation within sources due to small cluster sizes. However, the confidence intervals of the attack rates by source were similar to both facility and overall attack rates suggesting a lack of significant transmission heterogeneity. Third, since we did not collect resident-specific data, host factors of exposed patients such as comorbidities and prior history of COVID-19 were missing from our model. Fourth, given that physical parameters were only measured once at the end of study period, those with seasonal changes such as humidity may have affected results. Finally, these results do not apply to exposures in all types of CLS as we did not include some high-risk settings such as shelters and group homes.

Prospective assessment of SARS-CoV-2 exposures across a large number of CLS confirmed that source characteristics and location of exposure were most predictive of resident transmission. These findings can inform risk assessment and further opportunities to prevent transmission in CLS such as NH and independent living facilities.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/ice.2024.50.

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Competing interests. Dr Leis has provided expert testimony for Ontario Hospital Association, Ministry of Attorney General of Ontario, and Seneca College. None of the other authors have conflicts of interests to declare.

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