Infection Control & Hospital Epidemiology (2024), **45**, 1314–1318
doi:10.1017/ice.2024.121

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Original Article

SARS-CoV-2 burden on the floor was associated with COVID-19 cases and outbreaks in two acute care hospitals: a prospective cohort study

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Abstract

Background: Recent work demonstrated that detection of SARS-CoV-2 on the floor of long-term care facilities is associated with impending COVID-19 outbreaks. It is unknown if similar results will be observed in hospitals.

Methods: Floor swabs were prospectively collected weekly from healthcare worker-only areas (eg, staff locker rooms) at two hospitals in Ontario, Canada for 39 weeks. Floor swabs were processed for SARS-CoV-2 using quantitative reverse-transcriptase polymerase chain reaction. Results were reported as percentage of positive floor swabs and viral copy number. Grouped fivefold cross-validation was used to evaluate model outbreak discrimination.

Results: SARS-CoV-2 RNA was detected on 537 of 760 floor swabs (71%). At Hospital A, overall positivity was 90% (95% CI: 85%–93%; N = 280); at Hospital B, overall positivity was 60% (95% CI: 55%–64%; N = 480). There were four COVID-19 outbreaks at Hospital A and seven at Hospital B during the study period. The outbreaks consisted of primarily patient cases (ie, 140 patient cases and 4 staff cases). For every 10-fold increase in viral copies, there was a 22-fold higher odds of a COVID-19 outbreak (OR = 22.0, 95% CI 7.3, 91.8). The cross-validated area under the receiver operating curve for SARS-CoV-2 viral copies for predicting a contemporaneous outbreak was 0.86 (95% CI 0.82–0.90).

Conclusion: Viral burden of SARS-CoV-2 on floors, even in healthcare worker-only areas, was strongly associated with COVID-19 outbreaks in those hospital wards. Built environment sampling may support hospital COVID-19 outbreak identification, fill gaps in traditional surveillance, and guide infection prevention and control measures.

(Received 10 May 2024; accepted 3 August 2024; electronically published 20 September 2024)

Background

In any infectious disease-related public health crisis, early detection is essential for effective management. The longer an infection goes undiagnosed, the longer affected individuals can infect others due to a lack of treatment and necessary containment measures.[1,2] Delayed diagnoses also increase economic loss related to the management of the illness.[1] For example, unchecked transmission of COVID-19 often leads to additional resource requirements related to outbreak management, as well as the resources required to treat newly infected individuals.[1] It is important to find effective ways to identify COVID-19 cases as early as possible to implement management strategies, optimize resource use, and decrease disease burden.

Current practices to monitor COVID-19 status in hospitals rely on diagnostic testing and reporting. Community transmission is monitored by public health authorities, whereas infection and transmission among patients or healthcare workers are typically addressed at the facility level.[3] Although individual diagnostic testing is currently the gold standard to confirm COVID-19 positivity, it is not an optimal strategy for mass use.[4] Individual testing is more costly, invasive, and—because this approach often

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Cite this article: Fralick M, Moggridge JA, Wiebe M, *et al.* SARS-CoV-2 burden on the floor was associated with COVID-19 cases and outbreaks in two acute care hospitals: a prospective cohort study. *Infect Control Hosp Epidemiol* 2024. 45: 1314–1318, doi: 10.1017/ice.2024.121

targets symptomatic individuals only—can miss asymptomatic cases.[3,4] Current methods to minimize test use include pooled testing (which still requires many individual samples) and intermittent testing.[3–5] Another potential approach is environmental surveillance of SARS-CoV-2. Wastewater surveillance has been the dominant mode to date, but environmental surface surveillance has emerged as a complementary and more spatially resolved approach.

SARS-CoV-2 can be detected from the built environment, and the highest yield area to swab is the floor.[6–8] A recent multicenter, prospective study of weekly floor swabbing at long-term care homes demonstrated that the floor swab results mirror patient and staff cases therein.[8] The floor swabs also provided spatial resolution. For example, when there were staff cases of COVID-19 but not resident cases, the highest environmental burden of SARS-CoV-2 was found on the floors of worker-only areas (eg, locker rooms). The goal of our study was to identify the relationship between floor swab results from healthcare worker-only areas and COVID-19 cases and outbreaks in hospitals.

Methods

Study design

We conducted a multicenter prospective study at two hospitals in Ontario, Canada between July 2022 and March 2023. One hospital was a tertiary care academic teaching hospital in Ottawa, and the second was a community hospital in Sault Ste. Marie. At both hospitals, we swabbed the floors of healthcare worker-only areas on four inpatient adult wards. On each of the wards, these healthcare worker-only areas included change rooms, meeting rooms, staff washrooms, nursing stations, and interdisciplinary team rooms. Healthcare worker-only areas were swabbed for three reasons. First, healthcare worker-only areas are easy to access and do not disrupt direct patient care. Second, we know from prior work[7] that these areas were still likely to be reflective in some fashion of patient activity, given the known airborne transmission and disseminated distribution of viral genomic material over space and time. Third, the Infection Prevention and Control (IPAC) and Occupational Health teams at these hospitals were actively exploring methods to improve and enhance the identification of healthcare workers with COVID-19 in the context of increased COVID-19 hospitalizations. Specifically, they planned to offer rapid antigen tests to workers when higher environmental levels of SARS-CoV-2 were detected. Rapid antigen testing was voluntary and not tracked, and any asymptomatic staff positives detected were reported to Occupational Health and included in healthcare worker COVID-19 numbers. Symptomatic staff were excluded from work and underwent COVID-19 testing using polymerase chain reaction (PCR). Because this was a pragmatic study, there was no systematic screening for asymptomatic staff. The study received research ethics board exemption from both of the participating hospitals.

Swabbing procedure and detection of SARS-CoV-2

Trained research staff swabbed the floors using the P-208 Environmental Surface Collection Prototype kit from DNA Genotek (provided in-kind). A 2-inch by 2-inch area was swabbed; the duration of swabbing was 30 seconds of contact time with the floor. The same area was swabbed each week by the same research personnel. Each swabbing kit consisted of a flocked swab and semi-lytic nucleic acid stabilization solution for post-collection swab immersion. Following collection, swabs were sent to our central lab in Ottawa for SARS-CoV-2 detection.

Detecting SARS-CoV-2

We used primers and a TaqMan probe targeting the N1 region of the SARS-CoV-2 nucleocapsid gene. This approach has been validated previously by our study team.[7] We detected SARS-CoV-2 by quantitative reverse-transcriptase polymerase chain reaction (RT-qPCR) of the viral N-gene from RNA extracted from the stabilization solution using the MagMAX Viral/Pathogen II (MVP II) Nucleic Acid Isolation Kit (Thermo Fisher Scientific, Waltham, MA). The qPCR results provided us with a quantification cycle (Cq) of detection for each positive swab. Using the Cq, we then estimated the number of viral copies present based on a previously determined standard curve, and the standard curve was repeated during this current study.[7] The results are expressed as viral copies + 1 because when no SARS-CoV-2 is identified from a swab the value is reported as zero, but log transforming zero is undefined.

Staff safety measures at each hospital

Both hospitals required healthcare workers to wear masks while at work, and neither had routine COVID-19 testing in place for asymptomatic healthcare workers. Both sites also followed the provincial definition for declaration of an outbreak in effect during the study period: "Two or more patients and/or staff within a specified area (unit/floor/service) with positive results from a PCR test OR rapid molecular test OR rapid antigen test within a 10-day period where both cases have reasonably acquired their infection in the acute care facility."[9] The healthcare worker "return to work" rules were also similar at both study sites, with each advising that healthcare workers remain off work for 5 days from onset of symptoms or positive test (if asymptomatic); then, if afebrile and symptoms improving, could return to work wearing a mask at all times and taking breaks alone until 10 days from onset. Both hospitals had similar cleaning procedures and floors were cleaned once per day. Hospital A cleaned floors with Stride detergent. Hospital B used Vert-2-Go Oxy floor cleaner.

Study outcome

Our primary outcome was to assess the relationship between floor swab results and COVID-19 cases and outbreaks. Both the number of patients with COVID-19 and the number of staff with COVID-19 were available to us at each hospital.

Statistical analysis

To evaluate the relationship between viral detection of SARS-CoV-2 from floor swabs and healthcare worker cases of COVID-19, we fit Poisson regression models with random intercepts for wards. Models were computed with lme4:glmer and fit by maximum likelihood with the Laplace approximation. Poisson regression was used because the healthcare worker cases and absenteeism represented counts. Linear regression was used to evaluate the relationship between viral detection of SARS-CoV-2 from floor swabs and patient cases of COVID-19 with hospital included as a fixed effect. Logistic regression was used to calculate the association between a COVID-19 outbreak on the ward and the floor swab results from that same ward. We performed bootstrapping (B = 100; observations stratified by outbreak status) to

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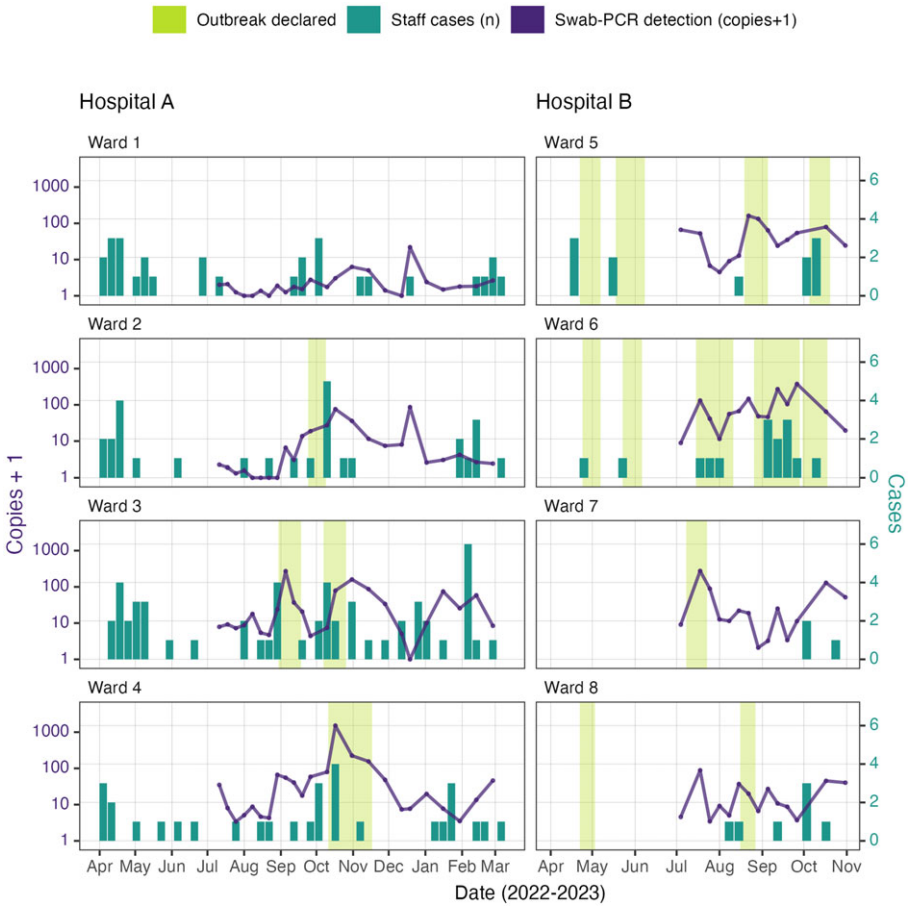

Figure 1. Weekly healthcare worker/staff cases (teal bars), outbreaks (light green shading), and floor-swab SARS-CoV-2 RNA detection (purple connected points) by ward at two hospitals. The purple points connected by a line represent the detection of SARS-CoV-2 from the built environment, which began in July 2022.

validate the accuracy of the outbreak prediction model using $\log_{10}$-transformed mean viral copies as the predictor. We evaluated accuracy and area under the receiver operating characteristic curve (AUC). We estimated the optimism-adjusted AUC using *lrm* and *validate* functions from the "rms" R package.[10]

Results

We collected 760 floor swabs over the course of our study. SARS-CoV-2 RNA was detected on 537 floor swabs (71%, 95% CI: 67%–74%). Hospital A had a greater prevalence of SARS-CoV-2 detection (90%, 95% CI: 85%–93%; N = 280) than Hospital B (60%, 95% CI: 55%–64%; N = 480). Similarly, the quantity of SARS-CoV-2 RNA recovered (in terms of copies plus one, per swab) was greater at Hospital A (geometric mean = 23 copies, 95% CI: 19–29) than at Hospital B (7.9 copies, 95% CI: 6.5–9.7). Hospital A had a greater rate of healthcare worker COVID-19 cases, with 89 cases over 34 weeks (2.6 per week), compared to 29 cases over 16 weeks at Hospital B (1.8 per week). During the surveillance period, four outbreaks occurred at Hospital A and seven outbreaks occurred at Hospital B, and all of these outbreaks primarily consisted of patient cases (ie, 140 patient cases and 4 staff cases). The daily patient census for COVID-19 admissions at Hospital B (median = 21 patients; interquartile range [IQR]: 15–28) indicated a greater case burden over the study period than the census for Hospital A (median = 12 patients, IQR: 7–19).

In Figure 1, we provide the weekly healthcare worker cases and swab viral load. When there were more healthcare worker cases of COVID-19, there was a higher number of viral copies of SARS-CoV-2 detected on the floor. This is also demonstrated in our Poisson regression model with random intercepts for wards, which estimated an incidence rate ratio (IRR) of 1.68 (95% CI 1.16, 2.44) for healthcare worker cases for a one-unit increase in the $\log_{10}$-transformed number of viral copies. A strong association was identified between the number of viral copies on the floor and patient cases of COVID-19 (Figure 2). Specifically, the linear regression model identified that for a 10-fold increase in viral copies on the floor there was a corresponding 15-fold increase in patient cases (ß = 15, 95% CI 11, 20). We also modeled our results using healthcare worker absenteeism as the outcome but did not find a clear relationship between healthcare worker absenteeism and the viral burden of SARS-CoV-2 on the floor (IRR 1.11, 95% CI 0.97, 1.28).

A greater number of viral copies were detected during outbreak periods compared to periods with no outbreaks (Figure 3). In our logistic regression model, for every 10-fold increase in viral copies, there was a 22-fold higher odds of a COVID-19 outbreak (OR = 22.0, 95% CI 7.3, 91.8). Test characteristics for detecting current outbreak status using floor swab results were as follows: sensitivity 0.44, 95% CI: 0.4–0.47, specificity 0.96, 95% CI: 0.95–0.96, negative predictive value 0.9, 95% CI: 0.89–0.91, positive predictive value 0.67, 95% CI: 0.63–0.72 (Figure 4).

The cross-validated area under the receiver operating curve for SARS-CoV-2 viral copies for predicting a contemporaneous outbreak was 0.86 (95% CI 0.82 – 0.90). We estimated the optimism-adjusted AUC through bootstrapping. The original (naive measure) AUC for the model fit to the full data was 0.889. The average AUC of models fit and evaluated with bootstrapped data (training AUC) was 0.89; the AUC for the same models

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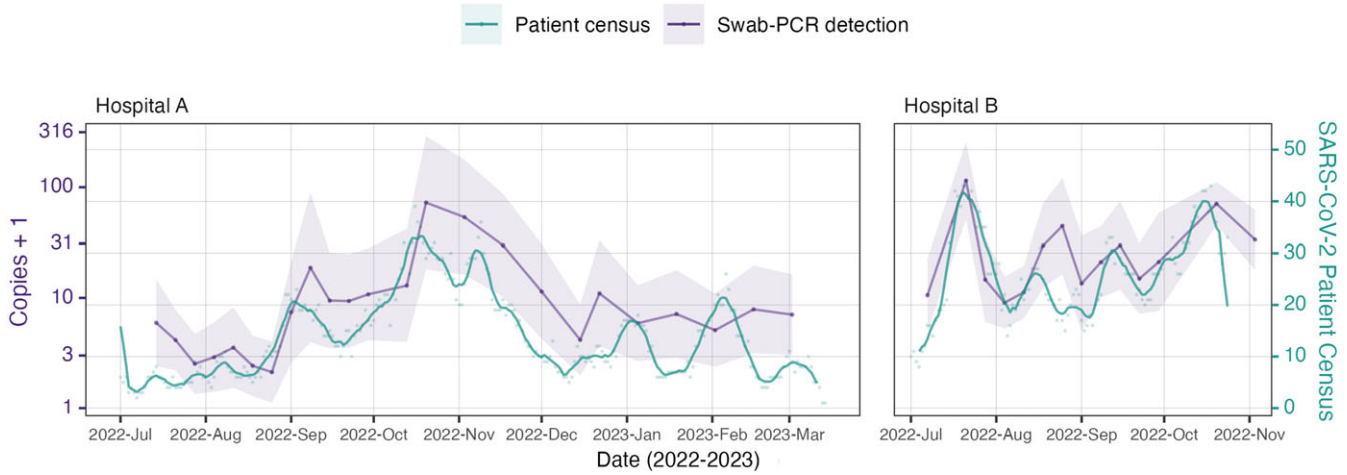

Figure 2. Viral copies of SARS-CoV-2 from floor swabs and patient census over time. The purple y-axis estimates the biomass of SARS-CoV-2 as viral copies + 1. The green *y*-axis is the number of patients with SARS-CoV-2. The figure demonstrates that the number of patients with SARS-CoV-2 mirrors the amount of viral biomass detected from the floor swabs.

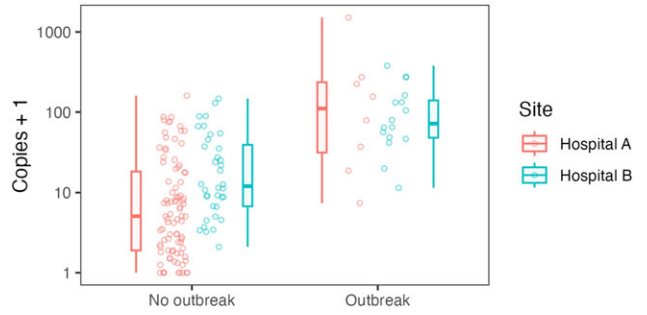

Figure 3. Viral copies of SARS-CoV-2 detected from floor swabs during outbreak and non-outbreak time periods. The *y*-axis estimates the biomass of SARS-CoV-2 as viral copies + 1. Each dot represents a single floor swab, boxplots show the minimum, maximum, median (bolded line), 25th percentile (bottom line of the box), and 75th percentile (top line of the box).

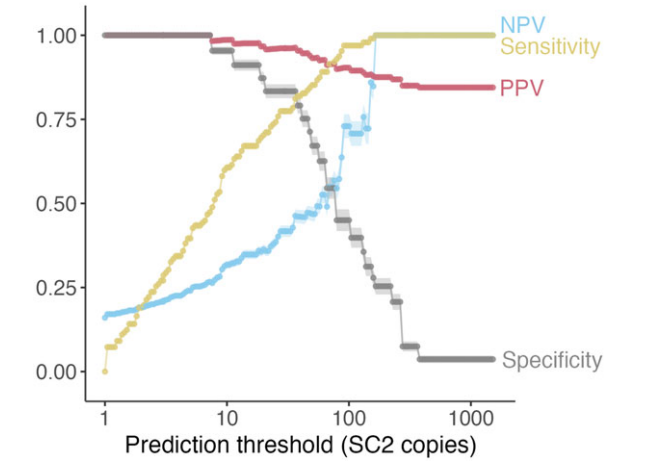

Figure 4. Test characteristics of current outbreak detection using mean viral copies from weekly floor sampling at varying copy number thresholds. NPV, negative predictive value; PPV, positive predictive value; SC2, SARS-CoV-2.

applied to the original data (test AUC) was 0.889, yielding an optimism estimate of 0.001 and an optimism-adjusted AUC of 0.889 (B = 5000).

Discussion

We implemented routine floor swabbing in healthcare worker-only areas in two hospitals in Ontario, Canada to evaluate the utility of environmental swabs to complement the contemporaneous monitoring procedures for COVID-19. SARS-CoV-2 detection from the built environment (ie, floors) in healthcare worker-only areas was strongly associated with COVID-19 cases and outbreaks. These data add to the mounting evidence that built environment detection for SARS-CoV-2 may provide an additional layer of monitoring and could help inform local IPAC measures.

One of the largest studies to date evaluating built environment testing for SARS-CoV-2 was a prospective multicentre study at long-term care homes in Ontario, which sampled both communal and staff-only areas and found the proportion of floor swabs that were positive for SARS-CoV-2 was 54% during outbreak periods, dropped to approximately 22% during non-outbreak periods, and after some outbreaks would fall as low as 0%.[8] In our current study of healthcare worker-only areas in hospitals, we found the proportion of floor swabs positive for SARS-CoV-2 was 71% across the study period, and weekly detection ranged from 25% to 85% at Hospital A and from 75% to 100% at Hospital B. Long-term care homes enforce extensive measures to minimize the entry of people with COVID-19 into the building. Hospitals, in contrast, actively admit patients who have COVID-19—this may explain why the average percentage of positive floor swabs over the course of our study was so much higher in hospitals compared to long-term care homes.

Our study also demonstrated that the viral burden of SARS-CoV-2 detected is strongly associated with COVID-19 cases and outbreaks among both healthcare workers and patients. This was surprising because we were sampling healthcare worker-only areas and had anticipated finding associations between viral burden and the number of healthcare workers with COVID-19, and/or healthcare worker absenteeism (to account for healthcare workers who may not have tested); we did not expect an association with patient cases. There are multiple potential explanations for why the distribution of viral particles in healthcare worker-only areas would reflect the COVID-19 case burden on the adjoining hospital ward. SARS-CoV-2 spreads via not only droplets but also smaller aerosols that can travel a relatively long distance before falling to

https://doi.org/10.1017/ice.2024.121 Published online by Cambridge University Press

the floor. There is the possibility that healthcare workers were the initial cases of COVID-19, which then led to patient cases and outbreaks. We believe this to be unlikely, as our results demonstrated a clear relationship with cases or outbreaks, and nearly all cases were patients hospitalized from the community with COVID-19, as opposed to acquiring it within the hospital. Outbreaks at both hospitals were composed largely of patient cases, with very few or no healthcare worker cases.

Our findings indicate that in settings such as hospitals, where there is a high burden of SARS-CoV-2, viral copies may prove more discriminatory than swab positivity when employing built environment surveillance for SARS-CoV-2. In the previously mentioned study of environmental detection of SARS-CoV-2 from long-term care homes, the percentage of swabs positive for SARS-CoV-2 was strongly predictive of impending outbreaks.[8] We had planned to follow a similar analytic approach for this study, but upon encountering the persistently high swab positivity rate, we identified that viral copy number provided a stronger association with COVID-19 cases and outbreaks than percent positivity. A similar finding was observed in a recent single-center prospective study, in which swabs were performed in patient areas on a hospital ward.[11] The percentage of positive floor swabs was nearly 100% throughout the study, thus viral copy number was used instead; the results demonstrated that a threefold higher number of viral copies was detected when the ward had an outbreak compared to when there was no outbreak.

There are a number of limitations to our study. First, the study was performed on adult inpatient wards, and thus may not be generalizable to other hospital settings (eg, intensive care unit) or pediatric wards. Second, our study focused on SARS-CoV-2 alone, and thus it is unknown whether similar findings would be observed for other respiratory viruses, like influenza or respiratory syncytial virus. Third, it is possible that floor swabbing results led to a greater number of healthcare worker cases of COVID-19 being identified because infection control units offered rapid antigen tests during periods of higher environmental SARS-CoV-2 detection. However, this was not done systematically and reporting was voluntary; thus we were unable to quantify how often this occurred. Fourth, we only swabbed once per week, and therefore it is unknown whether swabbing more frequently could improve predictions. Fifth, we were unable to analyze the correlation between community transmission and floor samples. We were unable to do so because of testing guidelines during the study time period, which stipulated only high-risk individuals who were symptomatic or at high risk of severe disease were eligible for PCR testing. Finally, genomic sequencing data for patient samples and environmental samples were not available. These data would allow a better determination of whether the infection was hospital-acquired and will be an important area of future work.

Another important area of future work will be evaluating how environmental testing can help inform IPAC measures in congregate settings like long-term care homes and hospitals. One potential role is surveillance, in which environmental surface sampling provides an additional metric to estimate the current risk of COVID-19 infection or outbreak. Another role may be to inform real-time IPAC measures with the goal of reducing nosocomial COVID-19 cases and COVID-19 outbreaks. Larger future studies would be needed to evaluate whether environmental sampling can help mitigate the size and scope of outbreaks from respiratory pathogens like SARS-CoV-2.

Our results provide further data on the potential of environmental surveillance for infection prevention and control; however, implementation studies are needed to determine what happens when this technique is employed. Without implementation studies, we lack clear information on whether environmental surveillance can mitigate the size and scope of an outbreak.

Author contribution. **Study concept and design:** All authors; **Acquisition of data:** All authors; **Analysis/interpretation of data:** All authors; **Drafting of the manuscript:** Nott C, Wiebe M, Fralick M; **Critical revision of the manuscript:** All authors; **Statistical analysis:** Moggridge J, MacFadden D, Nott C, Fralick M.

Financial support. This project was supported by funding from the Northern Ontario Academic Medicine Association Clinical Innovation Opportunities Fund, The Ottawa Hospital Academic Medical Organization Innovation Fund, and a Canadian Institutes of Health Research Operating Grant (EGA 179419).

Competing interests. MF was a consultant for ProofDx, a start-up company creating a point-of-care diagnostic test for COVID-19, and is an advisor for SIGNAL1, a start-up company deploying machine-learned models to improve inpatient care.

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