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Brief Report

Atmospheric CO_2 monitoring to identify zones of increased airborne pathogen transmission risk in hospital settings

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Measures to reduce airborne pathogen transmission in health care settings, such as increased air exchange, air decontamination, and reductions in peak occupancy, can be expensive and disruptive, particularly when employed in an untargeted manner. We report the empirical identification of high transmission risk zones in a tertiary hospital, using carbon dioxide-based assessments of air exchange. This rapid, cost-effective, and unobtrusive approach led to the targeted remediation of a high transmission risk zone.

BACKGROUND

Hospital infection control strategies focus primarily on addressing person-to-person, aerosol-mediated, and surface-mediated pathogen transmission pathways.[1] However, the COVID-19 pandemic highlighted the critical importance of airborne pathogen transmission in clinical settings.

Augmented infection control measures that were introduced in response to the pandemic, including facemask mandates, social distancing, and reduced in-person outpatient clinical services, were associated with substantial decreases in rates of common respiratory infections that spread via airborne transmission.[2] Such infections constitute a major health burden,[3] with strategies to maintain pathogen transmission rates below prepandemic levels representing an important public health goal.

While increased rates of air exchange have long been argued as an effective means to reduce airborne transmission in hospitals,[4] associated heating and cooling costs can be prohibitive.[5] Alternative measures, such as the introduction of air sterilization technology (including high-efficiency particulate air filtration and germicidal ultraviolet C light), represent a considerable investment when deployed in an untargeted manner.[6] Strategies that enable empirical identification of areas within hospitals where ventilation is inadequate relative to occupancy are therefore important to enable risk reduction measures to be targeted.

Carbon dioxide (CO_2) is a natural biproduct of human respiration, whereby its concentration in indoor spaces reflects relative levels of occupancy and effective ventilation. Elevated CO_2 levels have been used widely as a marker of indoor air quality and as a basis for assessing air exchange and ventilation efficiency.[7] Such measures have been shown to correlate strongly with infectious disease outcomes, including absenteeism due to acute respiratory infection.[8]

Inexpensive CO_2 monitors can be used to survey large facilities rapidly to identify areas of high airborne transmission risk.[9,10] Here, we describe the application of a CO_2 monitoring strategy to identify high transmission risk settings within a tertiary hospital in South Australia, as a basis for targeted infection control.

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METHODS

Our study was conducted in a public, > 500 bed, tertiary hospital in South Australia between February and October 2023. A project overview was reviewed by the Southern Adelaide Local Health Network and ethics approval was not deemed necessary. During the study period, surgical masks were mandated for staff and visitors, but occupant density limits were not applied. The hospital utilizes a ducted heating, ventilation, and air conditioning (HVAC) system with variable control of recirculated air.

We focused on nonclinical zones, which are typically subject to less stringent infection control measures than clinical areas. Longitudinal assessment of air quality was performed at 16 sites across 5 floors of the hospital. The areas assessed included the hospital main entrance atrium, waiting areas for the women's health clinic, rotating (main) outpatient clinic, ultrasound, medicine clinic, emergency department, cancer treatment center, and rehabilitation clinic. Other assessed zones included staff tearooms, student rooms, shared staff offices, and consulting rooms. Space utilization was assessed based on total occupant headcounts for each zone, conducted at mid-morning and mid-afternoon.

Air-quality assessments were performed using remotely monitored, wall-mounted, CO_2 sensors (Aranet4 Pro Sensors, CO_2 Radical), with CO_2 levels logged at 2-minute intervals over a 5-week period. Sensors were placed on walls approximately 2 m high and not adjacent to windows, doors, or ventilation ducts. Multiple sensors were deployed across large areas to measure the distribution of CO_2 levels within the entire space. Based on the recommendations of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), a CO_2 level greater than 1,000 ppm for 15 minutes or more was used as an indicator of elevated airborne transmission risk.[7]

Airborne bacterial load was assessed using a microbial impact air sampling device (Basic Air Microbial Air Sampler, CAT#5533, Neutec Group) with culture on horse blood agar (Oxoid, ThermoFisher Scientific). The air sampler was disinfected prior to sample collection and positioned centrally, at least 1 m from the floor and walls. Air was sampled at a rate of 100 L/min for 5 minutes. Air sampling was performed at 0800 (prior to clinic opening) and at 1200 (following peak occupancy) on 5 consecutive days. Plates were incubated at 37 °C for 48 hours with colony counts adjusted using positive-hole corrections.[11] Colony identification was performed by Matrix-Assisted Laser Desorption/Ionization Time-of-Flight Mass Spectrometry (Microflex MALDI-TOF, Bruker). Data were analyzed and visualized using GraphPad Prism (version 10.2.0).

RESULTS

Of the 16 zones assessed, only 1, the women's health clinic waiting room, had CO_2 levels that consistently exceeded the CO_2 threshold of 1,000 ppm (Fig. 1A). The women's health clinic, located on the ground floor of the hospital adjacent to the main entrance atrium, is the primary location for maternity services within the hospital and encompasses outpatient services for antenatal, midwifery, obstetric, and gynecology services. The identified waiting area was 48 m^2, had 3 associated staff members, and included seating for 45 clinic attendees. Adjoining the waiting area were 12 examination rooms, which were utilized at full capacity during peak appointment loadings. Clinic appointments were scheduled from 0830 and to 1730 on weekdays, with a staff break between 1230 and 1330. Peak occupancy times were Tuesday, Wednesday, and Thursday mornings.

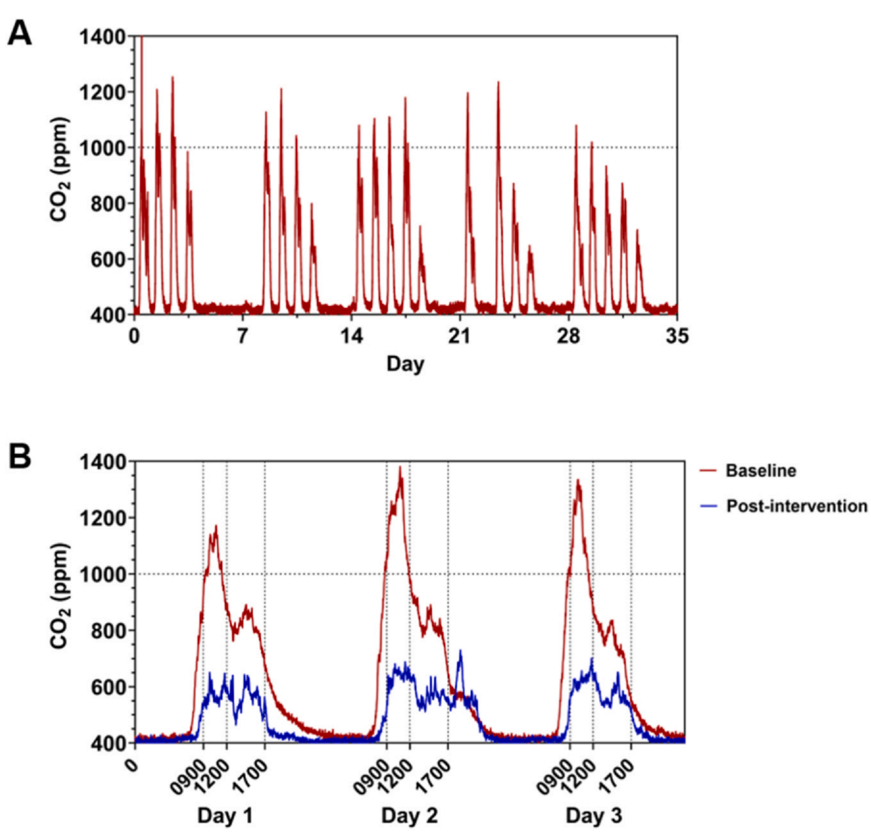

Fig. 1. CO_2 levels in a hospital outpatient clinic. (A) High CO_2 peaks consistently measured across a 5-week period in an outpatient clinic waiting area. (B) CO_2 levels over a 72-hour period in the outpatient clinic waiting area identified specific times of high transmission risk to be between 9 AM and 12 PM.

Empirically determined CO_2 levels corresponded to clinic occupancy patterns (Fig. 1B). When unoccupied, CO_2 levels reflected atmospheric concentrations (median ppm = 427, interquartile range [IQR]: 18). However, when occupancy was highest (morning clinics Mondays to Thursdays; median occupancy: 30, IQR: 7.5), CO_2 concentrations exceeded 1,000 ppm continuously for up to 118 minutes (median ppm: 896, IQR: 217, max: 2,033). Similar patterns of elevated CO_2 concentrations were observed during the less busy afternoon clinics (median occupancy: 14, IQR: 6.8), but with lower median and peak values (median ppm: 780, IQR: 132, max: 1,050). The scheduling of fewer appointments on Fridays (Friday morning median occupancy: 9, IQR: 7) was reflected in lower CO_2 levels (morning clinic median ppm: 639, IQR: 105, max: 987).

Airborne bacterial load, used here as a proxy for human-derived microbial dispersion, also varied in line with empirically determined CO_2 levels. Median colony forming units per cubic meter (CFU/m^3) of air ranged from 38 CFU/m^3 (IQR: 234, range: 32-290) in the morning prior to any appointments, to 268 CFU/m^3 (IQR: 130; range: 136-334) at the morning appointment peak, consistent with observed fluctuations in CO_2. Microbiological analysis confirmed that bacterial colonies largely represented species that are commonly associated with human respiratory mucosae or skin (*Dermacoccus nishinomiyaensis, Micrococcus flavus, Micrococcus luteus, Niallia circulans, Paenibacillus lautus, Pseudomonas stutzeri, Staphylococcus capitis, Staphylococcus epidermidis, Staphylococcus haemolyticus, Staphylococcus hominis,* and *Staphylococcus petrasii*).

Having identified a zone with air quality > 1,000 ppm for > 15 minutes,[7] an intervention decision tree was used to guide the selection of potential remedial measures. Four options were considered: (1) increasing local air exchange within the existing environmental management framework; (2) reducing clinic peak occupancy through adjustment of appointment scheduling; (3) reducing viable pathogen load through the introduction of decontamination appliances; and (4) improvement of HVAC infrastructure.

As with many large hospitals, particularly those housed in older buildings, HVAC systems at the study site lacked sufficient flexibility to regulate air exchange rates for small, specific areas. The location of the clinic in an internal area with no external walls, also prevented the installation of a simple auxiliary ventilation appliance, as has been used to increase air exchange in other settings.[9] The potential to reduce peak occupancy through the scheduling of clinical appointments or staggering visitor arrival was also considered. However, changes to either clinic scheduling or the timing of visitor arrivals were not favored by clinic teams.

The use of air sterilization technologies, which represent a less disruptive option to reduce the potential for airborne pathogen transmission, were considered. These typically capture airborne particles from the air column (eg, high-efficiency particulate air filtration) or render airborne microbes inviable (eg, germicidal UV). Like many infection control measures, air sterilization technologies rely on reduction in pathogen viability that have been demonstrated under laboratory conditions being translated in real world settings. Despite a considerable body of supportive evidence generated under controlled conditions, further well-designed randomized controlled trials are needed to establish the efficacy of these approaches in hospital settings, if the associated costs are to be justified.[6]

In relation to the women's health clinic waiting room, it was noted that the empirically determined levels of ventilation were inconsistent with the intended parameters of HVAC management. An HVAC system reset was undertaken and, while the reason for the reduced ventilation could not be identified, this reset resulted in CO_2 levels falling back within the acceptable range (Fig. 1B). As such, changes to clinic management or the deployment of additional infrastructure was ultimately unnecessary.

DISCUSSION

Blanket measures to address airborne transmission risk within hospital settings place an additional burden on staff and visitors (eg, mask mandates or social distancing) or constitute an additional running cost (air conditioning associated with high rates of ventilation). The ability to identify areas of increased transmission risk empirically offers an opportunity for targeted interventions that disproportionately improve the health and well-being of staff and visitors. Our findings support CO_2 assessments as a basis for the provisional identification of areas with inadequate air exchange. While the relationship between atmospheric CO_2 concentrations and airborne pathogen transmission risk vary based on the type of indoor environment and activity,[12] they still represent a rapid and inexpensive means to identify settings for further investigation. However, the wider application of using CO_2-based cut-offs from such sensors requires consideration of the environment and activities that take place across the respective facilities. Our findings also highlight the importance of considering nonclinical areas, such as waiting rooms, when assessing air quality. Clinic waiting areas have amongst the highest occupancy and turnover of any zone to which a hospital visitor is likely to be exposed, and we suggest that hospital infection control strategies are extended to include them.

The CO_2 threshold employed (approximately 600 ppm above atmospheric levels) is in keeping with ASHRAE recommendation[7] and is based on consideration of a number of different factors, including comfort. This threshold acts as a basis to prioritize areas for increased infection control. However, further research is needed to understand how these values align with the transmission risk for specific airborne pathogens, given considerable variance in dispersion patterns and viability within the air column.[3]

The approach that we describe here represents a means to target measures to improve air quality within hospital settings through rapid, cost-effective empirical surveys. In doing so, it addresses an important, but often overlooked, aspect of hospital infection control, and provides a practical means for facilities to align with recommended air quality standards.

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