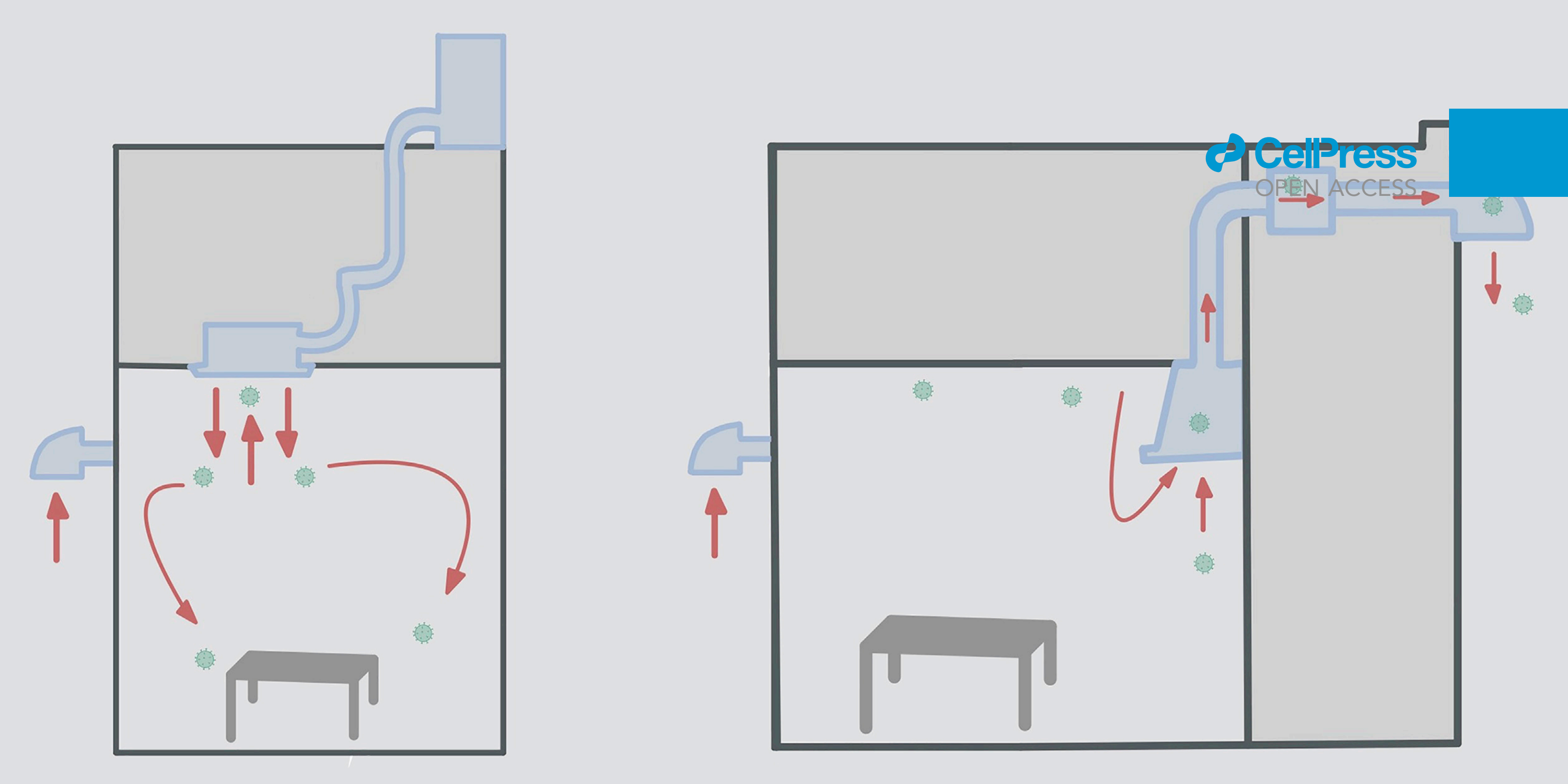

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Backstory

Procedure room innovation during the COVID-19 crisis: Protecting healthcare workers while learning from history

Dinesh Vyas,[1,2,*] Kayla K. Umemoto,[2] Arpita Vyas,[2] and Deepak L. Bhatt[3]

The impact of the recent pandemic on healthcare workers highlights the need to improve the working environment in hospitals. This is especially true in procedural rooms such as the operating and delivery rooms, which inherently require extended exposure to the virus, allows no social distancing, and generates aerosolized virus into the room through the use of the equipment. While reviewing the history of the development of the current Heating, Ventilation, and Air Conditioning Systems (HVAC), we identified inadequacies in the architecture and regulations of the system that resulted in insufficient protection during the current pandemic. Thus, we worked with building/facilities management, the operating room and nursing staff, and learned from research on airplane cabin air circulation to modify HVAC systems to address this issue. The modification includes calculating and implementing appropriate air changes per hour of the HVAC system. Modifying the existing system allows sufficient exchange of air within the procedure room to reduce the amount of exposure to viruses which results in safer working environments for healthcare workers. In the future, there will continue to be more pandemics, thus it is important to start creating safer working environments now, such as revisiting the hospital architecture and HVAC system, so that they can be improved upon and so that we are more prepared for the future.

Visual representation of the devices

(Left) The existing HVAC system depicting enhanced transmission of the virus in the chamber through air recirculation.
(Right) The novel HVAC system depicting secure air exchange which allows chamber air to leave while introducing fresh, uncontaminated air from the outside, thus reducing dissemination of the virus within the chamber.

Members of the team

Including Dr. Dinesh Vyas (Top Left), Dr. Deepak L. Bhatt (Top Right), Kayla K. Umemoto (Bottom Left), and Dr. Arpita Vyas (Bottom Right).

SARS-CoV-2 is intriguing, because it has an intermediate level of deadliness and contagiousness, compared with the plague which is highly deadly but less contagious, and the measles virus which is highly contagious but less deadly. This unique combination of virulence resulted in the COVID-19 pandemic exposing inadequacies in all parts of our society. Owing to the urgency of the situation, fixing some of these inadequacies required thinking outside the box and taking a page from other disciplines for creative solutions. One such issue was the great toll the pandemic had on the health of front-line workers: physicians and other hospital personnel (Wang and Bhatt, 2020). Globally, thousands of healthcare workers lost their lives in the line of duty, reinforcing the importance of finding ways to protect healthcare workers. To address this issue, we must close the gap in knowledge this pandemic has exposed—the interplay between virology, immunology, and environmental engineering. Thus, the success in mitigating both the COVID-19 pandemic and future pandemics will involve a strategy targeting three areas (1) decreasing exposure risk, (2) environmental control, and (3) pathogen-size appropriate personal protection (Centers for Disease Control and Prevention, 2003).

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Many current efforts to contain SARS-CoV-2 in the hospital focus on non-procedural care. However, the procedural room should be of more concern for worker infection in the hospital (i.e., endoscopy, cardiac catheterization, operating, or delivery rooms). In particular, the laminar flow of the operating room is not sufficient in reducing the risk of COVID-19. This insufficiency is because of multiple pathogen and carrier/disseminator factors such as the number and the size of active virus particles, route of shedding (e.g., airways and gastrointestinal tract), and patient infectivity stage (e.g., early or late). In this Backstory, we want to share our experiences during the COVID-19 Delta Variant surge, where we worked with those in other disciplines, particularly building/facilities management and the operating room nursing staff. Many hospitals, including ours, had high infection rates of healthcare workers, especially nursing staff. Thus, as administrators, we preemptively acted to protect our scarcest resource by collaborating with building/facilities management to establish an increase in air changes per hour. This collaboration was an extremely positive experience in preventing COVID-19 transmission to healthcare workers in the operating room at Dameron Hospital.

Proximity

What inspired/motivated your research?

Dr. Dinesh Vyas (Adventist Health Dameron Hospital) is a general surgeon who works in the operating room and Dr. Deepak L. Bhatt (Brigham and Women's Hospital Heart & Vascular Center, Harvard Medical School) is an interventional cardiologist who works in the cardiac catheterization laboratory. During the COVID-19 pandemic, we worked in procedure rooms that resulted in more exposure to the virus compared with other parts of the hospital. This is because of the innate nature of the work which requires (1) a long duration of exposure because of the length of procedures, ranging anywhere between 15 min to 10 h, (2) no social distancing because it is not feasible with five or more people who must work elbow to elbow, and (3) aerosolized viral exposure moving at high velocities through jet-streams because of the drills, cautery, scopes, saws, fluid spillage, and other equipment we work with on a daily basis. This unique situation makes COVID-19 a serious risk for all healthcare workers in the procedure rooms. Fortunately, during the heart of the pandemic, there was a voluntary reduction in elective procedures. But since reopening, those working in procedure rooms had to be cautious of the huge surge in infections because of the new COVID-19 strains.

Why did you feel the need to pursue this research?

In the 18th century, epidemics were the norm for crowded, impoverished urban inhabitants, where large urban hospitals had more cross-infections than rural hospitals. An article published in March 1942 in *Modern Hospital* laid the foundation of an innovative inpatient hospital floor plan. This article proposed the removal of patient room windows with a common nursing station, prioritizing efficiency over sunlight and fresh air for patients (Kisacky, 2017). This model did eventually succeed because of perceived reduced cross-infection rates and reduced costs that came with windowless buildings. However, the reduced cross-infection rates were more likely due to the introduction of antibiotics, which occurred around the same time. Antibiotics helped improve cross-infection rates because now more patients were treated, leaving fewer patients who were infected in closed rooms.

The process went full circle with a publication in 1984, in which hospital architect Roger Ulrich presented a significant finding: hospital rooms with windows lead to faster recovery than hospital rooms without windows (World Health Organization, 2009).

In the current day, Heating, Ventilation, and Air Conditioning Systems (HVAC) are indispensable in hospital building design (American Institute of Architects, 2006; American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2003). During prior SARS outbreaks and the more recent COVID-19 pandemic, filters and HVAC were implemented. However, they were implemented with a lack of Class 1 scientific evidence (Escombe et al., 2007). Based on current scientific knowledge, researchers believe that HVAC, with the size of particles, buoyancy of aerosol, current filter size, and air circulation pattern, is a double-edged sword. This may contribute to the continued prevalence of COVID-19 infecting physicians taking care of patients, even with the utmost precaution.

This history of devastating yet improving working environments, in conjunction with the COVID-19 pandemic, inspired us to pursue this research project. We hope this work will now inspire others to further research and improve procedure room working environments to help save healthcare workers from infection, and better prepare them for future pandemics.

Research methods

How did you approach developing the methodology for your research?

Our methodology consisted of examining current hospital ventilation standards in relation to SARS-CoV-2 and researching airplane cabin air circulation to further improve the ventilation.

Most healthcare facilities are more than 30 to 50 years old (The Joint Commission, 2003) and thus have a lower air exchange setup. Even newer facilities are not strictly mandated to be built according to the guidelines laid down by the Facilities Guidelines Institute (FGI) & the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) (American Institute of Architects, 2006; American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2003). These guidelines are updated annually; the latest policy suggests various air changes per hour (ACH) for different parts of the hospital (i.e., clinics, operation rooms, and hallways). ACH ranges from 2 to 15 per hour, and they are based on either droplet infection (>5μm) or aerosol (1 to 5μm) (The Joint Commission, 2003). The ideal ACH is 9 per hour in non-pandemic situations (The Joint Commission, 2003). However, because SARS-CoV-2 virus particles are small—0.12μm—rooms require an ACH of more than 25 per hour. To put it into perspective, the current HVAC is efficacious for particles as small as 0.3μm (Ridic et al., 2012).

This discrepancy exists because current guidelines are designed based on tuberculosis and HIV precautions, not for COVID-19. Tuberculosis is a large airborne particle that is easily trapped, and HIV is a small virus that is fluid transmissible. Therefore, both infectious diseases were well controlled with barrier improvements (e.g., proper masks and gloves). On the other hand, SARS-CoV-2 is 0.12μm in size with transmission through both air and liquid, a dual mode that is among the most unique transmission we have seen thus far in medicine.

Because the most recent guidelines were designed for tuberculosis and HIV, hospitals had to quickly adjust for SARS-CoV-2. The two standard cleaning measures currently used are ultraviolet radiation and high-rate ACH with HVAC. Taking into account our SARS-CoV-2 research, several immediate ventilation measures must be implemented, the most important is establishing localized ventilation: have a higher ACH (25 to 30 per hour) close to those in an airplane cabin. Traditionally, aircrafts replace 50% of the cabin with fresh air from the outside, the other 50% being recycled (Elwood and Space, 1994). Thus, the aircraft has a complete change in cabin air every two to three minutes or an ACH of 20 to 30 per hour (Elwood and Space, 1994). Presumably, this reduces the dissemination of germs.

Governance

Where did you get help from or seek advice to execute your project?

In our research, we sought out already studied technology-airplane cabin air circulation. This was possible because, "The survival of the airplane industry was dependent on safe travel for their passengers. During the pandemic they shared historical ventilation research on safety in the airplane chamber via mass communication." Airplanes, similar to procedure rooms, are very crowded and enclosed chambers with medium to long duration air exposure. The airplane industry intentionally exchanges air every two to four minutes resulting in 15 to 30 air changes per hour (ACH) (The Joint Commission, 2003).

"It's important for physicians to look at the engineering aspect of the environment including air, water, and food. During the COVID-19 pandemic we realized the most vulnerable population consists of older patients living in nursing homes with enclosed ventilation," thus we sought help from building/facilities management to help us implement this ACH technology gathered during our research, as patients in the hospital are similar, or even more vulnerable than older patients living in the nursing homes.

Can you answer how you decided to look into airplane cabin airflow?

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It's important for physicians to look at the engineering aspect of the environment including air, water, and food. During the COVID-19 pandemic we realized the most vulnerable population consists of older patients living in nursing homes with enclosed ventilation.

My partners and I are frequent fliers on major international routes with travel time in excess of ten hours. During the influenza season, our team developed minor or major flu-like symptoms, and it was a challenge for our project and health. The aviation industry did not share the literature on ventilation in the aircraft chamber before COVID-19. This epidemic caused a major upheaval in the industry, and passenger safety became the most important concern. This challenging circumstance forced the aviation industry to proactively share and publish the data in the mainstream media and implement its recommendations to assuage health concerns of the travelers.

Challenges

What challenges have you faced so far or project for the future?

Any large infrastructure change will be a challenge to implement because of the expense. Thus, we believe one challenge will be giving the hospitals a financial incentive to make the change. Though a challenge, we also believe that implementing a better air circulation system can be further supported because of decreased financial costs of having healthcare workers who are infected with COVID-19 or other future pathogens. It is estimated that inpatient admission to treat COVID-19 can be $20,292 for patients with major complications or comorbidities, $13,767 for patients with some complications or comorbidities, and $9,763 for patients without complications (Rae et al., 2020). Then, patients who require ventilator support for less than 96 h may cost $34,223 and those who require ventilator support for more than 96 h may cost $88,114 (Rae et al., 2020). Finally, these costs do not account for the time the healthcare workers are not able to work, indicating a heavy financial burden that can result from not improving the working environment of procedure rooms.

Publication/final thoughts

What breakthroughs do you imagine or hope to see in upcoming years?

In the upcoming years, we first hope to see windows that communicate with the outside environment and that have the option of localizing circulation in certain parts of the hospital. Next, we hope that more measures are taken to protect healthcare workers. During the height of the pandemic, some changes included a push to (1) suspend elective surgical procedures, (2) minimize staff during the procedure, (3) wear the appropriate personal protective equipment, and (4) use a negative or positive pressure room, if possible. However, though the appropriate personal protective equipment greatly reduces the infection rates of healthcare workers, there is still a risk. In one study assessing the effectiveness of universal masking, the risk dropped from 21.3% to 11.5% in one population and is in an overall downward trend in infection rates in other populations (Temkin et al., 2021). In addition, such decreases in risk of infection also depend on availability and the proper use of the appropriate personal protective equipment and thus potentially have limited use.

The major change we hope to see is implementing HVAC with the appropriate ACH and other changes in ventilation. This is crucial because, "Though we were able to quickly make changes to address COVID-19, we must use this warning sign as an opportunity to make the appropriate changes to our ventilation system now, as this will not be the last pandemic."

Though we were able to quickly make changes to address COVID-19, we must use this warning sign as an opportunity to make the appropriate changes to our ventilation system now, as this will not be the last pandemic.

What questions does your research open now?

This research challenges us to continue questioning the quality of the working environment in hospitals. Though the HVAC system can greatly improve this environment, researchers anticipate that there will be a few iterations of the HVAC innovation before a more cost-effective and better version is designed. However, we have a direction.

DECLARATION OF INTERESTS

Dr. Dinesh Vyas is founder and owner of MV Surgical Associates LLC, MV Surgical Technologies Inc. and MV Surgical Medical Devices Inc. Dinesh Vyas also has stock in Blackswan Technologies Inc.

Kayla umemoto has no relevant disclosures.

Dr. Arpita Vyas' spouse (Dr. Dinesh Vyas) has the following disclosures, is founder and owner of MV Surgical Associates LLC, MV Surgical Technologies Inc. and MV Surgical Medical Devices Inc. Dinesh Vyas also has stock in Blackswan Technologies Inc.

Dr. Deepak L. Bhatt discloses the following relationships - Advisory Board: AngioWave, Bayer, Boehringer Ingelheim, Cardax, CellProthera, Cereno Scientific, Elsevier Practice Update Cardiology, Janssen, Level Ex, Medscape Cardiology, Merck, MyoKardia, NirvaMed, Novo Nordisk, PhaseBio, PLx Pharma, Regado Biosciences, Stasys; Board of Directors: AngioWave (stock options), Boston VA Research Institute, DRS.LINQ (stock options), Society of Cardiovascular Patient Care, TobeSoft; Chair: Inaugural Chair, American Heart Association Quality Oversight Committee; Data Monitoring Committees: Acesion Pharma, Assistance Publique-Hôpitaux de Paris, Baim Institute for Clinical Research (formerly Harvard Clinical Research Institute, for the PORTICO trial, funded by St. Jude Medical, now Abbott), Boston Scientific (Chair, PEITHO trial), Cleveland Clinic (including for the ExCEED trial, funded by Edwards), Contego Medical (Chair, PERFORMANCE 2), Duke Clinical Research Institute, Mayo Clinic, Mount Sinai School of Medicine (for the ENVISAGE trial, funded by Daiichi Sankyo; for the ABILITY-DM trial, funded by Concept Medical), Novartis, Population Health Research Institute; Rutgers University (for the NIH-funded MINT Trial); Honoraria: American College of Cardiology (Senior Associate Editor, Clinical Trials and News, ACC.org; Chair, ACC Accreditation Oversight Committee), Arnold and Porter law firm (work related to Sanofi/Bristol-Myers Squibb clopidogrel litigation), Baim Institute for Clinical Research (formerly Harvard Clinical Research Institute; RE-DUAL PCI clinical trial steering committee funded by Boehringer Ingelheim; AEGIS-II executive committee funded by CSL Behring), Belvoir Publications (Editor in Chief, Harvard Heart Letter), Canadian Medical and Surgical Knowledge Translation Research Group (clinical trial steering committees), Cowen and Company, Duke Clinical Research Institute (clinical trial steering committees, including for the PRONOUNCE trial, funded by Ferring Pharmaceuticals), HMP Global (Editor in Chief, Journal of Invasive Cardiology), Journal of the American College of Cardiology (Guest Editor; Associate Editor), K2P (Co-Chair, interdisciplinary curriculum), Level Ex, Medtelligence/ReachMD (CME steering committees), MJH Life Sciences, Oakstone CME (Course Director, Comprehensive Review of Interventional Cardiology), Piper Sandler, Population Health Research Institute (for the COMPASS operations committee, publications committee, steering committee, and USA national co-leader, funded by Bayer), Slack Publications (Chief Medical Editor, Cardiology Today's Intervention), Society of Cardiovascular Patient Care (Secretary/Treasurer), WebMD (CME steering committees), Wiley (steering committee); Other: Clinical Cardiology (Deputy Editor), NCDR-ACTION Registry Steering Committee (Chair), VA CART Research and Publications Committee (Chair); Research Funding: Abbott, Acesion Pharma, Afimmune, Aker Biomarine, Amarin, Amgen, AstraZeneca, Bayer, Beren, Boehringer Ingelheim, Boston Scientific, Bristol-Myers Squibb, Cardax, CellProthera, Cereno Scientific, Chiesi, CSL Behring, Eisai, Ethicon, Faraday Pharmaceuticals, Ferring Pharmaceuticals, Forest Laboratories, Fractyl, Garmin, HLS Therapeutics, Idorsia, Ironwood, Ischemix, Janssen, Javelin, Lexicon, Lilly, Medtronic, Merck, Moderna, MyoKardia, NirvaMed, Novartis, Novo Nordisk, Owkin, Pfizer, PhaseBio, PLx Pharma, Recardio, Regeneron, Reid Hoffman Foundation, Roche, Sanofi, Stasys, Synaptic, The Medicines Company, 89Bio; Royalties: Elsevier (Editor, Braunwald's Heart Disease); Site Co-Investigator: Abbott, Biotronik, Boston Scientific, CSI, Endotronix, St. Jude Medical (now Abbott), Philips, Svelte, Vascular Solutions; Trustee: American College of Cardiology; Unfunded Research: FlowCo, Takeda.

REFERENCES

American Institute of Architects (2006). Guidelines for Design and Construction of Health Care Facilities (American Institute of Architects).

American Society of Heating, Refrigerating and Air-Conditioning Engineers (2003). ASHRAE Handbook: HVAC Applications (American Society of Heating, Refrigerating and Air-Conditioning Engineers).

Centers for Disease Control and Prevention (2003). Guidelines for Environmental Infection Control in Health-Care Facilities. https://www.cdc.gov/infectioncontrol/guidelines/environmental/background/air.html.

Elwood, H.H., and Space, D.R. (1994). The airplane cabin environment: issues pertaining to flight attendant. In International In-Flight Service Management Organization Conference. 10.1.1.304.7321.

Escombe, A., Oeser, C.C., Gilman, R.H., Navincopa, M., Ticona, E., Pan, W., Martínez, C., Chacaltana, J., Rodríguez, R., Moore, D.A.J., et al. (2007). Natural ventilation for the prevention of airborne contagion. PLoS Med. *4*, e68. https://doi.org/10.1371/journal.pmed.0040068.

Kisacky, J. (2017). When Fresh Air Went Out of Fashion at Hospitals. Smithsonian Magazine. https://www.smithsonianmag.com/history/when-fresh-air-went-out-fashion-hospitals-180963710/.

Rae, M., Claxton, G., Kurani, N., McDermott, D., and Cox, C. (2020). Potential costs of COVID-19 treatment for people with employer coverage. Health System Tracker. https://www.healthsystemtracker.org/brief/potentialcosts-of-coronavirus-treatment-for-people-with-employer-coverage/.

Ridic, G., Gleason, S., and Ridic, O. (2012). Comparisons of health care systems in the United States, Germany and Canada. Mater. Soc. Med. *24*, 112. https://doi.org/10.5455/msm.2012.24.112-120.

Temkin, E., Schwaber, M.J., Vaturi, A., Nadir, E., Zilber, R., Barel, O., Pavlov, L., and Carmeli, Y. (2021). Effect of a national policy of universal masking and uniform criteria for severe acute respiratory coronavirus virus 2 (SARS-CoV-2) exposure on hospital staff infection and quarantine. Infect. Control Hosp. Epidemiol. *43*, 757–763. https://doi.org/10.1017/ice.2021.207.

The Joint Commission (2003). Aerosol Generating Procedures. https://www.jointcommission.org/-/media/tjc/documents/covid19/aerosol-generating-procedures-infographic.pdf.

Wang, X., and Bhatt, D.L. (2020). COVID-19: an unintended force for medical revolution. J. Invasive Cardiol. *32*, E81–E82.

World Health Organization (2009). WHO Policy on TB Infection Control in Health-Care Facilities, Congregate Settings and House-Holds (World Health Organization).