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Major Article

Implementing a negative-pressure isolation ward for a surge in airborne infectious patients

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Background: During a large-scale airborne infectious disease outbreak, the number of patients needing hospital-based health care services may exceed available negative-pressure isolation room capacity.
Methods: To test one method of increasing hospital surge capacity, a temporary negative-pressure isolation ward was established at a fully functioning hospital. Negative pressure was achieved in a 30-bed hospital ward by adjusting the ventilation system. Differential pressure was continuously measured at 22 locations, and ventilation airflow was characterized throughout the ward.
Results: The pressure on the test ward relative to the main hospital hallway was –29 Pa on average, approximately 10 times higher than the Centers for Disease Control and Prevention guidance for airborne infection control. No occurrences of pressure reversal occurred at the entrances to the ward, even when staff entered the ward. Pressures within the ward changed, with some rooms becoming neutrally or slightly positively pressurized.
Conclusions: This study showed that establishing a temporary negative-pressure isolation ward is an effective method to increase surge capacity in a hospital.

BACKGROUND

Infectious disease epidemics, such as severe acute respiratory syndrome in 2003, H1N1 influenza in 2009, and the outbreak of Middle East respiratory syndrome starting in 2012, are public health threats that are best mitigated by deliberate planning at the health system level.[1-3] A robust response to a large-scale infectious disease outbreak is predicated, in part, on coordination between public health and health care delivery systems.[1,4,5] Hospital pandemic preparedness plans typically include protocols for handling a surge of infectious patients.[6] Hospitals need to respond rapidly if they are among the first impacted by a highly contagious outbreak.[7]

Most U.S. hospitals use negative-pressure airborne infection isolation rooms (AIIRs) to house patients with suspected or confirmed airborne transmissible infections. The pressure difference between an AIIR and the hospital corridor is recommended to be –2.5 Pa in the United States.[8,9] It is also recommended to have an air exchange rate (AER) of 12 air changes per hour (ACH), of which 2 ACHs must be outside air in an AIIR.[2,8] In approximately one-half of urban hospitals, only 2%-4% of rooms are equipped with negative pressure.[10] The number of patients needing health care services may rapidly exceed such a small AIIR capacity during an airborne transmissible pandemic or bioterror event.[11]

There are no regulations stipulating surge capacity requirements for U.S. hospitals. Guidance for intensive care unit capacity has been published, ranging from a 20%-300% increase in bed numbers, depending on the type of incident.[5,6,11-14] One option to meet capacity needs would be to implement a temporary negative-pressure isolation ward that could house a large number of patients. To date, there are few studies detailing the effectiveness of temporary isolation wards to be used during a surge. Rosenbaum et al demonstrated during a hospital disaster preparedness drill that multiple high-efficiency particulate air (HEPA)–filtered negative air machines placed in a physical therapy gymnasium produced the

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recommended pressure and AER for negative-pressure isolation.[15] In another demonstration, a 3-unit temporary patient shelter was constructed out of plastic sheeting and ventilated using negative-air machines.[16] Containment was estimated using fluorescent tracer particles, and very high levels of containment were achieved (>99%) with AERs of 15 ACHs.

Although it is recognized that increased surge capacity is an important component of hospital preparedness, more knowledge and field experience are needed to guide decisions about increasing airborne surge capacity.[17] The purpose of this project was to demonstrate and test whether a functional hospital wing could be operated effectively as a negative-pressure isolation ward for an entire day. Data collected included the following: pressure differentials at the isolation ward's outer envelope, internal variability of pressure on the ward, performance of the temporary anteroom (ANT), pressure fluctuations when ingress or egress events occurred, flow rates and AERs in bedrooms, and ultraviolet (UV)-C fluxes in stairwells.

MATERIALS AND METHODS

Isolation ward layout

A functioning hospital in the San Francisco Bay Area, Northern California, was chosen as the study site. The project was completed in March 2015. A temporary negative-pressure isolation ward was located where it could be effectively isolated from the rest of the hospital. A ward on the top floor of the hospital was chosen because it had a dedicated air handling unit (AHU), a dedicated bathroom exhaust system, a separate dedicated exhaust system for return registers in existing isolation rooms (ISRs), and a firewall separating the ward from the rest of the hospital. Figure 1 depicts the ward layout.

The ward was sealed from the rest of the hospital by closing the fire doors in one hallway (main hospital hallway [MHH]) (Fig 1) and by setting up an ANT in the other hallway (Fig 1). The ANT was constructed of a wood frame bolted to the ceiling. Plastic sheeting was taped to the ceiling frame, walls, and floors and fitted with 2 zippered openings for doors. All doorways with access to the ward, and internal bedroom and bathroom doors, were kept closed during the study except for brief times during staff ingress or egress.

Ventilation design and control

During the demonstration, the AHU was operated with supply airflow reduced to 60% of its normal operating speed and exhaust airflow operating at capacity. The AHU was an air-to-air, constant-air-volume system, set to 100% outside air and 100% exhaust manually for this study. All return and exhaust air was directly released through on-roof stacks with no mixing or recirculation. This ventilation scheme generated –29 Pa of pressure across closed fire doors in the MHH, while limiting nuisance noise on the ward produced by the AHU.

Two HEPA-filtered negative-air machines (MICROCON MAP800; Biological Controls, Eatontown, NJ) were operated at 1,104 m^3/h to establish negative pressure in the ANT and were exhausted into the MHH. Negative-air machine flow rates were set such that the anteroom pressure was highly negative relative to the MMH, yet not as negatively pressurized as the isolation ward, to direct air flow toward the isolation ward.

During planning visits, pressure measurements collected from the stairwells indicated that they were positively pressurized relative to the ward, limiting the possibility of infectious particles escaping through these spaces except when stairwell doors were opened. One solution to ensure any escaping particles are disinfected was to install upper room germicidal UV lamps. These lamps (nonlouvered GL-188; Lumalier, Memphis, TN) were installed near the door in each stairwell internal to the ward at a height of 2.1 m. UV-C fluxes were measured in both stairwells using a radiometer (Model IL1400A; International Light, Peabody, MA) with an SEL240

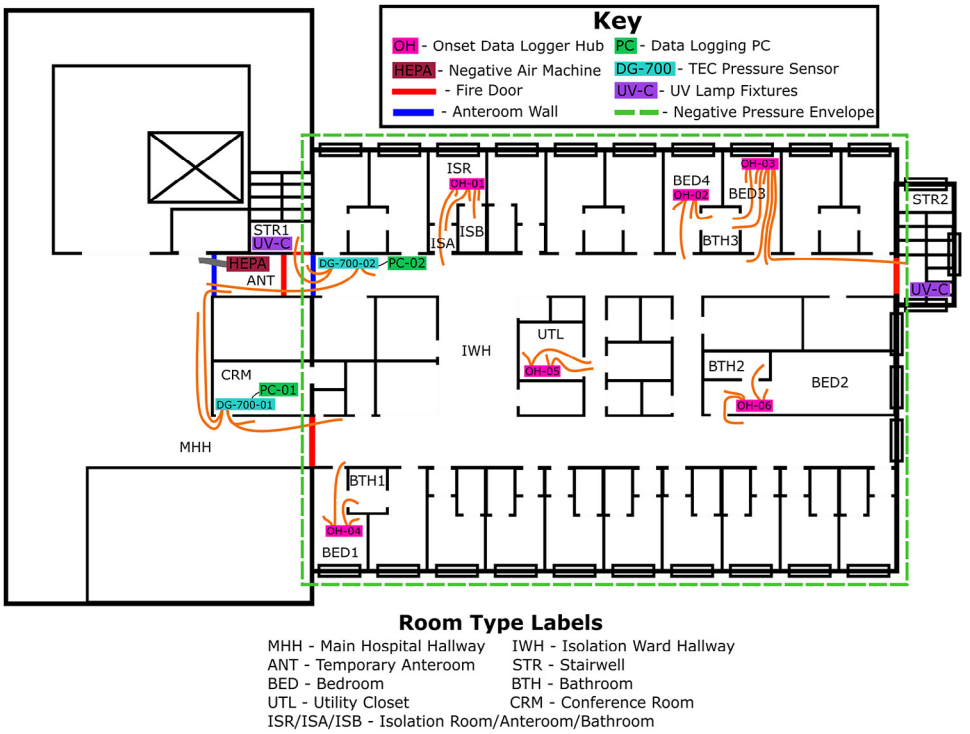

Fig 1. Isolation ward layout and instrument locations. *PC*, personal computer; *TEC*, the energy conservatory; *UV*, ultraviolet.