Use of Simulation to Visualize Healthcare Worker Exposure to Aerosol in the Operating Room

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Summary Statement: Simulation resources offer an opportunity to highlight aerosol dispersion within the operating room environment. We demonstrate our methodology with a supporting video that can offer operating room teams support in their practical understanding of aerosol exposure and the importance of personal protective equipment.
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Key Words: Aerosol, operating room, healthcare worker, COVID-19.

Protecting staff from occupational exposure to aerosol dispersed from the airway has become a priority during the COVID-19 pandemic because of the infection risk posed by viral deposition. Healthcare worker (HCW) SARS-CoV-2 infection rates worldwide are concerning with evidence of high rates of seroconversion in up to 45% of staff in high-prevalence areas. Although droplet and contact spread were initially thought to be the main modes of transmission, substantial concerns remain for healthcare staff during aerosol-generating procedures. The paucity of literature describing movement of aerosols in this environment prevents development of an evidence-based approach to personal protective equipment (PPE) requirements for operating room teams. Simulation offers an opportunity for operating room teams to develop a greater awareness and understanding of aerosol spread within this setting.

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We present our method and supporting video highlighting our visual model of aerosol dispersion from a simulated patient in the operating room with the aim to inform HCWs, policymakers, and nonclinical researchers tackling this issue. It was developed through a multidisciplinary group collaborating between otolaryngology, anesthesiology, simulation, and respiratory medicine. The model mimics normal tidal breathing during routine airway procedures. By using light sources to visualize the aerosol plume, we are able to demonstrate the efficacy of several interventions aimed at reducing occupational exposure to aerosols.

METHODOLOGY

Simulations were undertaken in a standard operating room (7.2 × 6 × 3 m) with laminar flow. Relative humidity was 42.8%. Temperature was 22.1°C.

A GE Carestation 650 anesthesia machine (GE Medical Systems, IL) simulated spontaneous expiration. The breathing circuit (intersurgical anesthetic breathing system 3.2 M; Intersurgical LTR, Berkshire, UK) was attached to the distal end of a TruCorp AirSim Child Combo X mannequin (TruCorp, Lurgan, Northern Ireland) trachea. Pressure control ventilation parameters were selected to best mimic physiological expiration in a spontaneously breathing 5-year-old, 18-kg child. A spirometer (SPIRO; Philips Medizin System, Boeblingen, Germany) was positioned distal to the breathing circuit to measure the expired minute volume generated. An inspired pressure of 5 cmH_2O was selected on the anesthetic machine to mimic the low positive pressure generated in the alveoli during passive expiration. A rate of 20 breaths per minute and an inspiration:expiration (I:E) ratio of 2:1 was selected. The reverse ratio was used as the ventilator inspiratory time was simulating mannequin expiration. A simulated expiratory phase of 2 seconds was produced. With these ventilation parameters, fresh gas flow was titrated to measured expiratory volume. A flow fresh gas flow of 1.2 L/min of air generated an expired tidal volume of 148 mL and an expired minute volume of 2.97 L/min. Although these volumes are representative, the decelerating flow rate pattern of the “closed lung” was not demonstrated with this model.

An aerosol delivery system (Aerogen Pro-X Controller, Aerogen Ltd, Galway, Ireland) was also incorporated into the circuit, combining aerosolized water into the exhaled breath. This has a mass median aerodynamic diameter range of 1 to 5 μm without providing additional flow to the circuit. Aerosol distribution was visualized and recorded in front of a black screen with backlighting with both white light or using a DeWalt DW088 cross-hair green laser beam (wavelength 630–680 nm).

Examples included were as follows: airway maneuvers (jaw-thrust), preoxygenation, endotracheal tube cuff inflation, and laryngeal mask airways (See video, Supplementary Digital Content 1, http://links.lww.com/SIH/A681, HCW exposure to aerosol in the operating room; see transcript, Supplementary Digital Content 2, http://links.lww.com/SIH/A682, transcript of video voiceover).

Video recordings of procedures performed on the model demonstrate the dispersion of the aerosol plume and potential operator exposure with the mannequin head appropriately orientated according to the intended procedure. White light from dual sources was used to enhance visualization of local aerosol distribution (See Figure, Supplementary Digital Content 3, http://links.lww.com/SIH/A683, comparison of aerosol dispersal around airway devices in the operating theater), whereas a green laser light source generating 2-dimensional plane light sheet demonstrated aerosol movement along eddies of turbulent operating theater airflow.

Interventions, such as the application of a facemask, markedly reduced the aerosol exposure of the HCW. The use of a cuffed endotracheal tube offered a striking reduction in dispersion. These videos have been promoted locally to inform healthcare providers. Although limited as a qualitative, nonvalidated demonstration of an airway plume, our experience is through making “the invisible” now “visible,” the importance of correct usage of PPE is further emphasized. The equipment required was sourced within our existing hospital resources, and applying our methodology through in situ simulation may allow others to use within HCW education.

The COVID-19 pandemic has raised awareness of aerosol dispersion in hospitals, particularly during routine medical procedures. Correlating aerosol exposure and risk of infection will be key to developing safe, effective techniques to minimize HCW exposure to infection. As healthcare services recover from the pandemic peak, vigilance in the use of protective measures should be maintained, but to return to capacity, quantitative studies are now required to inform evidence-based guidelines and policies that define appropriate ways to maintain safe practice as we upscale services with sustainable use of PPE.

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