

Novel repurposing of a Laerdal Airway trainer to simulate aerosolisation

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ABSTRACT

COVID-19 has claimed over 200 000 lives in the USA and put healthcare workers at risk. Healthcare workers have an increased exposure risk from aerosol-generating procedures such as endotracheal intubation. New barrier designs such as the acrylic box and horizontal plastic drape have emerged to reduce exposure to airborne particles. Particle generating models are needed to test aerosol generating procedure (AGP) barrier designs. To achieve this, an aerosol model that generates a visible and measurable increase in particles which SARS-CoV-2 could travel on and that can also be intubated was created. The model was created using a Laerdal Airway Management Trainer (Laerdal Medical, Stavanger, Norway) combined with a nebuliser and Ambu bag-valve resuscitator (Ambu, Columbia, Maryland, USA). Nebulised Glo Germ (Glo Germ, Moab, Utah, USA) dissolved in saline solution was moved through the tubing and out of the mannequin's mouth with compression of the Ambu bag. This nebulisation was visualised under ultraviolet light and the quantity of particles between 0.3 and 10.0 µm was measured with a particle counter. Nebulisation was visible exiting the mouth of the mannequin. Nebulised Glo Germ was visualised under ultraviolet light moving in the ambient air. Particles in the size range of 0.3–0.5 µm increased by 20-fold and 1–10 µm increased by 10 252%. SARS-CoV-2 can travel on aerosol and droplet particles and particle generating models are needed to visualise and measure exposure areas and the path particles take during AGPs. We used existing medical and simulation supplies to create a particle simulator.

INTRODUCTION

Since the emergence of the novel SARS-CoV-2 causing COVID-19 pandemic, over 900 US healthcare workers have contracted and died from COVID-19.¹ Thus, it has become increasingly important to protect healthcare workers from infectious particles from infected patients. Protection has been difficult as SARS-CoV-2 transmission has been reported not only by droplets, but also aerosols.² Protective measures include using barrier protection, such as personal protective equipment (PPE), locating patients or performing aerosol generating procedures (AGP) in negative pressure rooms, minimising aerosolising procedures, such as nebulisation for persons under investigation or confirmed cases, and reducing the number of staff that care for these patients or participate in aerosolising procedures.

Further efforts are needed to develop and test methods and models that further reduce exposure.

One potential target of intervention is the wide dispersal of aerosolised particles that occurs during AGP. New barrier designs such as the acrylic box and horizontal plastic drape have been developed to shield healthcare workers from these potentially infectious particles.³ Their ability to mitigate the spread of potentially infectious aerosol and droplet sized particles is in question.⁴ To test the efficacy of these new designs, readily accessible and inexpensive particle generating simulation models are needed that generate a large amount of airborne particles to easily visualise and measure where the particles travel. We aimed to create a model that allows for particles to be easily visualised and measured during potentially AGP, with readily accessible medical supplies available in most healthcare and simulation settings.

METHODS

The model created was centred around a Laerdal Airway Management Trainer (Norway), as it can be used for simulating endotracheal intubations, laryngeal mask insertion, bronchoscopies, oral and nasal airway insertion, and using a mask with bagging. A nebuliser was used to produce varying sizes of particles at a degree that was measurable and visible. An Ambu bag-valve resuscitator (USA) was used to simulate patient breaths. All three were combined to create the particle generating model. The Laerdal trainer has a plastic tube that comes from the model's mouth and nose mimicking the pharynx, larynx and trachea. This single upper airway tube then bifurcates, mimicking the bifurcation in the main stem bronchi at the main carina, and then each secondary tube enters a model lung. The right main stem bronchi tube was disconnected from the right lung and connected to the nebuliser tee where the mouthpiece would typically insert. Tape was used to secure this connection and make it airtight. The other end of the tee was connected to the nebuliser reservoir and this, in turn, was connected to an Ambu bag-valve via the non-rebreathing valve. Tape was used to cover the exhaust valve, though if available a positive end-expiratory pressure valve could be inserted ([figure 1](#)). Tubing attached to the nebuliser jar was connected to an air source. A 0.9% saline solution was added to the nebuliser jar and 15 L/min of air was used to generate nebulisation. The nebulisation of the saline solution is the simulated particle generation. The self-inflating bag of the Ambu bag-valve was squeezed periodically by a team member, creating a puff of nebulised saline through the nebuliser and tubing and out



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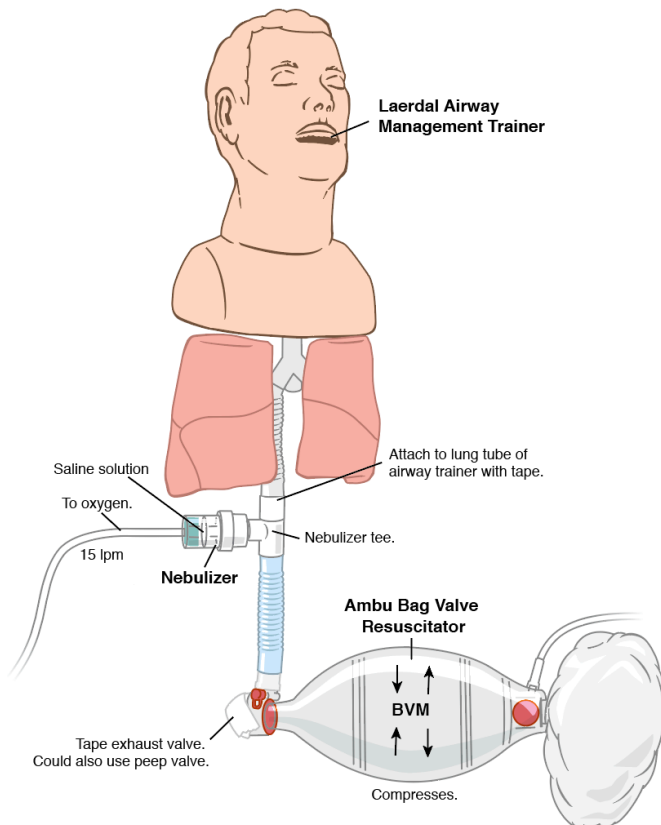


Figure 1 Configuration of Laerdal Airway Management Trainer, nebuliser and Ambu bag valve. The nebuliser tee was connected to the right lung tube and secured with tape. The nebuliser reservoir was attached to the non-rebreathing valve of the Ambu bag valve mask (BVM). The nebuliser tubing is connected to air source at 15 L/min.

of the mannequin's mouth. Alternatively, a mechanical ventilator could be connected instead of the Ambu bag to generate movement of nebulisation out of the mannequin's mouth. The self-inflating bag was compressed 12–16 times per minute to mimic a normal respiration rate. To better visualise these particles, Glo Germ (USA) was dissolved in the saline solution and added to the nebuliser jar. The following reference includes a link to a video demonstrating the materials used, construction of the particle simulator and aerosolisation of particles using the described setup.⁵

A light scattering particle counter was used to measure the quantity of particles in sizes of 0.3, 0.5, 1.0, 2.0, 5.0 and 10.0 μm (FLUKE 985; Everett, Washington, USA). This particle counter uses a laser that measures how much it is scattered to size particles as they are pulled through the counter. The International Organization for Standardization has endorsed this type of particle counter.⁶ The ambient air was initially sampled with the model not emitting any particles. The model was then turned 'on' and then particle counts were obtained 0.9 m away from the model.

RESULTS

With 15 L/min of air flowing into the model nebulised Glo Germ visibly emanated from the mannequin's mouth under ultraviolet light. Compressing the Ambu self-inflating bag resulted in puffs of nebulised Glo Germ.⁵ Particles in the size range of 0.3–0.5 μm increased by 20-fold and 1–10 μm increased by 10252% (table 1).

Table 1 The distribution of particle size and count before and during nebulisation

Particle size (microns)	Particle quantity (counts/litre)	
	Baseline	Nebulisation
0.3	12 158	201 682*
0.5	2525	98 320*
1.0	336	30 113
2.0	50	8669
5.0	4	1478
10.0	3	32

*The distribution of particle sized remained the same during testing. The smallest particles, that is, 0.3–0.5 μm , which represent the size that airborne SARS-CoV-2 can travel on, increased from 14 683 to over 200 000 during nebulisation.

DISCUSSION

Like the SARS-CoV-1 strain that emerged in 2003 the new SARS-CoV-2 causing COVID-19 also can travel on aerosolised particles less than 5 μm .^{7,8} Our model generated a large increase in aerosol and droplet-sized particles that could harbour SARS-CoV-2 and their movement was visualised in real time. This model can be used to easily track the movement of and measure where these particles travel. This property has several applications in simulation and simulation training. For instance, this model or similar ones could be used to demonstrate the efficacy of masks and social distancing.⁹ Teams that perform AGPs could practice on this model in order to reduce exposure when a procedure is subsequently performed on a patient. This model can also be used to help design rooms to determine the flow of air through a room to minimise exposure, which is especially important for AGPs that occur in small rooms, such as, spirometry and exercise testing, as these have shown to have increased particle counts.^{10,11} The practice could focus on PPE with ultraviolet light tracking of Glo Germ to see what has been exposed to these particles and where the particles travel. Did particles breach the integrity of the PPE or move near the face or nasopharynx? These questions can be addressed with the model in a safe environment and ensure PPE quality control.

Repetitive procedure simulation would also lead to reduced procedure duration leading to reduced particle generation and dispersal. AGPs such as endotracheal intubation could also be practised with barrier devices such as the acrylic box and plastic drape covering the model. After obtaining a baseline particle measurement of the room the model could be turned 'on' thus generating particles which could then be visualised to see where they move with or without a barrier in place and to test for the number of particles with a particle counter. The change in particle count from baseline could be used to determine whether the barrier reduced the number of particles compared with the control.

A variety of models have been developed to simulate a cough and aerosolisation of respiratory secretions, including a bursting balloon,³ a mechanically produced cough^{12,13} and a human volunteer inhaling vapours generated from a handheld battery-powered vaporiser.¹⁴ Our intention, on the other hand, was to create a strong and consistent source of measurable particles that mimic AGPs.

This nebulisation model increased the count of 0.3 to 0.5 μm particles in the room by 20-fold, which SARS-CoV-2 could travel on. The number of particles generated by the model far exceeds what would be expected from a coughing patient, even one with COVID-19. However, this produces a better signal-to-noise ratio because there are more particles to detect, unlike a human cough

that creates far fewer particles, somewhere between 4 and 50 particles in the 2–8 μm size range even at a close distance, which would also be expected for a coughing COVID-19 infected patient.¹⁵ That being said, the number of coronavirus particles contained on these respiratory particles also depends on the severity of the COVID-19 infection, with more severe cases expected to have more virus particles per respiratory aerosol or droplet.¹⁶ The dissemination of aerosolised saline and Glo Germ was visible to the naked eye, a property that could be used to study their movement, and compressing the Ambu bag (air volumes up to 1500 mL) consistently generated large increases in the particle count.

Additional features of the model are that it uses an existing trainer and materials available in most healthcare settings. Though the Laerdal Airway Management Trainer represents a significant investment (approximately US \$2300), many teaching hospitals and simulation centres already have access to it. The other components of the model including a nebuliser (approximately US \$2) and the Ambu bag-valve resuscitator (approximately US \$30) are relatively inexpensive. The model is also easy to assemble. Scotch home and office masking tape (3M) was required only to attach the nebuliser tee to the Laerdal Airway trainer lung tube and to cover the exhaust valve of the Ambu bag-valve. These connections held together even under a high flow rate and a large volume of air when the Ambu self-inflating bag was fully compressed. The model is easy to disassemble and can be reused to teach airway management or to again rebuild the model. There is no need to clean the model afterwards, though the lung tube should remain disconnected from the lung to allow evaporation of saline solution that may be left in the mannequin and then may be subsequently reattached. Glo Germ contains non-hazardous ingredients and is not visible unless visualised under ultraviolet light. It does not need to be cleaned off, unless the model were to be used to track distribution of particles, in which case soap and water would suffice.

We did not measure the properties of nebulised particles including projectile speed, direction or how far the particles travelled. Even though nebulisation generates more particles, the way the particles travel should be unaffected, but is dependent on room laminar flow, room air exchange rate, temperature and humidity. The duration of airborne particle suspension was also not measured which is important to consider since SARS-CoV-2 can remain viable on airborne particles for 3 hours.⁸ These factors warrant further investigation, particularly when it comes to how well AGP barriers may mitigate particle spread.

As we anticipate further transmission of SARS-CoV-2, it is important to develop ways to protect front-line healthcare workers. Our model generates a large amount of micrometre-sized particles, which SARS-CoV-2 could travel on, and can be used to see and measure where they travel. It is made from materials available at most healthcare institutions and can be used to test AGP teams and barriers, which we hope will aid in COVID-19 mitigation efforts.

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