Aerosol-Generating Procedures and Simulated Cough in Dental Anesthesia

Brian Chanpong, DDS, MSc,* Michelle Tang, DDS, MSc,† Alexander Rosenczweig, DMD,* Patrick Lok, DDS,* and Raymond Tang, MD, MSc‡

*Private Practice, Vancouver, British Columbia, Canada, †Faculty of Dentistry, University of Toronto, Toronto, Ontario, Canada, and ‡Clinical Associate Professor, Anesthesiology, Pharmacology and Therapeutics, University of British Columbia, Vancouver, British Columbia, Canada.

Dental professionals are at an increased risk for exposure to the severe acute respiratory syndrome coronavirus 2 with aerosol-generating procedures (AGPs), and dental anesthesia practices have additional risks due to airway management procedures. The purpose of this pilot study was to examine the extent of splatter on dental personnel that may occur with AGPs and coughing in a dental anesthesia practice. A Dentoform model was fitted into a dental mannequin and coated with Glo Germ to detect splatter during simulated dental AGPs produced with use of a high-speed handpiece, an ultrasonic scaler, and an air-water syringe, all in conjunction with high-volume suction. A simulated cough was also created using a ventilator programmed to expel Glo Germ within the velocity and volume parameters of a natural cough with dental personnel in their customary positions. A UV light was used after each procedure to systematically evaluate the deposition of Glo Germ splatter on each person. After AGPs were performed, splatter was noted on the face, body, arms, and legs of the dentist and dental assistant. The simulated cough produced more extensive splatter than AGPs; additional Glo Germ was seen on the shoes, the crown of the head, and the back of the dental personnel. Therefore, it is recommended that full personal protective equipment consistent with AGPs be used and changed between patients to reduce the risk of contamination and infection for dental personnel and patients.

Key Words: Splatter; Aerosols; Cough; Aerosol-generating procedures; AGP; Aerosol-generating medical procedures; AGMP.

Based on data from the US Department of Labor, 4 of the top 5 professions at highest risk of contracting severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and the disease it causes (coronavirus disease 2019) are in the dental field.[1] At highest risk are dental hygienists, followed by oral and maxillofacial surgeons, dental assistants, and dentists. Furthermore, anesthesiologists are ranked just below those in the dental profession.[1]

High titers of SARS-CoV-2 are found in the oral, nasal, and pharyngeal mucosa as well as in pulmonary secretions. The virus spreads primarily by droplet and contact contamination and by aerosols during aerosol-generating procedures (AGPs). The close proximity and contact with these oropharyngeal structures put dental professionals at high risk. AGPs such as the use of high-speed handpieces, ultrasonic scalers, and air-water syringes increase the extent of exposure and risk of infection. In anesthesia-based dental practices, AGPs including intubation, extubation, manual ventilation, and tracheal suctioning further add to this risk.[2] In addition to these AGPs, there are reflex-induced events such as gagging and coughing that can occur without warning and can also generate aerosols.[3] Activation of these protective reflexes is not uncommon and can be evoked during a variety of procedures.[4]

In an anesthesia-based dental practice, the operating dentist, dentist anesthesiologist, or other licensed trained individual responsible for maintaining airway patency may be at highest risk of exposure because of being positioned at the patient's head. The protective reflexes may be blunted with sedation or general anesthesia, and it is not uncommon for patients to

Received May 4, 2020; accepted for publication May 28, 2020.

Address correspondence to Dr Brian Chanpong, 750 West Broadway #806, Vancouver, BC V5Z 1H8, Canada; brian@chanpong.com.

Anesth Prog 67:127–134 2020 | DOI 10.2344/anpr-67-03-04

cough when irritants enter the oropharynx.[5,6] For cases that require a secured airway, coughing may still occur during intubation and extubation despite measures to reduce this protective reflex.[7]

It has been estimated that over 40% of those who test positive for SARS-CoV-2 may be asymptomatic.[8] Currently, without a reliable highly sensitive rapid molecular assay test or an effective vaccine against SARS-CoV-2, it must be assumed that all patients who present for dental care are considered to be positive for SARS-CoV-2. Therefore, the purpose of this pilot study is to examine the potential splatter that can be generated from AGPs and coughing in a dental anesthesia practice.

MATERIALS AND METHODS

In this study, Glo Germ (Glo Germ, Moab, Utah) was used to simulate the splatter produced by dental AGPs and that produced by a simulated cough. Glo Germ is a melamine resin that is 1–5 μm in size and appears blue under UV light.[9] In comparison, the SARS-CoV-2 virus is 0.12–0.16 μm in size but is carried on bioaerosols within 1–5 μm and droplets >5–10 μm in size.[10–12]

Dental AGP Simulation

To simulate the spread of dental splatter produced by AGPs encountered in dentistry, 1 g of Glo Germ was mixed with 5 mL of water and applied to the teeth of a dental mannequin head outfitted with a dental model (Dentoform, Columbia Dentoform, Lancaster, Pa). A piece of plastic wrap (Saran Wrap Premium Wrap, S. C. Johnson & Son, Inc. Racine, Wis) was used to create the oropharynx behind the Dentoform. Wearing short-sleeve scrubs, goggles, American Society for Testing and Materials level 3 surgical masks, and gloves, a dentist and dental assistant performed 3 different simulated dental procedures that are considered to produce aerosols: use of a high-speed handpiece for 60 seconds, an ultrasonic scaling unit for 120 seconds, and an air-water syringe for 3 seconds, all in conjunction with continuous high-volume evacuation (HVE) suction. The equipment and procedures represented those typically used during routine dental care, and the shorter-than-normal times were chosen based on the constraints of this study. During the procedures, the dentist and dental assistant were positioned at 9 and 3 o'clock, respectively, relative to the dental mannequin head.

Simulated Cough

For the simulated coughing portion of the study, a third individual (anesthesiologist), wearing a face shield in addition to the same personal protective equipment (PPE) as the dentist and the dental assistant, was positioned at 12 o'clock relative to the dental mannequin head. This person took the role of managing the simulated patient's airway.

To simulate coughing, a ventilator was fabricated using the specifications outlined by the University of Florida Health Open Source Ventilator Project,[13] and 500 mg of Glo Germ mixed with 2.5 mL of water was placed in the ventilator's distal end. The ventilator was programmed to open for 0.5 seconds to produce a simulated cough. The expired volume of the cough was 1000 mL, as measured with a Datex Ohmeda Cardiocap 5 (GE, Boston, Mass) monitor with spirometry, with a flow rate calculated to be 2 L/s. These parameters were within the ranges of previous human studies, which demonstrated cough expired volume measurements of 250–1600 mL and cough peak flow rates from 1.6 to 8.5 L/s.[14] In addition, the mouth opening area for those previous studies was measured[11] to range from 1.97 to 4.95 cm^2. For this report, the simulated mouth opening used was 3.8 cm^2. A tape measure was affixed to the orifice to measure the height of the expelled material as captured on slow-motion video.

Analysis

Immediately after each simulated procedure or cough, the participants were taken to a dark room and a Certified 9-bulb UV light (Canadian Tire, Corporation Limited, Toronto, Canada) was used to visualize the Glo Germ. Standardized photographs were taken of all participants of the crown of the head, face, chest, back, arms, legs, and shoes.

Two examiners independently viewed the photographs and scored them based on how much splatter appeared on the participants for the dental procedures and the simulated cough, although only the maximum scores for each of the 3 dental procedures were recorded. Scores were rated using a 3-point Likert scale. A score of 0 represented no traces of splatter, 1 indicated light splatter, and 2 indicated heavy splatter. The Cohen κ

Table. Rating of Glo Germ Splatter by 2 Examiners*

	AGP				*Cough*					
	Dentist		*Dental Assistant*		*Dentist*		*Dental Assistant*		*Anesthesiologist*	
Examiner Location	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*
Crown of head	0	0	0	0	2	2	2	1	2	2
Face	1	1	0	0	1	1	1	2	1	2
Body	1	1	1	1	1	1	1	2	1	2
Back	0	0	0	0	1	1	1	2	1	0
Arms	2	2	2	2	2	2	2	2	2	2
Legs	1	1	2	2	1	1	2	2	2	2
Shoes	0	0	0	0	0	0	0	1	0	1

* κ = 0.655 (weighted 0.738). 0 = no splatter, 1 = light splatter, 2 = heavy splatter. AGP indicates aerosol-generating procedure.

coefficient of interrater reliability between the 2 examiners was calculated.

RESULTS

When AGPs were performed, Glo Germ was evident on the face, body, arms, and legs of the dentist and dental assistant (Table). The Cohen κ coefficient of interrater reliability score was 0.655 (weighted 0.738), which demonstrated substantial agreement between the 2 examiners.[15]

Figure 1 captures the extent of splatter as the air-water syringe was used with HVE. The majority of splatter on the dentist was seen on the hands and arms, whereas smaller amounts were seen on the face, body, and legs (Figure 2). The majority of splatter on the dental assistant was observed on the hands and arms, but a large amount of splatter was also seen on the legs. A smaller amount of splatter was noted on the dental assistant's body; however, no splatter was detected on the face (Figure 3).

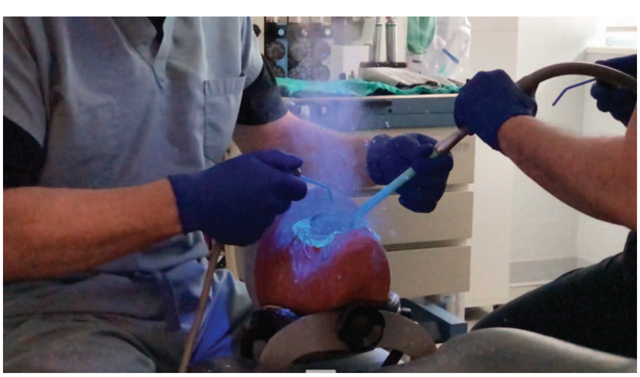

Figure 1. Splatter captured during the use of an air-water syringe and continuous high-volume evacuation suction.

When a cough was simulated, the splatter was seen on the anesthesiologist, dentist, and dental assistant. Glo Germ was clearly visible while being expelled in the cough simulator, with the plume traveling over 1 m above the orifice (Figure 4). A significant amount of splatter was seen on all surfaces of the anesthesiologist that were evaluated except for the shoes and the back, which had a small amount and no splatter, respectively. Also, Glo Germ was found behind the face shield and underneath the chin of the anesthesiologist. In addition, a considerable amount appeared along the top part of the face shield (Figure 5). On the dentist and dental assistant, the simulated cough created spray patterns in areas that were clear of Glo Germ contamination during AGPs, such as the crown of the head, back, and shoes.

DISCUSSION

In this investigation, when AGPs were performed, the splatter patterns observed on the dentist and dental assistant were consistent with previous studies.[16,17] AGPs produced a significant amount of splatter on the dentist's arms and the dental assistant's arms and legs despite the continuous use of HVE. The HVE suction was being held in a fashion simulating normal clinical care, which was as close to the plume as possible. Although the dental assistant did not have any Glo Germ contamination noted on the face, the dentist did have a small amount on the face. This evidence supports the inclusion of long-sleeve gowns and face shields as part of the PPE required for the dentist and dental assistant.

When a single cough was simulated, the dentist and dental assistant had more splatter than that observed with AGPs. The contaminated areas included the crown of the head, back, and shoes of the dentist and

Figure 2. Splatter on dentist after aerosol-generating procedures, with the majority evident on arms.

dental assistant. The anesthesiologist had a large amount of splatter visible in all areas except for the back. Interestingly, splatter appeared above the eyebrow and underneath the chin of the anesthesiologist despite the face shield, which may be a consequence of particles falling through the ventilation holes of the foam cushion (Figure 5) or the angulation of the face shield with respect to the simulator. There was also heavy splatter on the crown of the head and top of the face shield that could lead to self-contamination during doffing. Additional headwear, like a bouffant cap worn over the top of the face shield, may reduce this risk.

The simulated AGPs and model used in this study reflect real clinical practice, but there are limitations that must be recognized. The study was conducted at a

Figure 3. Splatter on dental assistant after aerosol-generating procedures, with the majority evident on arms and legs.

single site in an operatory where dentistry and anesthesia is performed in an outpatient facility. As such, ventilation and airflow in this environment may not accurately reflect all dental offices, which may affect spray and aerosol contamination patterns. The duration of each AGP used was significantly shorter than a typical dental appointment, and therefore this study likely underrepresents the extent and level of splatter from AGPs. Given the resource constraints during the pandemic, our goal was to identify the potential extent of splatter with a simulation that replicates normal clinical care and, at the same time, to minimize the number of participants exposed to each other. Our health authority had mandated all nonessential contact outside of household members to stop in order to minimize potential spread of SARS-CoV-2.

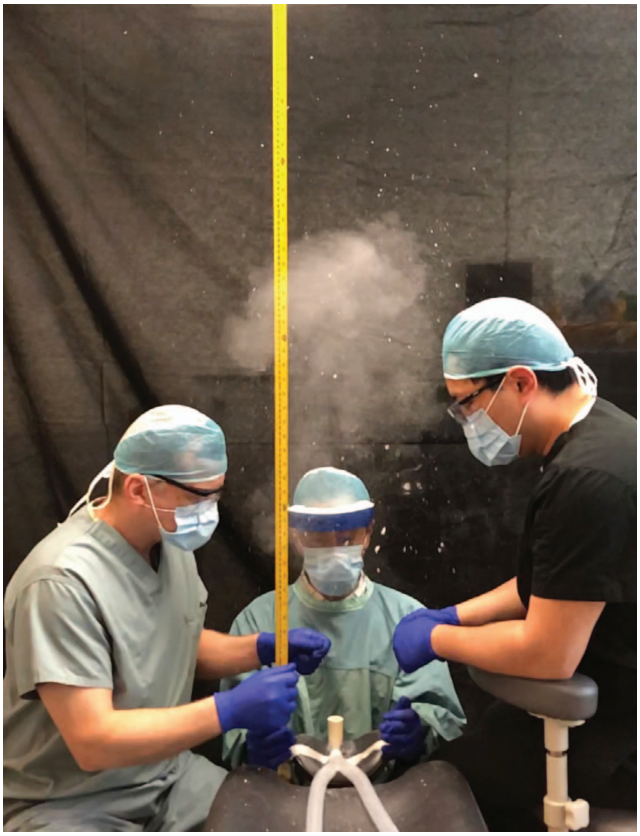

Figure 4. Plume and splatter captured during the simulated cough.

All participants at minimum wore droplet precautions throughout the entire study. Only one run of each simulated AGP and cough was performed and analyzed for these reasons. In addition, because there was no blinding of the participants, inherent biases may be present; however, all participants were practicing dentists and anesthesiologists familiar with all procedures performed.

The coughing simulation model aimed to replicate a natural cough. The cough expired volume and cough peak flow rate generated were within the measured values of a natural cough. Patients may try to suppress coughs during dental procedures, so this model may overestimate the splatter produced by a live patient. However, the distance the coughing plume traveled was consistent with other studies.[18]

The splatter on the chair, floor, equipment, and tray tables was not documented but was noted during cleaning between all procedures. Settling of the droplet and aerosol splatter may allow for fomite transfer to dental personnel and other patients. Evidence also suggests that dental aerosols may remain airborne anywhere between 30 minutes and up to 2 hours before settling and is heavily dependent on the air changes per hour in the room.[16,19] Ensuring sufficient changeover times between patients coupled with thorough cleaning of equipment and clinical surfaces between cases may reduce this risk.

Based on these findings, routine dental AGPs produce significant splatter, whereas a cough produces an even more extensive spread pattern. Accordingly, there may be an increased risk of spreading SARS-CoV-2 if a dental patient is positive and proper PPE and environmental infection controls specifically suited to mitigate AGP risks are not utilized routinely by all dental personnel. The extent of splatter also demonstrates the importance of proper doffing technique. With so many areas covered with splatter, care must be taken not to self-contaminate when doffing PPE, which has been recognized to occur in up to 90% of people.[20–22] A recent study showed high concentrations of SARS-CoV-2 RNA in aerosols located in the doffing areas of 2 hospitals.[23] Care should be taken to follow proper sequencing for donning and doffing PPE, with visual aids posted as a reminder.[24,25]

CONCLUSION

This study confirms that AGPs produce significant splatter on the arms and legs of the dentist and dental assistants. In addition, this study demonstrates that coughing generates an even larger splatter pattern that includes the crown of the head and shoes of all staff. Although eye protection, masks, and gloves are universally worn, other items such as long-sleeve gowns, face shields, headwear, and shoe covers are not. With the ability of SARS-CoV-2 to live on fomites for an extended period, protecting all exposed areas would be prudent. Therefore, it is highly recommended that PPE cover dental personnel from head to toe and, most importantly, include face shields, bouffant/surgical caps, and shoe coverings to prevent cross-contamination between patients and staff in the dental clinic.

ACKNOWLEDGMENTS

The authors of this paper would like to thank Dr Andrea Esteves and the Faculty of Dentistry, UBC, for the use of the dental mannequin head and Dentoform.

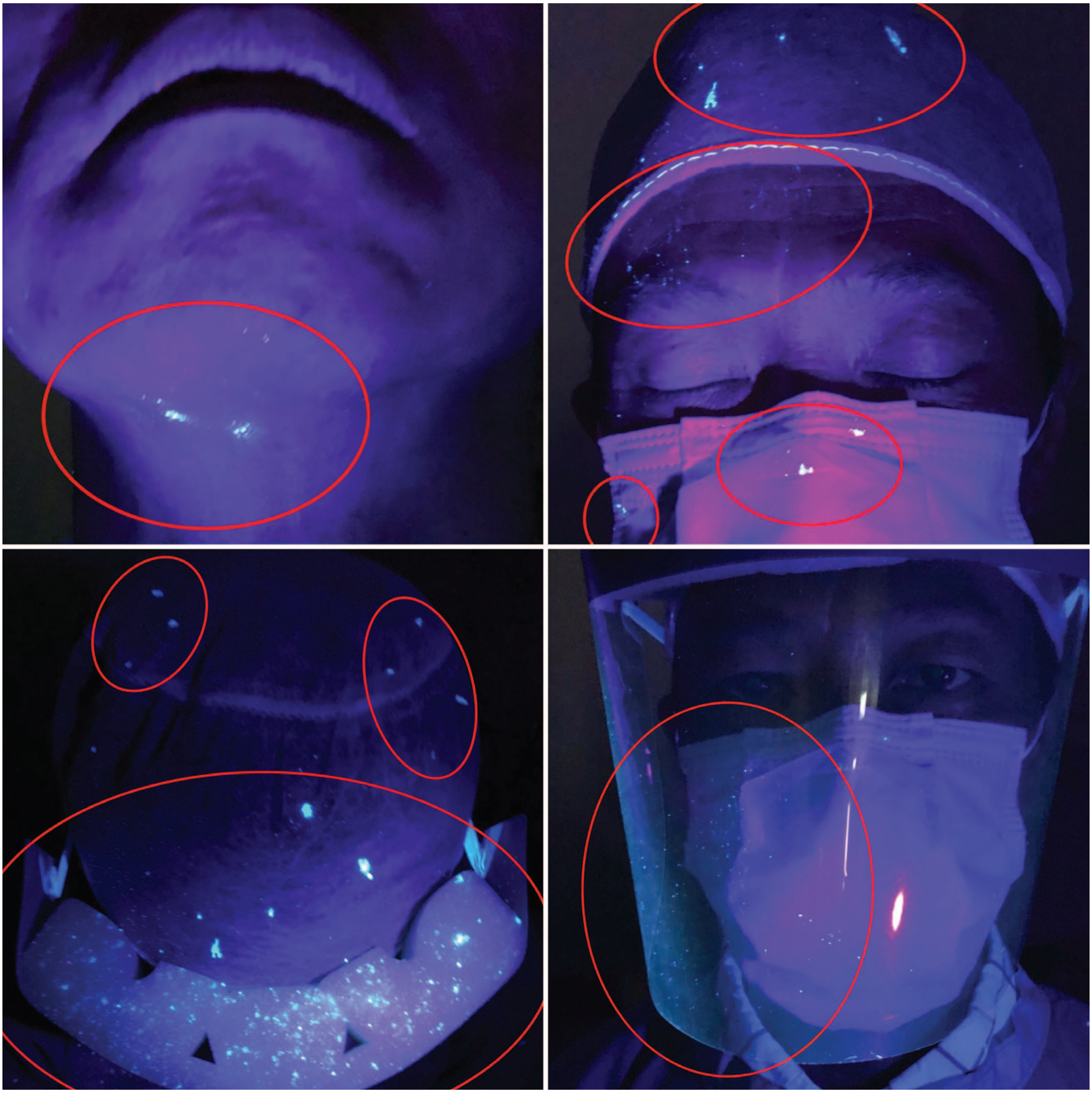

Figure 5. Splatter on anesthesiologist after a simulated cough, covering head, face, body, arms, and legs.

REFERENCES

1. Gamio L. The workers who face the greatest coronavirus risk. *New York Times*, March 15, 2020. Available at: https://www.nytimes.com/interactive/2020/03/15/business/economy/coronavirus-worker-risk.html?searchResultPosition=1. Accessed April 20, 2020.

2. Tran K, Cimon K, Severn M, Pessoa-Silva CL, Conly J. Aerosol generating procedures and risk of transmission of acute respiratory infections to healthcare workers: a systematic review. *PLoS One*. 2012;7:e35797.

3. Gupta JK, Lin CH, Chen Q. Flow dynamics and characterization of a cough. *Indoor Air*. 2009;19:517–525.

4. Randall CL, Shulman GP, Crout RJ, McNeil DW. Gagging and its associations with dental care-related fear, fear of pain and beliefs about treatment. *J Am Dent Assoc*. 2014;145:452–458.

5. Hanamoto H, Sugimura M, Morimoto Y, Kudo C, Boku A, Niwa H. Cough reflex under intravenous sedation

during dental implant surgery is more frequent during procedures in the maxillary anterior region. *J Oral Maxillofac Surg*. 2013;71:e158–e163.

6. Kohjitani A, Egusa M, Shimada M, Miyawaki T. Accumulated oropharyngeal water increases coughing during dental treatment with intravenous sedation. *J Oral Rehabil*. 2008;35:203–208.

7. Tung A, Fergusson NA, Ng N, Hu V, Dormuth C, Griesdale DEG. Medications to reduce emergence coughing after general anaesthesia with tracheal intubation: a systematic review and network meta-analysis. *Br J Anaesth*. 2020;124: 480–495.

8. Gudbjartsson DF, Helgason A, Jonsson H, et al. Spread of SARS-CoV-2 in the Icelandic population [published online ahead of print April 14, 2020]. *N Engl J Med*. doi:10.1056/ NEJMoa2006100

9. Glo Germ. Glo Germ [product information online]. Available at: https://www.glogerm.com/index.html. Accessed April 20, 2020.

10. Liu Y, Ning Z, Chen Y, et al. Aerodynamic characteristics and RNA concentration of SARS-CoV-2 aerosol in Wuhan Hospitals during COVID-19 outbreak. bioRxiv Web site. 2020. doi:10.1101/2020.03.08.982637

11. Morawska L, Johnson GR, Ristovski ZD, et al. Size distribution and sites of origin of droplets expelled from the human respiratory tract during expiratory activities. *J Aerosol Sci*. 2009;40:256–269.

12. Chao CYH, Wan MP, Morawska L, et al. Characterization of expiration air jets and droplet size distributions immediately at the mouth opening. *J Aerosol Sci*. 2009;40:122–133.

13. Center for Safety, Simulation and Advanced Learning Technologies, University of Florida Health. Open-source ventilator project: open-source, open-architecture ventilator design. Available at: https://simulation.health.ufl.edu/technology-development/open-source-ventilator-project/. Accessed April 2, 2020.

14. Hanamoto H, Morimoto Y, Kudo C, Boku A, Niwa H. Cough reflex under intravenous sedation during dental implant surgery is more frequent during procedures in the maxillary anterior region. *J Oral Maxillofac Surg*. 2013;71: e158–e163. doi:10.1016/j.joms.2012.12.014

15. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33:159–174.

16. Harrel SK, Molinari J. Aerosols and splatter in dentistry: a brief review of the literature and infection control implications *J Am Dent Assoc*. 2004;135:429–437.

17. Bentley CD, Burkhart NW, Crawford JJ. Evaluating spatter and aerosol contamination during dental procedures. *J Am Dent Assoc*. 1994;125:579–584.

18. Bourouiba L, Dehandschoewercker E, Bush JWM. Violent expiratory events: on coughing and sneezing. *J Fluid Mech*. 2014;745:537–563.

19. Dutil S, Meriaux A, de Latremoille MC, Lazure L, Barbeau J, Duchaine C. Measurement of airborne bacteria and endotoxin generated during dental cleaning. *J Occup Environ Hyg*. 2009;6:121–130.

20. Kang J, O'Donnell JM, Colaianne B, et al. Use of personal protective equipment among health care personnel: results of clinical observations and simulations. *Am J Infect Control*. 2017;45:17–23.

21. Osei-Bonsu K, Masroor N, Cooper K, et al. Alternative doffing strategies of personal protective equipment to prevent self-contamination in the healthcare setting. *Am J Infect Control*. 2019;47:534–539.

22. Tomas ME, Kundrapu S, Thota P. Contamination of health care personnel during removal of personal protective equipment. *JAMA Intern Med*. 2015;175:1904–1910.

23. Liu Y, Ning Z, Chen Y, et al. Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals. *Nature*. 2020. Available at: https://www.nature.com/articles/s41586-020-2271-3. Accessed April 28, 2020.

24. Vancouver Coastal Health. Donning (put on) personal protective equipment. Available at: http://ipac.vch.ca/Documents/Acute%20Resource%20manual/Donning%20PPE.pdf. Accessed April 28, 2020.

25. Vancouver Coastal Health. Doffing (put off) personal protective equipment. Available at: http://ipac.vch.ca/Documents/Acute%20Resource%20manual/Doffing%20PPE.pdf. Accessed April 28, 2020.