International Case Reports Journal
Short Commentary (ISSN: 2770-9647)

AGP, EOSD and UVGI – Learning From COVID-19 to Prepare for the Next Pandemic

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ABSTRACT

The outbreak of novel coronavirus (SARS-CoV-2) is associated with human-to-human transmission and constituted COVID-19 pandemic, a public health emergency of global concern. Knowledge and understanding of the effective control and disinfection protocols are critical for public health interests and the overall financial survival of the dental profession. Misinformation and outright lies are rampant during the COVID-19 outbreak. Similar misinformation can be found in the dental world. It is challenging to identify reliable research evidence and guidance during these times. For this reason, our group would like to share some critical insight for dental colleagues to evaluate for themselves. This paper focuses on Aerosol-Generating Procedures (AGP), Extraoral Suction Device (EOSD), and Ultraviolet Germicidal Irradiation (UVGI). With the introduction of effective SARS-CoV-2 vaccines and possible medications, the pandemic, albeit with the onslaught of more infectious variants, appears to be under control and improving. However, given our previous experience with SARS, MERS, and other viral diseases, it is almost confident that a new and unexpected viral infection will emerge. Dental Health Care Workers (DHCW) can take what we have learned so far and prepare to handle the next viral pandemic attack.

Keywords: COVID-19; SARS-CoV-2; Dental; vaccine

Citation: *Daniel CN Chan, Alireza Sadr, E R Schwedhelm, Larry Le, Densen Cao. AGP, EOSD and UVGI – Learning From COVID-19 to Prepare for the Next Pandemic. Int Case Rep Jour. 2022;2(6):1-15.*

Received Date: 23 April, 2022; **Accepted Date:** 28 April, 2022; **Published Date:** 30 April, 2022

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INTRODUCTION

The outbreak of novel coronavirus (SARS-CoV-2) is associated with human-to-human transmission and constituted COVID-19 pandemic, a public health emergency of global concern.[1] The virus was identified in the saliva of infected patients, and Dental Health Care Workers (DHCW) faced an enormous unknown risk of occupational

exposure.[2] Since saliva and Aerosol-Generating Procedures (AGP) play a role in the transmission of SARS-CoV-2, the ADA and other agencies mandated dental practices to only provide emergency and essential care, postponing elective treatments.[3] With the reopening of routine dental care, DHCW must adequately protect themselves and assure the public that it is safe to resume dental care. The anticipated increase in overhead with anticipated lower patient volume could make it financially unsustainable for dental practices. Knowledge and understanding of the effective control and disinfection protocols are critical for public health interests and the overall financial survival of the dental profession.

Centers for Disease Control and Prevention (CDC) and American Dental Association (ADA) guidelines recommended possible management of aerosol-generating procedures (AGP).[3,4] Use of rubber dam in combination with High-Volume Evacuator (HVE), hand instrumentation, and anti-retraction valves for treatment waterlines/handpieces are all strategies recommended to help minimize aerosols. Despite the lack of evidence-based information on COVID-19, some dental clinics across the United States have already made investments to upgrade safety equipment, such as air purifiers and vacuum systems. Therefore, there is an urgent need to evaluate these untested strategies for reducing aerosol generation.

A Misinformation Campaign?

Due to the novelty of SARS-CoV-2, the current primary and translational research lack the necessary data on reducing and managing bacterial and viral pathogens in AGP. The pandemic created an opportunity for fraudulent activities by those seeking to take financial gains quickly. The Food and Drug Administration (FDA) and the Federal Trade Commission issued a list of warning letters in early November 2020, including two companies selling fraudulent COVID-19-related unapproved and misbranded consumer goods.[5] One company sold products labeled to contain silver with misleading claims that the products can mitigate, prevent, treat, diagnose or cure COVID-19 in humans. Another company sold an antimicrobial facial spray with similar misleading claims. There are currently no FDA-approved products to prevent COVID-19 from an infection control point of view. The FDA requested that both companies immediately stop selling these unapproved and unauthorized products. These are just two blatant examples of unscrupulous merchants taking advantage of an unsuspecting public. Misinformation and outright lies are rampant during the COVID-19 outbreak.[6,7]

Similar misinformation can be found in the dental world. A survey of 54 studies on COVID-19 and dental aerosols published between 2019 and 2020 indicated that most studies were published in open access mode and lacked proper peer review. In addition to the explosion of information available online and through social media, even those published in reputable journals are in the form of “Opinions” or “Letters to Editors” and in pre-printing mode.[6] The lack of proper review and the vested editorial process has caused much confusion and contradiction among publications. It is challenging to identify reliable research evidence and guidance during these times.

For this reason, our group would like to share some critical insight for dental colleagues to evaluate for themselves. This paper focuses on AGP, Extraoral Suction Device (EOSD), and Ultraviolet Germicidal Irradiation (UVGI).

Dental AGP and Airborne Transmission of SARS-COV-2

Dental rotary instruments and ultrasonic devices are the primary means of aerosol production during AGPs. High-speed air-turbine dental hand pieces can reach speeds as high as 420,000 rpm, and electric hand pieces can reach up to 200,000 rpm. Although their rate may drop as much as 40% or more once their burs hit a surface, the linear speed of the aerosols generated can be between 34 ft/s and 68 ft/s (Table 1). The inherent speed plus the mass of the spatter may make it impossible for the traditional dental suction or HVE to capture all of the generated aerosols. Once an aerosol is generated, a substantial bioburden of SARS-CoV-2 virions can theoretically become suspended, but the aerosol may move about in the air for some time. The aerosols can remain in the air after the patient has been dismissed and a new patient has been admitted, as the airborne transmission was the main transmission route of the SARS-CoV-2 in the indoor cases studied.[8]

RPM	Linear Speed			
	ft/s	mi/h	m/s	km/h
200,000	34.36	23.43	10.47	37.7
400,000	68.72	46.85	20.94	75.4
600,000	103.08	70.28	31.42	113.1
1,000,000	171.79	117.13	52.36	188.5
Note: the linear speed (m/s) = RPM/60*π*Rtool Rtool is roughly of 1mm range				

Ft/s = foot per second; mi/h = Miles per hour; m/s = meter per second; m/h=kilometer per hour.

Table 1: Relationship between escape velocity (linear speed) and RPM of the high-speed hand piece.

Furthermore, an appropriate decontamination method of SARS-CoV-2 carried via AGP onto different surfaces has not yet been adequately evaluated.[9] As of today, COVID-19 has not been tested during aerosol experiments,[10] while there is one study performed concerning SARS CoV-1. Another study used transmissible gastroenteritis virus (TGEV) of pigs as a surrogate for the SARS virus[11] as their physicochemical properties are similar. Although TGEV has been utilized previously as a SARS CoV-1 surrogate for genome expression studies,[12] it has not been used in studies investigating the sampling and behaviour of viral aerosols.[13-14]

Currently, primary and translational research data are lacking in reducing and managing bacterial and viral pathogens in AGP. It is believed that the most effective method shall be to remove splatter and aerosol by AGP at the source before these contaminants reach practitioners.

Rubber dam usage, HVE and IOSD

In a recent survey by The Dental Practice-Based Research Network (DPBRN), data on 9,890 consecutive restorations done in previously unrestored tooth surfaces from 5,810 patients indicated 63% of general dentists did not use a rubber dam for any restoration in the study.[15] Using a rubber dam in combination with an HVE is one of the control measures recommended in recent CDC and ADA guidelines for reducing aerosol production.[3-4] Rubber dam use alone may not eliminate aerosols produced during an AGP. It can lessen a load of pathogens generated and their spread. The shape of the finished rubber dam can act as a reflector and direct the aerosol outwards as an unintended consequence if a barrier is used alone. (Figure 1)

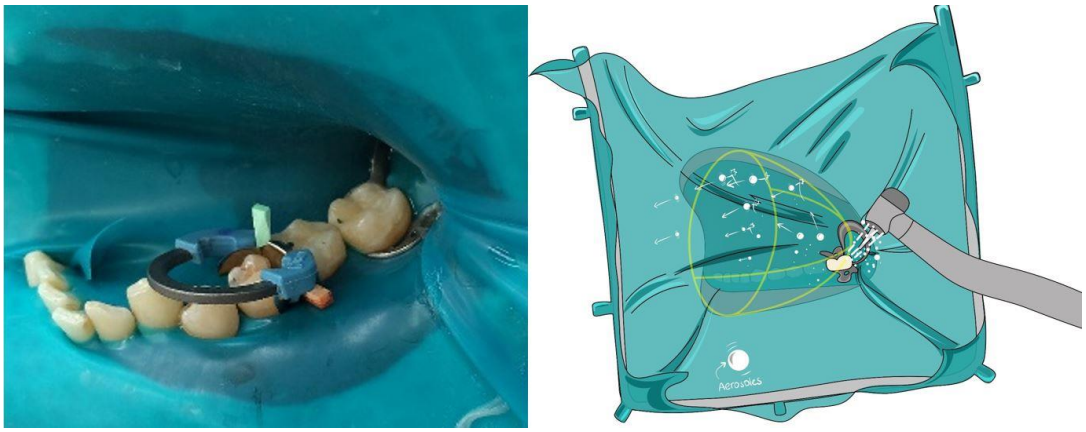

Figure 1: Rubber dam may form a reflective funnel and bounce back aerosols from high-speed hand pieces. If teeth and saliva are already contaminated with SARS-CoV-2, they can be suspended in the aerosols even after rubber dam placement. Some protocols call for rinsing with mouthwashes to reduce viral loads before dental procedures.

Intraoral Suctioning Devices (IOSD) has been proposed for use by general dentists who may not be using the traditional rubber dam procedure. Such systems may have a higher dentist and patient acceptance because of ease of placement and offer some advantages of rubber dam placement.[16] A study showed that isolation with the combination of the dental dam and HVE or with an IOSD system aided in the reduction of spatter during dental procedures compared with the use of HVE alone.[17] It should be noted that this study showed that the microbial content of the aerosol and the spatter produced with the IOSD was higher and more diverse than that with the dental dam and HVE combination. None of these methods eliminated the contamination. Therefore, further control of the AGP at both chair side and at strategically positions is required, and the use of the rubber dam and HVE or IOSD should be complemented with EOSD to be effective.

Methodology to evaluate AGP

Almost all dental procedures generate aerosols. When dentists use dental hand pieces, ultrasonic devices, or air/water syringes, they generate aerosols that mix patient body fluids (saliva, blood, crevicular fluid, pharyngeal secretions) and water from the devices.[18-19] These aerosols are propelled into the surrounding air as droplets. They range in size from visible droplets to less than one micron. Dental aerosols can travel up to six feet from the patient's mouth and can remain suspended in the air for up to 30 minutes.

Published data indicate that AGP from the oral cavity can produce a many-fold increase in Colony-Forming Units (CFUs) of bacteria compared to pre-and post-operatively.[20-22] Aerosols in the form of 0.5 µm -10 µm have a tremendous potential to penetrate the respiratory passages and the lungs and possess a more extraordinary ability to transmit disease. COVID-19 is reported to be 0.12 µm in size and thus is very infectious.[23] Proper forms of PPE and aerosol reduction are crucial in preventing human-to-human transmission. A recent publication from The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) reviewed several environmental settings, including cruise ships, airlines, buses, call centers, hospitals, and restaurants after COVID spread, and offered beneficial suggestions.[24]

Various investigators, including our group, have used smoke generating machines to illustrate the efficiency of high vacuum evaluations (Figure 2). Although the method is very visual and demonstrates well to the general public, it is difficult to quantify and publish as data. Smoke generating machines employ sodium chloride (molar mass 58.4428 g/mol) compared to water with a molar mass of 18.01528 g/mol. Typical dental aerosol's molar mass, including saliva, blood, crevicular fluid, and pharyngeal secretions, is predicted to be between.

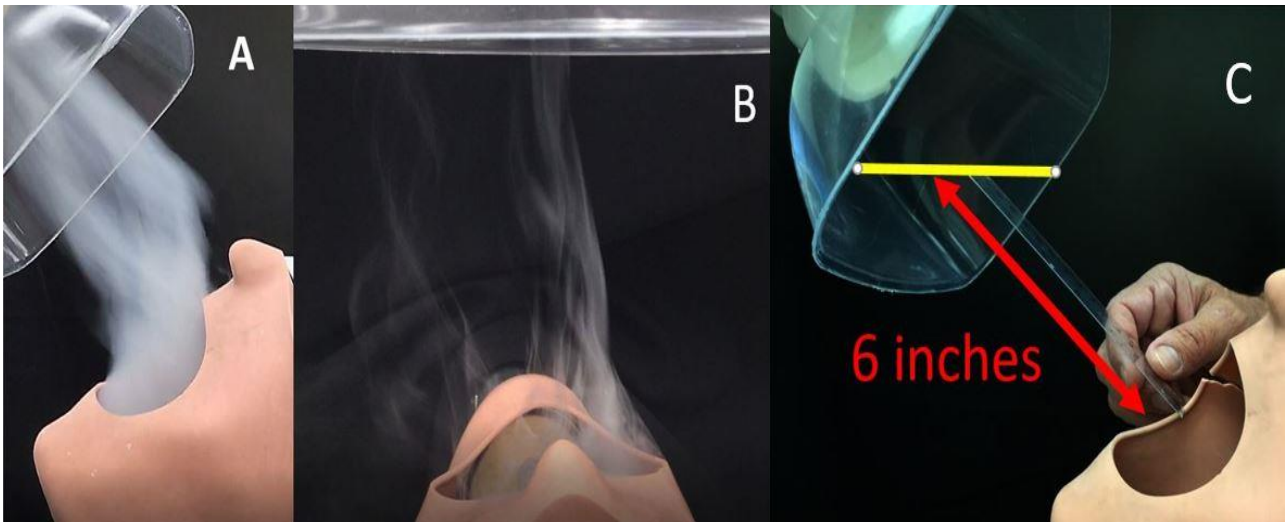

Figure 2A & B: Smoke generator is excellent for visual observation but may not represent an accurate picture. It may overestimate the effectiveness of EOSD. Other manufacturers also used humidifier vapour stream to illustrate the effect.

Figure 2C: 4-6 inches has been recommended as the distance between the shield and the patient's oral cavity. Size, position (distance), and orientation of the shield is also essential to minimize aerosols escaping.

In addition, the smoke generated is essentially passive with minuscule mass and velocity and can be evacuated by suction with ease. On the other hand, the aerosols generated by hand pieces and ultrasonic instruments have both mass and velocity. The liner speed related to the RPM of hand pieces is shown in Table 1. High-speed hand pieces will generate aerosol traveling at 171 ft/s and have some mass, so EOSD will not be as effective as passive smoke.

When aerosol is generated, it can remain in the air after the patient has been dismissed and a new patient has been admitted to the treatment room. This risk currently exists in all dental practices worldwide but is higher in dental school environments with hundreds of dental cubicles. Many patients are being treated simultaneously, and aerosol suspension can be a source of cross-contamination and infection.

UWSOD currently insists that all incoming patients be screened and tested for SARS-CoV-2 if we perform AGP. This screening seems like a very harsh requirement compared to outside practices and did cause a drop in patient visits. However, our numbers are gradually climbing back up to 80% of the pre-COVID time with our focused devotion to patients and operator's safety. It seems that we are in a better position than other schools.

One study by a group of researchers came the closest to simulating a clinical situation to test the effectiveness of various suction devices.[20] The study was conducted through the following protocol: placing a fluorescing dye in the waterline of the high-speed hand piece; a high-speed hand piece procedure was performed, as usual, using a manikin head analog; the spatter was measured by tracing of the dye and aerosol with particle sizes of 2.5um or less, using a particle counter on the operator's face area. A variety of devices, including High-Volume Evacuators (HVEs), isolation devices, a new innovative cheek retractor, and chairside extra oral suction devices, were tested. The results showed that the only device that can remove splatter and aerosol is a chairside extra oral suction device with a 12-inch collection cup positioned 8 inches from the operating site. This is in agreement with our results when we placed the collection cup 6 inches from the operating site. Even with that short distance, particulates were still able to escape (Figure 2C). We have to balance particulate capturing efficiency with visibility interference with normal dental procedures.

EOSDs

One study evaluating bacterial aerosols in dental practice concluded that the area that becomes contaminated during dental procedures is far more significant than previously thought and encompasses the whole room.[25] To combat this contamination, filtering the operatory by EOSD may be effective if the machine is designed correctly.

Devices that place a vacuum closer to the origin of the aerosol have been rapidly developed and brought to market. Many designs of the EOSD are currently available (Figure 3 B & C).

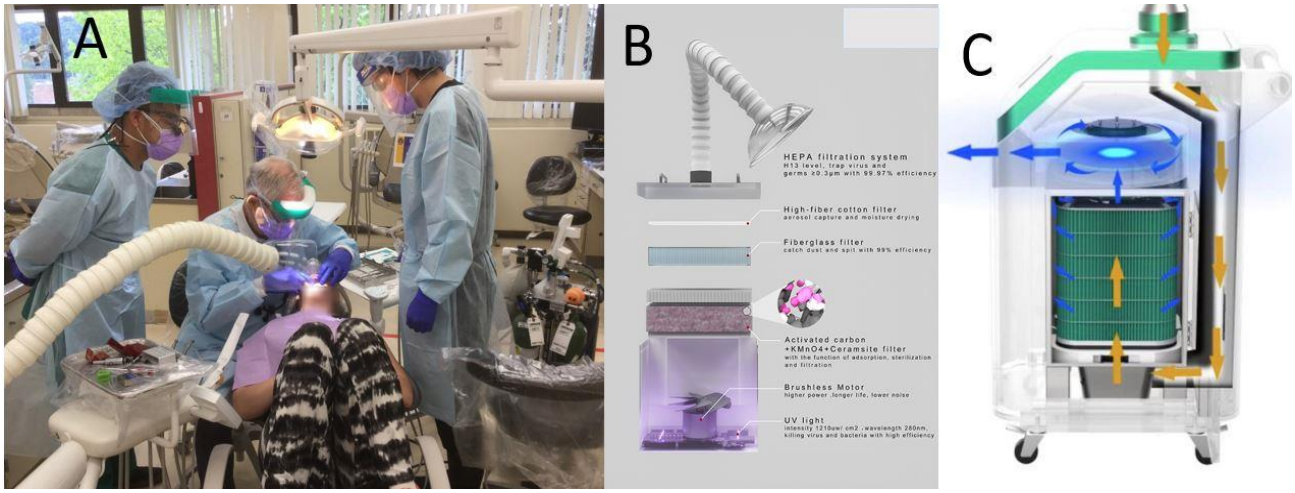

Figure 3A: The EOSD system placed close to the source of AGP has been proven to be most effective but will not eliminate aerosol 100%.

Figure 3B&C: Many different designs are available on the market. Practitioners are encouraged to evaluate salient characteristics.

Dental professionals must be aware that not all extraoral suction is created equal. To our experience, the following characteristics are what one should look for:

- A large collection cup/shield is critical to cover the entire pattern of splatter and aerosols exiting the mouth
- At least three cubic meters per min flow (>3 M^3/min)
- Higher than 1200 Pa suction power (>1200Pa)
- Multistage filters – e.g., initial moisture control, HEPA (Certified and validated), active carbon
- Proper UVC light is an additional benefit
- Low noise level below 70 dB at maximum power (<70dB)
- Articulated arms that create dead space and reduce suction power will not be successful in the long term
- Ease of maintenance; replacement of filters should be practical for a busy practice
- Relevant certification by authorities is a requirement.

It is recommended to place the suction cup of the EOSD about 8 inches in front of the patient. In addition to distance from the patient's mouth, the size of the shield also plays a role. The manufacturer recommends 8 inches and 12-inch cup/shield to eliminate 100% spatter and 99.8% aerosol.

Like the previously mentioned shield manufacturer, this manufacturer claimed a 99.97% reduction of 0.2 *u*m size particulates and recommended placing the receptacle shield 4 inches in front of the patient. Although the reduction

is impressive, the distance may not be clinically convenient for the dentists and dental hygienists to operate. We performed our evaluation at 6 inches in front of the patient (Figure 3 C).[26-27] As noted in Figure 4, there are peaks of red (above green background) in our particulate evaluation. Our latest results show an improvement of 68% in aerosol reduction when space filtration units are used in clinic aisle away from the operatory; however, the reduction is not as high as promised in the theoretical specification of 99.8%.

Figure 4: Even with the operation of EOSD, there are peaks of red (high particulates) above the green background level, which means that aerosols (particulates) are escaping.

We would like to emphasize the distinction between HVE and EOSD. DHCW are used to HVE, such as saliva ejectors and high-volume suction tubes. The HVE's main target is to remove fluid accumulation near the site of operation. EOSDs, on the other hand, are designed to capture aerosols and infectious material at the source with suction adjacent to the patient's mouth for immediate capture. Moreover, we propose to further control AGP by EOSD air purification both chairside and at strategical positions.

Dentistry needs a solution that will work in all practices, large and small. It is further recommended that EOSD units be used for additional in-room air purification when it is not used at the chair. If the airflow rate is 3.5 m^3/min, the unit can turn standard room (8 x 8 x 10 ft) air 11 times per hour.

Although the EOSD has been recognized as an effective device to remove aerosol, the cost for multiple cubicles in a dental practice can be expensive. Most of the units on the market now are large and unwieldy. As seen in Figure 3A, the operatory can be crowded with personnel and other equipment such as nitrous oxide equipment. In a small space, the EOSD can be noisy. From the patient's perspective, the extended arm and shield placed close to the face can be construed as invading and frightening.

It must be cautioned that the EOSD devices should come with certifications from governing authorities. Many of them are designed and sold globally, with different countries have varying standards and guidelines. Claims that

any such device will eliminate SARS-CoV-2 must be taken with a grain of salt. Some floor models with incorrect air intake design can unintentionally spread harmful aerosol. (Figure 5 A & B) At best, the device can filter sizes of particulates similar to SARS-CoV-2. Notice that some manufacturers claim that the filter can be as effective as a 99.97% reduction of 0.3 *u*m size particulates based on a HEPA (High-Efficiency Particulate Air) filter. Although the size of the SARS-CoV-2 is reported to be of the size 0.12 µm, HEPA filters remove particles smaller and larger than 0.3 um at greater efficiency.

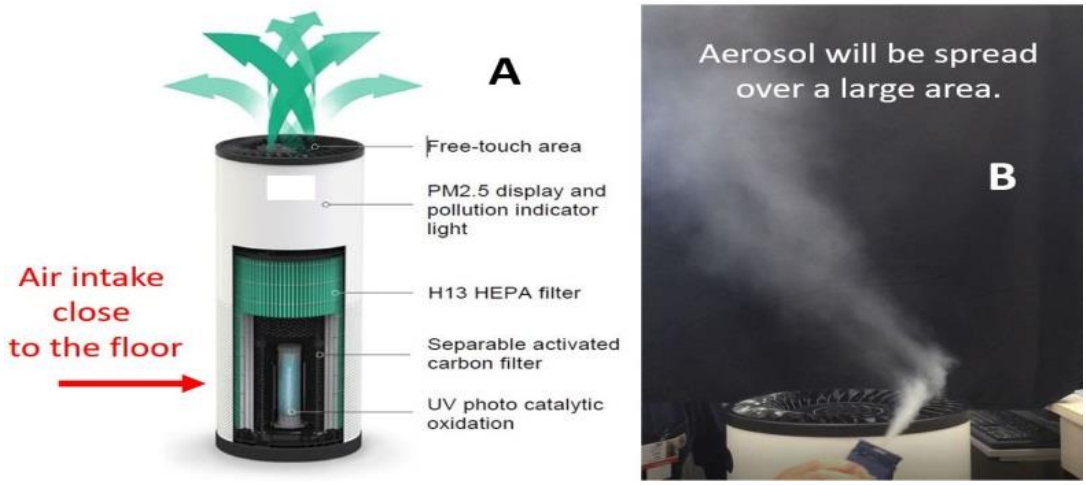

Figure 5 A: Incorrect design of floor model can unintentionally spread harmful aerosol.

Figure 5 B: Smoke generator study performed by authors LL & DCNC. Although air-purifying capabilities are satisfactory, such units can best be placed away from AGP areas.

It should be noted that the risk of exposure stems from the location of the device, the position of the exhaust/discharge, and filter fit and security inside the device. Our particulate study in a real clinical setting indicated that the operator site is most at risk.[26-27](Figure 6 & 7).

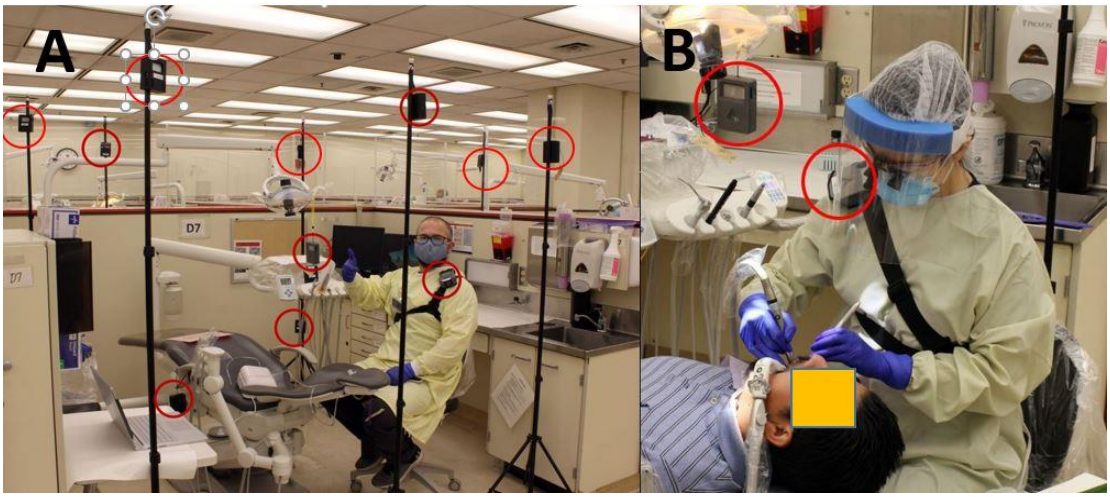

Figure 6 A: Particulate study partnered with the UW College of Mechanical Engineering team in a real clinical setting. Red circles indicate detectors.

Figure 6 B: Data collected while the operator is working on a live patient.

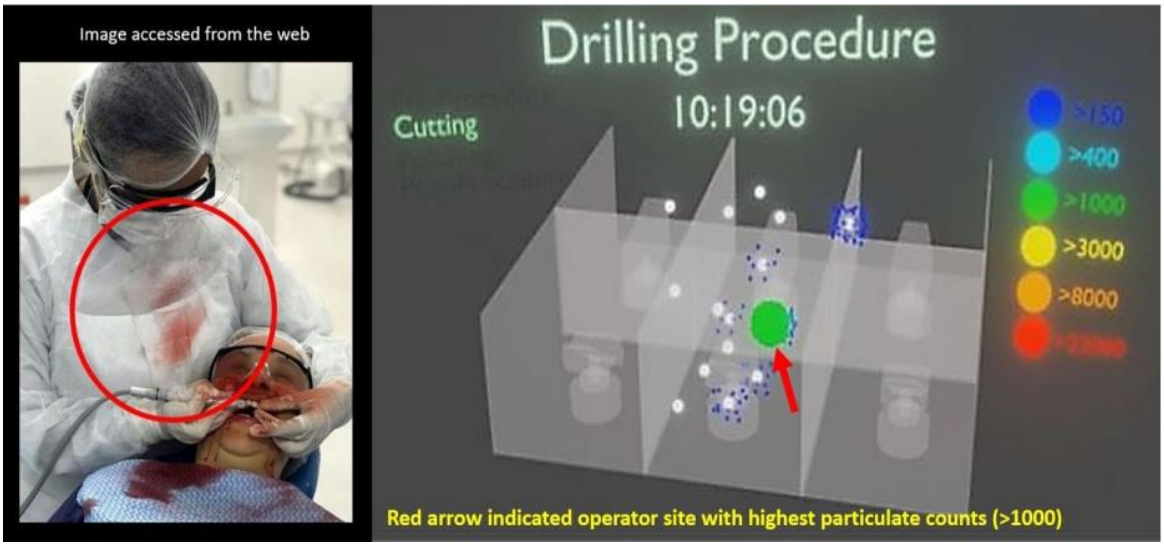

Figure 7 A: Dye indicator study accessed from the web showing the operator is at highest risk.

Figure 7 B: Particulate evaluation indicates that the most elevated risk site is at the operator position.

Based on current understanding, we recommend using EOSD during AGP, disinfect surrounding surfaces using surface disinfection or UVC, use EOSD to purify the air for 15 to 20 min before subsequent patients. Practitioners shall use a face shield, level II or above medical masks, and a fully covered suit ideally from head to toes or at least fully covered the upper body.

Many manufacturers only publish the filter efficiency rating but do not validate the filter efficiency with the filter inside the device under normal operating conditions. For these reasons, there is still an unknown inherent risk. We tested two types of air purifiers floor models in actual clinical settings and found the experimental efficiency well short of the manufacturer's claims (68% *Vs* 99.97% reduction). Additional UVC lights in the filtration path will be beneficial to kill the remaining virus to mitigate any additional unknown risks. We will address UVIC in the following section.

Proposed UV disinfection

Once the aerosols or droplets containing the viral pathogens are spread thru AGP, it is almost impossible to disinfect the operatory afterward. Decontaminating bacterial and viral pathogens carried via AGP onto different surfaces can be performed by handheld and ceiling-mounted UVGI. UV light sources can be produced by mercury lamps or Light-Emitting Diodes (LEDs). LEDs are a little more expensive but environmentally friendly. LEDs are solid-state and robust for a prolonged lifetime.

As with a small number of EOSD manufacturers, UV products are being marketed with unsubstantiated claims. Power, distance from the surface, and duration are all variables that haven't been thoroughly studied. Currently, many such devices are advertised and sold, but their efficacy is not known. Such a UVGI approach is innovative since routine disinfection procedures performed by hand are appropriate for patient-care areas in which AGPs are performed. A low-cost and straightforward protocol is paramount for increasing confidence and subsequent patient flow.

It has been shown that that far-UVC efficiently inactivates airborne aerosolized viruses, with a very low dose of 2 mg/cm^2 of 222-nm light inactivating >95% of aerosolized H1N1 influenza virus.[28] In one of the UVGI applications, it has also been shown that A high-power UVGI light kills poliovirus with wavelength 200 – 280 and light output intensity of 15 Watt.[29] Although far-UVC light (207 – 222 nm) cannot penetrate even the outer (non-living) layers of human skin or eye, it is still prudent to incorporate motion sensors activated to avoid human exposure. It must be cautioned that UV lamps should NOT be used to disinfect hands or other areas of your skin. Cleaning your hands with an alcohol-based hand rub or washing your hands with soap and water remains the most effective way to remove and deactivate the virus.

One recent study looking at disinfection of coronavirus concluded that sensitivity of human Coronavirus (HCoV-OC43) was wavelength dependent with 267-279 nm > 286 nm> 297 nm.[29] We performed a pilot study evaluating three UV devices claimed to be antibacterial and antiviral (Figure 8).[30] All three devices claimed to be utilizing UVC of 253.7 nm; the significant difference was the power output of the devices. It was evident from our pilot study result on *Porphyromonas gingivalis* that power, distance, and duration are of utmost importance.

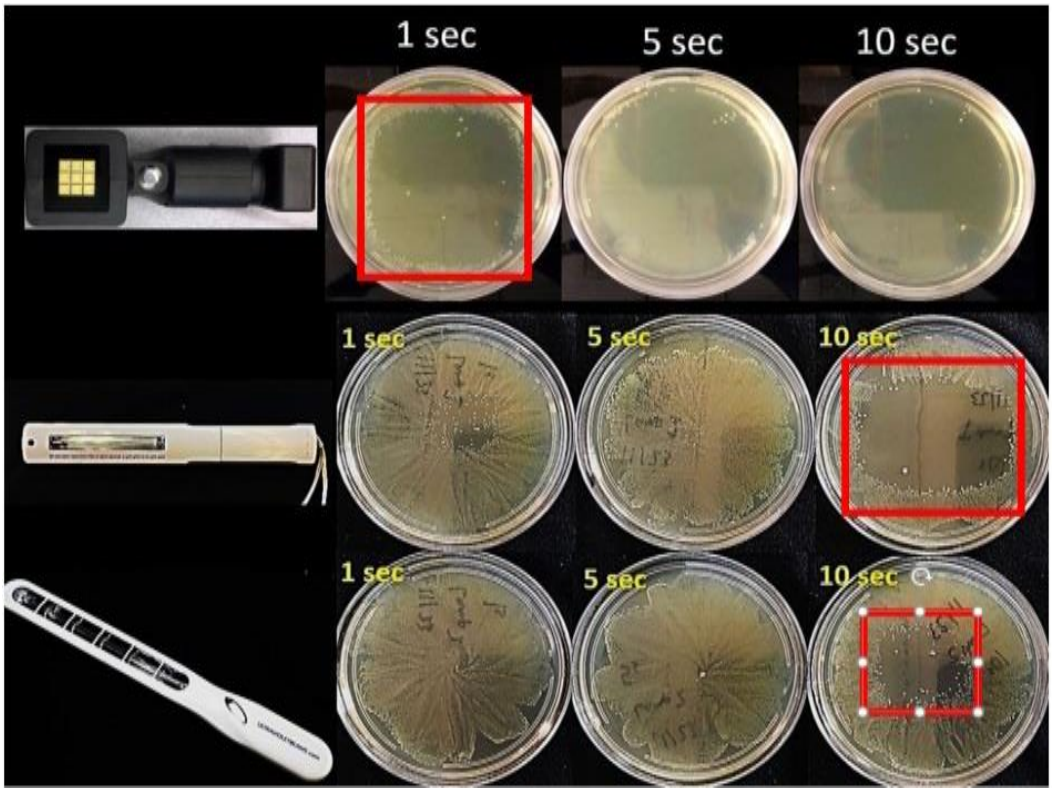

Figure 8: A pilot study shows that power output, distance, and duration are of utmost importance in the antibacterial property. The red rectangle indicates the area of growth inhibition. The first UVGI device showed effectiveness with only 1-sec exposure, while the others showed various efficacy only after 10-sec exposure.

We concluded that many of the UVC lamps sold for home use are of low dose, so it may take more prolonged exposure to a given surface area to provide effective inactivation of a bacteria or virus. Far-UVC light (222 nm) radiation has been shown to destroy the outer protein coating of the SARS-Coronavirus, which is a different virus from the current SARS-CoV-2 virus. The destruction ultimately leads to the inactivation of the virus and safely inactivates airborne human coronaviruses. However, FDA has not officially claimed that far-UV can be effective in inactivating the SARS-CoV-2 virus. Most published studies were done with surrogates for the SARS virus of similar sizes.[31-35]

UV radiation can only inactivate a virus if the virus is directly exposed to the radiation. Therefore, the inactivation of viruses on surfaces may not be practical due to blocking UV radiation by soil, such as dust, or other contaminants such as bodily fluids. We believe that continuous, very low dose-rate far-UVC light in indoor public locations is a promising, safe and inexpensive tool to reduce the spread of airborne-mediated microbial diseases.

It must be emphasized that UV radiation is not all equal. It is classified into three primary types: ultraviolet A (UVA), Ultraviolet B (UVB), and Ultraviolet C (UVC). These groups are based on the measure of their wavelength, where UVA is 315- 399 nm, UVB is 280-314 nm, and UVC is 100-279 nm. Although implicated in skin aging and the risk of skin cancer, UVA radiation is less hazardous than UVB radiation. Still, UVA is also significantly (approximately 1000 times) less effective than either UVB or UVC radiation at inactivating other SARS viruses.
Other factors that are of importance in using UVGI are:

- Direct exposure of skin and eyes to UVC radiation from some UVC lamps may cause painful eye injury and burn-like skin reactions. Never look directly at a UVC lamp source, even briefly. This is why UVC is preferred to be deployed and used as an upper room source to prevent eye contact
- Some UVC lamps generate ozone. Ozone inhalation can be irritating to the airway.
- UVC can degrade certain materials, such as plastic, polymers, and dyed textile.
- Some UVC lamps contain mercury. Because mercury is toxic even in small amounts, extreme caution is needed to clean a lamp that has broken and disposes of the light. Some states, such as Washington, banned the use of UVC lamps containing mercury.

CONCLUSION

Rubber dam and HVE help reduce splatter and aerosol but are not near complete. EOSD close to the source of the aerosol is the primary approach and most effective way to lowering splatter and aerosols from AGP. EOSD needs multiple filtrations, including UVC light source to filter moisture, splatter, and aerosol, and kill the virus before the air exits the system. The size of the collection cup and distance from the mouth exit of EOSD is a critical factor. Many UVC lamps sold for home use are of low dose, so it may take longer exposure to a given surface area to potentially provide effective inactivation of a bacteria or virus.

With the introduction of effective SARS-CoV-2 vaccines, the pandemic appears to be under control and improving. However, given our previous experience with SARS, MERS, and other viral diseases, it is almost confident that a new and unexpected viral infection will emerge. DCHW can take what we have learned so far and prepare to handle the next viral attack.

ACKNOWLEDGMENT

- Data for the particulate testing was done after consultation and approval by the UWIRB committee. The process was deemed not related to human subject research since no patient information was collected and the procedure was part of routine dental care.
- The particulate study was partnered with the UW College of Mechanical Engineering team with Drs Igor Novosselov & Sep Makhsous as Co-I in real clinical setting.
- The UVGI pilot study was funded by a grant from the CAO group (DCNC PI).
- Diagram in Figure 1 was illustrated by Ms Kateryna Tonyuk.

- Authors are thankful to Mr. Amirnima Danaei for his contribution to the writing of this manuscript.

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