Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Investigation

Effectiveness of barrier devices, high-volume evacuators, and extraoral suction devices on reducing dental aerosols for the dental operator

A pilot study

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ABSTRACT

Background. The COVID-19 pandemic has increased the importance of minimizing exposure to aerosols generated during dental procedures. The authors' objective was to measure the aerosolized particles in the breathing zone of operators using several facial protection and filtration methods.

Methods. Twenty-one dentists performed maxillary anterior incisor veneer preparations using a microscope and drape and loupes with or without a face shield. In each test condition, the following 3 levels of filtration were tested: no filtration, a high-volume evacuator [HVE], and an HVE with an extraoral suction device. Measurements were made using a mass monitor attached to the operator's chest with inlet within 10 inches of the operator's face.

Results. The authors found that the microscope and drape provided the lowest levels of aerosolized particles compared with loupes with or without a face shield ($P < .001$). There was no detectable difference in the concentration of particles between operators wearing a face shield and wearing loupes alone ($P = .47$). The particles in each test condition were lowered when an HVE was used ($P < .001$) and further lowered with an extraoral suction device.

Conclusions. The findings of this study suggest that the use of a surgical microscope and bag barrier drape, HVE, and extraoral suction device result in the lowest concentration of aerosolized particles. The face shield did not appear to offer any protection from aerosolized particles. HVE and extraoral suction were effective in decreasing aerosols regardless of the type of facial protection used.

Practical Implications. Dentists can reduce exposure to aerosols with a drape, HVE, and extraoral suction.

Key Words. Aerosols; microscope; CDC; OSHA dental handpieces; filtration; SARS.

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Aerosolized particles resulting from dental treatments can pose a considerable risk of developing infection to dentists and staff members.[1-4] Aerosols are a suspension of solid or liquid particles in a gas, with particle sizes generally ranging from 1 through 100 μm in diameter.[1,5] The fine aerosol droplets generated from a high-speed handpiece can remain suspended in air and can contain infectious material.[2] Operators performing aerosolizing procedures can inhale these particles, putting them at higher risk of developing infection. This has been a persistent concern for the oral health care community; however, the COVID-19 pandemic has created renewed concern regarding aerosols, especially because the spread of COVID-19 is thought to be mainly from asymptomatic patients.[6-8]

Both aerosols and spatter are important concerns during dental procedures. In our research, we considered aerosols as particles smaller than 50 μm in diameter.[7] Spatter was defined by Miller and colleagues[9] as airborne particles larger than 50 μm in diameter. They stated that, owing to their size, gravity affected the particles, causing ballistic behavior.[9] Fine aerosol droplets

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generated with a high-speed handpiece are usually 5 μm or less in diameter and can remain suspended in air.[2,10] The combination of both aerosols and droplets (spatter particles) make up respiratory transmission particles,[11] and pathogens are not limited to 1 size particle,[12] even though the pathogen itself might be a particular size. We recognize that particles smaller than 10 μm are capable of reaching lower parts of the airway system and are therefore more likely to be involved in disease transmission.[12,13]

Methods of filtering particulates out of the air have been examined previously in the dental setting. Aerosol reduction has been tested in a laboratory setting with high-volume evacuators (HVEs)[14] and with high-efficiency particulate room air filtration devices.[15] Although various suction units have been touted as able to remove dental aerosols,[14] there has been little independent, third-party research testing these devices. Room-level filtration has been studied with negative-pressure rooms (that is, suction applied on an entire room)[16] and extraoral suction devices, such as a high-efficiency particulate room air filtration.[17]

The optimal method for providing protection from aerosolized infectious particles during dental treatments has not been established. These previous studies did not measure particulates in the breathing zone, which is defined by the Occupational Safety and Health Administration as within 10 inches of the operator's face.[18] Similarly, the Centers for Disease Control and Prevention (CDC) has suggested that dental staff members use face shields,[8] without supporting data regarding their effect on mitigating dental aerosols. Other groups, such as the Academy of Microscope Enhanced Dentistry, have suggested using surgical microscopes with barriers as a method of reducing aerosols to the operator, but the effectiveness of this method has not been evaluated.[19]

The optimal type of filtration device and protective facial covering for routine dental treatments should be based on exposure of the operator to aerosol particulates. We hypothesized that the use of a microscope and drape would be superior to the protection offered with a face shield, and that filtration devices would decrease operator exposure to aerosols.

METHODS

Twenty-one participants, which included 13 dentists and 8 dental students, were recruited from our area of practice and a regional dental school. Experience levels ranged from fourth-year dental students to experienced practitioners, including a prosthodontist, a periodontist, and an endodontist; the balance were general dentists. Only the endodontist and 5 of the general dentists had experience using a surgical microscope. Participants generated aerosols during veneer preparation procedures on a Kilgore International dental model of maxillary central and lateral incisors. These teeth were chosen because there is more potential spray of aerosols from anterior teeth versus posterior teeth.[20]

Particle measurement

We selected a Temtop PMD 351 Aerosol Mass Monitor (Elitech) to detect aerosolized particles. This monitor was chosen because it is compatible with wet aerosols, is wearable by the operator, and has a comprehensive range (1-, 2.5-, 4-, and 10-μm size and total suspended particles [TSP]) that is appropriate, according to the literature regarding particle size associated with COVID-19 transmission.[21] Mass monitors have a high correlation with other filtration-based measurements with insignificant bias and allow for faster and more convenient estimates of indoor particulate matter (PM).[22] We measured aerosol samples in the breathing zone of the operator, as defined by the Occupational Safety and Health Administration.[18] The mass monitor was worn in a radio vest (Swix), with the inlet nozzle positioned within the recommended 10 in from the mask of the operator[10,18] (Figures 1 and 2). The monitor takes 1 minute to obtain a new air sample, so all measurements were taken at least 1 minute apart.

At the beginning of each experiment, study participants would sit motionless in front of the manikin with all instruments in place. Three measurements were taken to determine the aerosols present in the ambient air around the dentist's breathing zone (preoperative test condition). In a separate series of experiments, the aerosol levels were also recorded in the ambient air at the foot of the dental chair with no aerosolizing procedures being performed. This measurement served as our control.

ABBREVIATION KEY

CDC: Centers for Disease Control and Prevention.
HVE: High-volume evacuator.
PM: Particulate matter.
PPE: Personal protective equipment.
TSP: Total suspended particles.

Figure 1. Author (W.D.R.) with surgical microscope and bag barrier drape, high-volume evacuator, and extraoral suction device.

Aerosol generation

The participant began a veneer preparation of the maxillary incisors on a dental model (Kilgore International Model 200 with throat/pharynx attachment OCC-W). The procedure was performed using a Brasseler 5878k tapered chamfer diamond bur in a dental high-speed handpiece (J. Morita) run at 275.79 kPa via a Midmark Continental delivery system. A high-speed handpiece was selected for aerosol generation because it is the aerosol-producing tool most commonly used by dentists and has been identified as a source of aerosol production and potential hazard.[2-4,6,7] Three measurements of the aerosolized particles were made before the initiation of aerosol generation. These measurements served as the baseline aerosol exposure if no filtration is used.

Air filtration and evacuation

After the baseline aerosolization level was obtained, an HVE was activated and used by the participant while the veneer preparation continued. We used a plastic HVE tube (Patterson Dental) attached to a Midmark rear delivery unit connected to a Midmark Classic Series suction unit delivering suction of −40 kPa (0.4 bar). Three measurements were taken after use of the HVE was initiated.

An extraoral suction device was then activated, with the opening of the intake tube of the FlexVac (IQAir) arm placed 20 cm from the manikin chin. The extraoral suction used was the IQAir HealthPro Plus with optional FlexVac arm attached. It was set at an airflow rate of 3,681.19 L per minute (130 cu ft/min).

Facial protection

In all experiments, the participants wore an N95 respirator covered with a surgical mask to minimize exposure to aerosols generated by the participant. Measurements for all filtration test conditions (preoperative, no filtration, HVE, HVE and extraoral suction) were made while the participant was using a surgical microscope (A-Series 4-step microscope, Global Surgical) with a barrier drape. The entire procedure was then repeated with the participants using their choice of loupes (Q-Optics 3.5x expanded view or similar) with full face shield or loupes alone. The combination of filtration devices and facial protection resulted in 8 total test conditions per participant. Three measurements were recorded for each test condition, for a total of 24 measurements per participant.

Figure 2. Author (B.C.O.) with face shield, high-volume evacuator, and extraoral suction device.

No live virus or bacteria were used to duplicate viral or bacterial loads. Control values of particles available for detection in the treatment room were measured with 3 sets of measurements from the Temtop PMD 351 Aerosol Mass Monitor before activation of any aerosols. This was an aerosol only study.

Measurements included particles detected in the ambient air in front of the manikin with the monitor placed on the bracket table attached to the continental arm of the delivery system and at the participant's face mask in the breathing zone (in back of the bag drape barrier for microscope use and under the face shield for loupe use). The aerosol mass monitor provided information on aerosols potentially escaping into the treatment room past the suction systems and gave information on the aerosols that were reaching the participants beyond their protective face shields.

Analysis

The differences between filtration methods and facial protection were examined using a Mann-Whitney *U* test. A threshold of $P < .05$ was used to determine statistical significance. The TSP measurement was used to determine the relative difference between test conditions.

All analyses were performed using R statistical programming language with the stats package, Version 3.6.1 (R Project for Statistical Computing).

RESULTS

Distribution and correlation of particles sizes

Measurements from the mass monitor showed the mass of the particles followed a non-Gaussain distribution (Figure 3). When separated according to particle size, the median density measurement increased as the particle size increased. The median density of the 10-μm particles was approximately 5 times greater than the 1-μm particles.

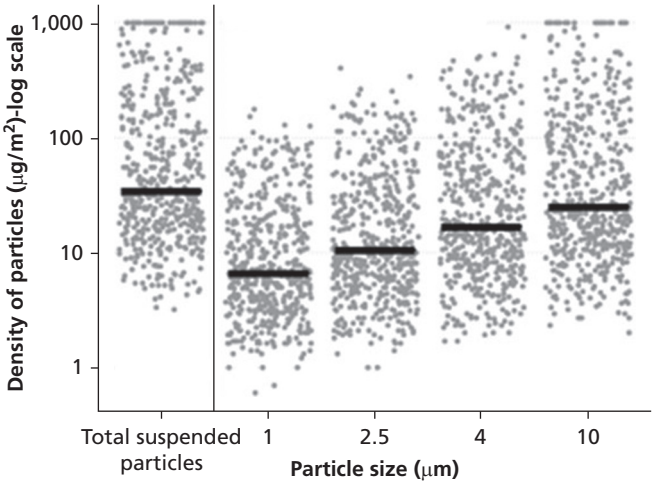

Figure 3. Measured density at various particle sizes. Black bars represent the mean of all measurements for each size.

There was a strong correlation among density measurements at each particle size (Figure 3). These correlations were strongest among similarly sized particle and decreased as size difference increased. However, the correlations remained statistically significant even between the smallest and largest particle sizes.

Particles density based on filtration type

The density of aerosols detected was highest when no filtration was used (Figure 4). The density of particles decreased when the HVE was used and was lowest when the HVE was used in conjunction with the extraoral suction device. The density of particles during the aerosolizing procedures was greater than preoperative levels.

Density of particles based on facial protection

The density of particles was lowest when a microscope and plastic drape were used (Figure 5). There was no statistically significant difference in density of particles between participants using loupes and a face shield compared with loupes only. The density of particles detected in ambient air measured at the foot of the chair was higher than behind the microscope, but no statistically significant difference was found between the face shield or loupes.

Comparison of TSP between test conditions

The values obtained for TSP varied considerably among test conditions. The preoperative test condition was always the lowest because no aerosolizing procedures were being performed (Figure 6). In the microscope and drape test condition, the density of particles was detected at every stage. In each set of experiments, there was a decrease with HVE relative to no filter, and a further decrease with HVE and extraoral suction. The analysis was slightly confounded because the upper limit of the mass monitor was exceeded for the experiments with the loupe and with the face shield when there was no filtration or suction (Table 1).

Table 2 provides the average of aerosolized PM for every test participant in each category. Aerosol amounts for participants the face shield ranged from 3 through 7 times the PM or TSP versus the bag barrier drape with the surgical microscope.

DISCUSSION

Aerosols were detected using a Temtop PMD 351 Aerosol Mass Monitor. This monitor was chosen because it is compatible with wet aerosols, is wearable in a vest pack, and has a comprehensive range (1-, 2.5-, 4-, and 10-μm size and TSP) that is appropriate, according to the literature regarding particle size associated with COVID-19 transmission.[23-25] Mass monitors have a high correlation with other filtration-based measurements with insignificant bias and allow for faster and more convenient estimates of indoor PM.[22,26,27]

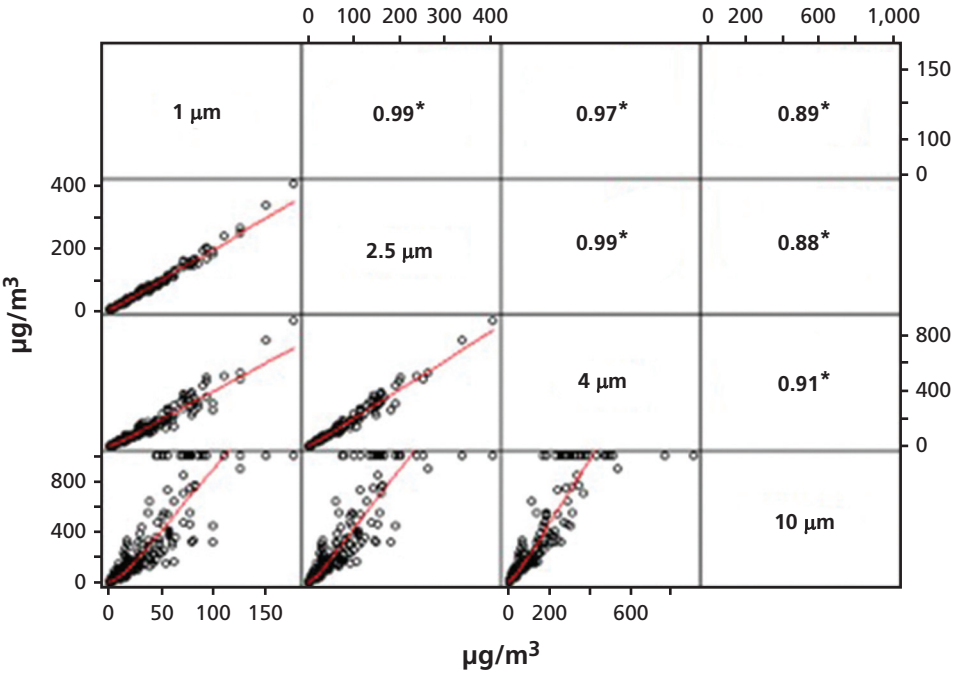

Figure 4. Correlations between density measurements among different particle sizes. The upper panels provide the correlations using the Pearson correlation coefficient and statistical significance. * $P < .001$.

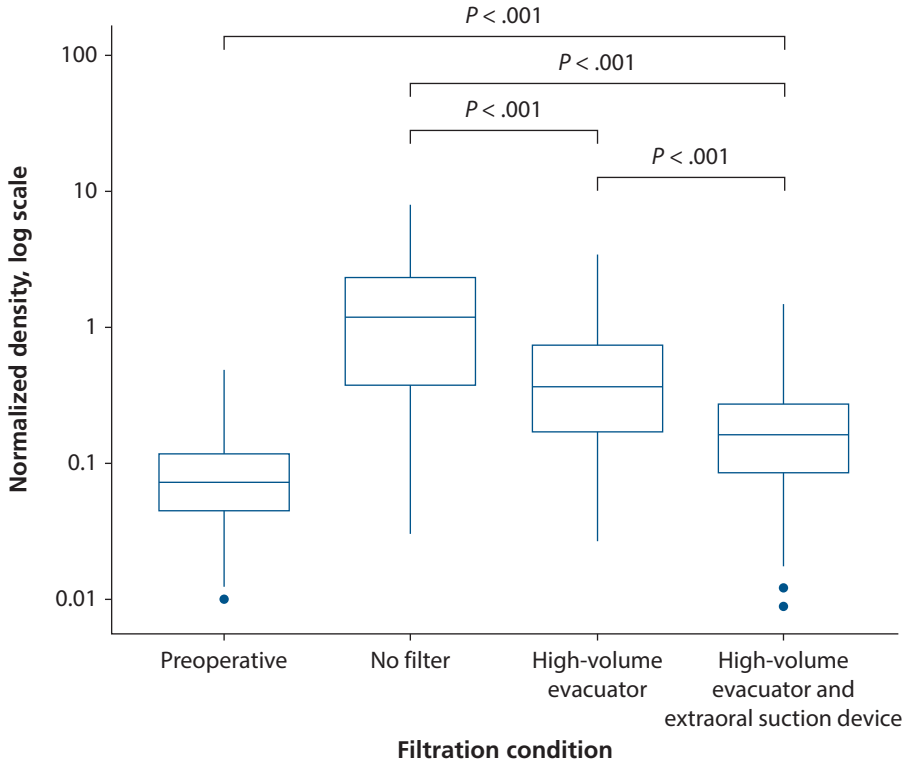

Figure 5. Normalized density of particles under different filtration test conditions. The preoperative test condition represents when no aerosol-generating procedure was being performed. HVE: High-volume evacuator.

It is clear from a comparison of the data in the supplemental figure (available online at the end of this article) that all of the test participants reduced their exposure to generated aerosols and most of the test participants (75%) were able to substantially reduce their exposure to aerosols by means of the surgical microscope and bag barrier drape in virtually every category from 1-μm PM to TSP,

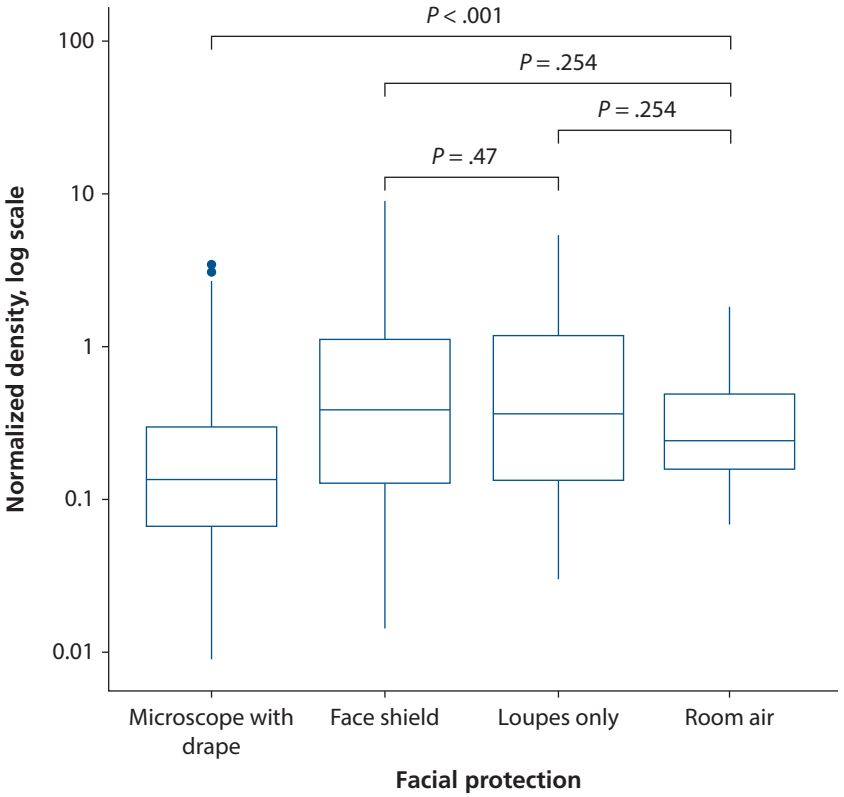

Figure 6. Normalized density of particles using different facial protections. Comparison of total suspended particles between test conditions.

Table 1. Total suspended particles for test conditions and relative change.*

VARIABLE	PREOPERATIVE, MEDIAN $\mu g/m^3$ (IQR†)	NO FILTER, MEDIAN $\mu g/m^3$ (IQR)	HVE‡		HVE AND EXTRAORAL SUCTION DEVICE	
			Median $\mu g/m^3$ (IQR)	% Change§	Median $\mu g/m^3$ (IQR)	% Decrease
Room	24.6 (23.5-24.9)	147 (118-196)	57.3 (50-58.2)	−61.0	20.8 (18.5-22.6)	−85.9
Microscope and Drape	12.2 (7.6-20.9)	66.2 (35.2-188)	30.3 (17.8-61.4)	−54.2	15.1 (10-21.5)	−77.2
Loupes	17.4 (15.3-31)	999 (999-999)	93.7 (71.6-251)	−90.6	29.9 (22.2-47.2)	−97.0
Face Shield	17.8 (12.7-23.8)	999 (378-999)	158 (71.7-419)	−84.2	59.9 (29-190)	−94.0

* The upper limit of the test device was 999 $\mu g/m_3$. † IQR: Interquartile range. ‡ HVE: High-volume evacuator. § Percentage change from the no filter test condition for HVE and HVE and extraoral suction was calculated on the basis of the median values.

from unsuctioned aerosols to aerosols removed with HVE to aerosols removed with HVE and the extraoral suction device (the number after the PM is the diameter in micrometers).

We found that facial protection and filtering devices substantially altered the aerosolized particles in the breathing zone of a dentist performing a routine treatment. Our results showed that there is a strong positive correlation among particles of different sizes, so methods that were effective at decreasing particles at a certain size also decreased particles of other sizes. The microscope and drape provided the lowest levels of aerosolized particles in the breathing zone of the test participant, and the use of a face shield did not appear to lower these levels compared with no face shield. Regardless of the facial protection, the use of an HVE decreased aerosolized particles substantially and the addition of extraoral suction decreased these levels even more.

Our data indicated that face shields appear to have no substantial value at preventing aerosols from reaching the dentist's face. This is consistent with data from other researchers that showed

Table 2. Average detected particles under different test conditions.

DEVICE	ACTIVITY	AVERAGE OF PARTICULATE MATTER, μm				AVERAGE $\mu g/m^3$ OF TOTAL SUSPENDED PARTICLES
		1	2.5	4	10	
Microscope and Drape	Preoperative	2.72	3.87	5.68	8.75	14.93
Microscope and Drape	Aerosol	20.68	35.64	58.28	83.77	106.91
Microscope and Drape	Aerosol/HVE*	8.18	13.07	20.48	29.49	36.66
Microscope and Drape	Aerosol/HVE/extraoral suction device	4.03	6.07	9.02	12.55	16.86
Face Shield	Preoperative	3.12	4.66	7.13	11.3	19.13
Face Shield	Aerosol	61.15	118.23	243.68	558.16	740.66
Face Shield	Aerosol/HVE	21.95	39.81	74.02	134.57	243.86
Face Shield	Aerosol/HVE/extraoral suction device	9.45	15.94	28.41	61.5	139.64

* HVE: High-volume evacuator.

aerosol contamination in a study with fluorescent dye.[2] However, both aerosols and droplets (spatter particles) make up respiratory transmission particles.[11] Although virus particles are typically small (< 1 μm), they are usually contained in larger particles.[12] Lindsley and colleagues[28] reported that face shields can be associated with a decrease in projectile aerosols from coughing particles of larger than 8.5 μm (large particle spatter) at 18 in and 72 in (96% and 92%, respectively). Decreasing the particle size to 3.4 μm resulted in an increase in particles going around the edges of the face shield. However, dental care professionals should understand that wearing a face shield is unlikely to decrease aerosol exposure. Roberge[29] suggested that face shields only be used as adjunctive to other personal protective equipment (PPE), such as protective face mask and goggles.

The CDC's recommendation of the use of face shields for oral health care providers takes into account measurements that our study did not observe.

During testing, the droplets were seen on the surface of the drape, and the operator's clothing remained dry compared with the clothing worn during the face shield and loupes phase of the study. Particles larger than 50 μm tend to have ballistic behavior owing to their size and the effect of gravity.[9] The aerosols measured at the participant behind the microscope were actually lower than the levels measured at the foot of the chair. This makes the use of a microscope and drape an effective option for dental care professionals because it blocks droplets and decreases aerosol exposure substantially.

Other researchers have reported the effectiveness of HVE in reducing aerosols.[14,28,29] The relative decreases in aerosols that we observed were similar to those reported in previous studies (89.7%-90.8%) for the nonmicroscope experiments. The decreases were more modest with the microscope and drape in place, likely due to effectiveness of that configuration for blocking aerosols. Our results showed that filtration devices decreased aerosol exposure in all test conditions, and that extraoral suction provided additional decreases in aerosol levels. The combination of barriers and various suction devices was suggested by Harrel and Molinari[4]; however, they did not specify the type of mitigation efforts in the studies that they reviewed. Results from another study[30] showed that aerosols from COVID-19 can travel more than 6 feet. Extraoral suction decreased the aerosols detected at the foot of the dental chair.

It does seem like the COVID-19 pandemic is driven by asymptomatic or presymptomatic patients,[8] and they are the ones our profession will most likely see and treat before they are aware that they are shedding the virus.[23] This line of thinking, that all of the patients we see might be potential carriers of the virus, is why we use standard and airborne precautions for other diseases (for example, HIV, hepatitis B and C, and tuberculosis).[31]

Therefore, use of standard and airborne precautions (such as masks, eye protection, and gloves[31]) along with other measures seems to be reasonable. Several forms of PPE have been suggested by various authors, including face shields,[23,28,29] face masks,[9,32] and powered air-purifying respirators.[33] Our study is the only one, to our knowledge, that proposes the use of a surgical microscope and an attached bag barrier drape are more effective PPE than a face shield.

The use of a surgical microscope and the bag barrier drape and extraoral suction devices is applicable to many areas of medicine (for example, ear, nose, and throat procedures[34]; ophthalmologic surgery[35]; and neurosurgery[36]) and can be adapted and adopted by those specialties.

Results from using the face shield also are consistent with the lack of severe infections seen in frontline health care professionals who wear face shields routinely. Estrich and colleagues[35] reported that 99.6% of dentists surveyed were using PPE when treating patients, and 72.8% reported using PPE as recommended in the interim guidance from the CDC. Estrich and colleagues[35] also found that fewer than 1% of dentists were estimated to be COVID-19—positive as of June 2020.[35] They do not detail how many were engaged in active practice or patient care and do not describe how the infections were acquired.[37] The World Health Organization[38] and the CDC[39] have maintained that COVID-19 is droplet-borne as opposed to aerosol- or airborne. The lack of aerosol protection we found in our pilot study seems consistent with their scientific evidence.

The results from the use of a surgical microscope and the attendant bag barrier drape showed a reduction in aerosols of all types tested (1-10 μm and TSP) with all of the participants able to reduce generated aerosols. Several of our participants (30%) were able to reduce aerosol loads to lower than preoperative, ambient levels. In addition, a full 75% of participants were able to reduce aerosol PM to within the range of preoperative values.

HVE in both the face shield tests and the surgical microscope tests and drape appeared to reduce aerosols from reaching the operator's breathing zone effectively but not as consistently as reported by other authors.[14,28,29] These other tests used aerosol spray that was more contained inside the oral cavity versus aerosols generated on the facial aspect of maxillary anterior teeth. However, our testing method appears to be unique, and we believe it provided a better representation of a true clinical picture for the profession as a whole. There were more and less proficient participants, both with generating aerosols and with reducing them with HVE. The proficiency of the participants did not seem to vary greatly between dental students with no experience with a surgical microscope and private practice dentists with no experience with a surgical microscope. Several dental students had experience with a surgical microscope and were as proficient as private practice dentists with surgical microscope experience. We did not separate out the less proficient participants to boost the potential levels for this study. Our profession needs to see the range of possibilities. However, the most proficient participants provide our profession with a picture of what is clinically attainable with our available equipment.

With the use of the face shield, we also saw reductions in aerosols when using the HVE and the extraoral suction. Although these reductions are not as substantial as with the surgical microscope and the bag barrier drape, they were fairly consistent. The consistency of measurements when not using the bag barrier drape was the converse of the previous argument for aerosols staying behind the drape. If the effects of the suction devices (HVE, extraoral suction) are not impeded with a barrier, then the effects should be more profound.

Although our study used the IQAir HealthPro Plus unit with the FlexVac arm, there are several other extraoral suction devices on the market (for example, those from ADS) that can adequately reduce aerosols not removed with normal dental HVE; however, they were not tested in this study and should be investigated more thoroughly in future studies.

CONCLUSIONS

The results of our study suggest that the use of a surgical microscope and bag barrier drape, HVE, and an extraoral suction device can result in the lowest concentration of aerosolized particles (1-10 μm) in the breathing zone of a dental operator performing an aerosolizing procedure. When a microscope was not used, there was no substantial decrease in aerosol exposure for operators using a full face shield compared with no face shield, although face shields likely have a role in droplet protection. Our data also indicated that HVE and extraoral suction were effective in decreasing aerosols regardless of the type of facial protection used. The combination of these filtration devices was more effective than HVE alone. Additional institutional testing is needed to replicate this study

to reduce institutional bias. Independent testing of different extraoral devices to determine whether they all possess characteristics similar to those of the IQAir unit that we tested is necessary for the profession to have confidence in those units. ■

SUPPLEMENTAL DATA

Supplemental data related to this article can be found at: https://doi.org/10.1016/j.adaj.2021.08.011.

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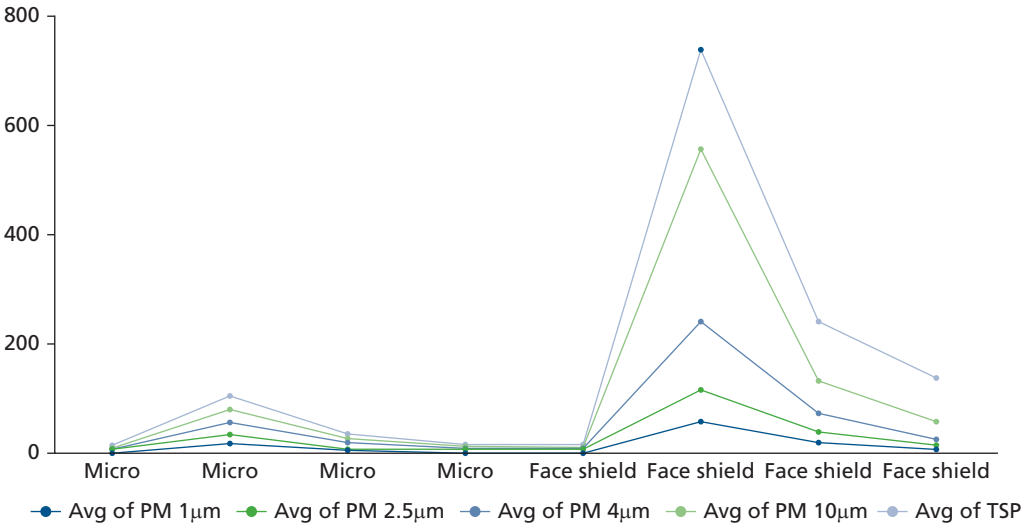

eFigure. Average (Avg) for all particulate matter (PM) and total suspended particles (TSP). Number after PM is the diameter in micrometers. Micro: Microscope and drape.