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Can extraoral suction units minimize droplet spatter during a simulated dental procedure?



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ABSTRACT

Background. Aerosol and droplet production is inherent to dentistry. Potential for COVID-19 spread through aerosols and droplets characterizes dentistry as having a high risk of experiencing viral transmission, with necessity for aerosol and droplet mitigation.

Methods. Simulations of restorative treatment were completed on a dental manikin with a high-speed handpiece and high-volume evacuation suction. Variable experimental conditions with use of an extraoral vacuum suction at different distances from the simulated patient's mouth and different vacuum settings were tested to evaluate extraoral suction ability for droplet reduction.

Results. Using the extraoral suction unit during dental procedure simulations reduced droplet spatter at the dentist's eye level, as well as the level of the simulated patient's mouth. When the extraoral suction unit was used at level 10 and 4 inches from the simulated patient's mouth, less spatter was detected.

Conclusions. Extraoral suction units are an effective method of reducing droplet spatter during operative dental procedures and can be useful in helping reduce risk of experiencing COVID-19 spread during dental procedures.

Practical Implications. During the pandemic, dentistry and its aerosol-generating procedures were placed on hold. The process to getting back to patient care is multifactorial, including personal protective equipment, patient screening, and mitigating aerosol spread.

Key Words. COVID-19; aerosol; droplet; occupational health; personal protective equipment; risk reduction.

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COVID-19 transmission is attributed to severe acute respiratory syndrome coronavirus–(SARS-CoV-2)—containing aerosols and droplets generated during breathing, speaking, sneezing, and coughing of infected people. Direct or indirect oronasal and ocular mucous membrane exposure to the virus is the route of infectivity.¹⁻⁵ Owing to the close proximity of oral health care providers (that is, dentists, dental hygienists, and dental assistants) to a patient's face during procedures and frequent use of high-speed handpieces and ultrasonic scalers capable of aerosolizing bodily fluids like saliva and blood, there is heightened potential for SARS-CoV-2 transmission in these professionals.^{6,7} The use of water-cooled, rotating, or vibrating instrumentation within the oral cavity combined with normal patient respiration, coughing, and sneezing creates aerosols and droplets ranging in size from small inhalable aerosols to large droplet spatter capable of contaminating proximal surfaces and personal protective equipment (PPE).⁸⁻¹¹ Smaller aerosols remain suspended in the air for a protracted length of time owing to their low sedimentation rate and can be inhaled into the upper and lower respiratory tracts.^{12,13} Droplets larger than 10 micrometers in aerodynamic diameter sediment rapidly in air. Although they can be inhaled into the upper respiratory tract, they are less likely to reach the lower respiratory tract, but they can cause surface contamination or directly contact exposed mucus membranes.¹⁴ In view of the cubic relationship between spherical droplet diameter and volume, it seems apparent that larger droplets are potentially able to carry larger viral loads than smaller droplets or aerosols.^{12,14} Dental providers therefore need protection from both inhalable aerosols and larger droplet spatter.

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Table 1. Experimental design for evaluation of aerosol escape from the manikin's (simulated patient's) mouth.

EXTRAORAL SUCTION UNIT SETTINGS		
Vacuum Airflow Level	Distance From Collection Cone to Tooth No. 9, In	AEROSOL DETECTION LEVEL
Off	4.0	Simulated patient's mouth
Off	4.0	Dentist's eyes
4	4.0	Simulated patient's mouth
4	4.0	Dentist's eyes
10	4.0	Simulated patient's mouth
10	4.0	Dentist's eyes
10	7.5	Simulated patient's mouth

To ensure patient and provider safety, it is necessary to use methods to limit both aerosol inhalation and droplet spatter. Masks and respirators are the primary tools used to limit release and inhalation of respirable aerosols, and physical barriers are used to minimize direct exposure of skin and mucous membranes to both aerosols and droplet spatter.¹⁵ In pre-COVID-19 dental practice, attempts were made to minimize aerosol and droplet escape from the oral cavity using intraoral suction with low and high vacuum, tooth isolation with a rubber dam, use of mouth props with attached suction, and saliva drying agents, but respirable aerosols and droplet spatter were still dispersed with these methods in place.^{10,16,17} In view of the COVID-19 pandemic, dental providers are now searching for additional approaches to mitigate inhalable aerosol and spatter emission and limit procedural risks and oral health care professional exposure.¹⁸ Some methods of risk mitigation include the use of extraoral suction units (ESUs), negative pressure operatories, increased physical barriers, and augmentation of PPE.¹⁹

In our study, we evaluated the ability of an ESU to mitigate droplet spatter during simulated restorative tooth preparation. ESUs are high airflow vacuum systems intended to scavenge aerosols and droplets from the vicinity of the patient's mouth and trap droplets by depth filtration for safe disposal. ESUs were not widely used prepandemic, but they have been tested in experimental simulations to assess their efficacy for spatter reduction.^{20,21} ESUs offer flexibility in terms of positioning the collector relative to the patient's face and selection of vacuum airflow level, but guidance on appropriate parameters is limited. In our study, we used a visual droplet detection method particularly suitable for spatter detection to evaluate the effectiveness of a single ESU at 2 vacuum airflow levels and collector positions relative to a model patient's oral cavity compared with control experiments in which the ESU was not deployed.

METHODS

Setting

We conducted the experiments in a standard indoor dental procedural room in a dental school. Two single-chair clinical spaces were separated by a partial barrier wall but shared ventilation. The clinical space connected to a hallway without a door. No other clinical activities occurred concurrently with the experiments. The air-handling system functioned as per usual practice. The operatory temperature was set to 71°F, with approximately 50% humidity and 15 air exchanges per hour. Five team members were present in the clinical space during experiments.

Simulated dental procedure

The tooth preparation phase of a standardized restorative treatment procedure was conducted on a dental manikin fitted with removable Dentoform teeth (Columbia Dentoform) using an EVO.15 Micro Series High-Speed Handpiece (Bien-Air Dental USA) fitted with a no. 6 round bur (Benco) operated at 200,000 rotations per minute (maximum speed). Drilling in manikin tooth no. 8 mesial, incisal, lingual, and facial aspects or tooth no. 9 mesial, incisal, lingual, and facial aspects; tooth no. 14 distal and occlusal aspects; tooth no. 21 distal and occlusal aspects; and tooth no. 31 mesial and occlusal aspects occurred for 1 minute each with handpiece deactivation between tooth

ABBREVIATION KEY

- ESU:** Extraoral suction unit.
- PPE:** Personal protective equipment.
- SARS-Cov_2:** Severe acute respiratory syndrome coronavirus 2.

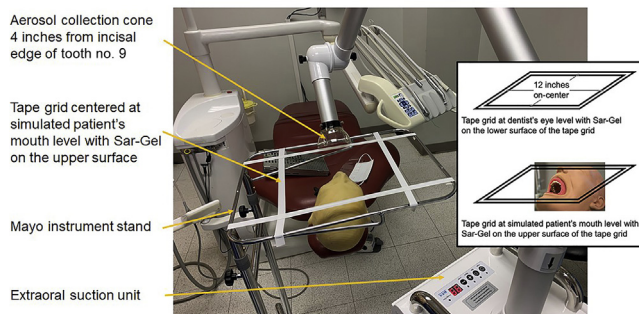


Figure 1. Photograph of simulation setup. Sar-Gel Water Finding Paste is manufactured by Arkema.

preparations. The handpiece water feed rate was 58 milliliters per minute (95% of maximum), and all droplet spatter and aerosols generated originated from this water source. All simulations were conducted by the same right-handed dentist (S.E.C.) and her assistant (N.C.W.) and included use of standard intraoral high vacuum suction. Both the dentist and assistant were clad in PPE, including face mask and shield, head bonnet, disposable gown, and nitrile gloves.

ESU operating conditions

An ADS EOS Extraoral Suction System (ADS Dental System) was used for all experiments. The floor-standing ESU was positioned with the opening of the collection cone directly facing the oral cavity at a distance of 4 or 7.5 inches (measured from the incisal edge of tooth no. 9). Four inches was considered the closest practical distance that enabled access for tooth preparation, and 7.5 inches was considered a more comfortable working distance. Distances were confirmed before and after each simulation. Duplicate simulations ($n = 2$) were completed with the ESU operating at vacuum level 4 and level 10 (the lowest and highest vacuum airflow settings recommended by the manufacturer for removal of droplets and aerosols) and with no vacuum airflow.²² The overall experimental design is shown in [Table 1](#).

Droplet spatter detection

Throughout the 4-minute simulated dental procedure, water spatter was collected on a 12-inch on-center square grid constructed from three-fourths-inch wide white polyvinyl chloride electrical tape mounted on the frame of a Mayo instrument stand that could be positioned at preset heights centered over the oral cavity. This arrangement ([Figure 1](#)) did not impede the dentist's or assistant's access to the dental preparation positioned in the center of the grid at either simulated patient's mouth or dentist's eye level (close to the top of her face shield).

Immediately before each simulated dental procedure, the nonadhesive side of the polyvinyl chloride tape strips used to construct the grid were painted with a thin layer of Sar-Gel Water Finding Paste (Arkema) (paste), which instantaneously and permanently changes from white to purple when it comes into contact with liquid water. When the grid was at the simulated patient's mouth level, the upper surface of the tape was coated with paste. When the grid was at the dentist's eye level (close to the top of her face shield), the lower surface of the tape was coated with paste.

At the conclusion of each simulation the Mayo instrument stand was relocated so the paste-coated grid could be photographed against a white background under ambient lighting conditions using a Nikon 850 digital camera and 50-millimeter lens from a distance of 37.5 inches (F-stop 5.6, 1/60 second, ISO 400). The time from painting the paste on the tape to obtaining the photograph never exceeded 9.5 minutes, which included construction of the tape grid and the 4-minute simulated dental procedure.

Control experiments

In negative control experiments, the paste-coated grid was photographed after approximately 10 minutes without exposure to the simulated dental procedure, but with the dentist and assistant in their usual positions to confirm that humidity did not cause a substantial color change. In positive control experiments, the grid was sprayed with tap water and rephotographed after obtaining a photograph collected as part of the experimental design ([Table 1](#)) to confirm the grid turned purple

and was therefore capable of detecting droplets if they were present. On several occasions, duplicate photographs were obtained several minutes apart to confirm the permanence of the color change. Photographs were also obtained under identical conditions with labels indicating the placement of the grid relative to the dentist, assistant, and simulated patient, and with a scale in the frame to confirm the size of the grid.

Aerosol spatter image analysis

Photographs of the paste-coated grid on the Mayo instrument stand were imported into Photoshop, Version 21.2.0 (Adobe) (Figure 2A) and cropped to the smallest square that encompassed the outer edges of the 12-inch on-center tape grid (Figure 2B). Photoshop's (Adobe) spot healing brush tool was used to remove labels used to identify each experiment from the image (Figure 2C) before the threshold setting was adjusted to 128, yielding the image in Figure 2D. This threshold setting was chosen to allow visualization of dark purple droplet spatter in black, with minimal interference from any light purple that developed at the edges of the tape due to ambient humidity. Photoshop's histogram tool was then used to determine the percentage of black pixels by selecting histogram levels 0 through 50, which correspond with the area of droplet spatter (percentage spatter) within the image. The same procedure was applied to each experimental simulation and the negative and positive control images (Figure 3). The pixel percentage attributed to droplet spatter in each simulation and the negative controls was then normalized to the mean percentage of pixels identified as spatter in the positive controls to yield the percentage of the grid area turning purple during each simulation due to aerosol spatter. Validation tests associated with the use of paste to detect water droplets were described in detail by Kundoor and Dalby.²³

RESULTS

Validation of droplet spatter detection method

Actual tape grid dimensions varied by a maximum of 0.4 inches from the 12-inch on-center intended square grid size. This minor variation was associated with both unavoidable stretching of the tape during grid creation and a diagonal support strut on the Mayo instrument stand slightly interfering with placement of the paste tape grid during the experiments at the dentist's eye level. Results of negative control experiments (Figure 3) showed that ambient humidity caused only a small area of purple to develop during the time of each experiment. After normalization less than 0.8% of pixels in the negative controls were falsely attributed to droplet spatter, so background correction was deemed unnecessary. Results of positive control experiments (Figure 3) showed that paste was successfully painted over the entire tape area that was analyzed for the presence of droplet spatter and detected water. Duplicate photographs of water-spattered grids were indistinguishable over time (presumably because the clear-to-purple change in phenolphthalein [in the paste] is due to a permanent pH increase once water contacts the paste). Although there was evidence of minor cracking in the paste coating at the end of each positive control experiment, it amounted to only a tiny fraction of the tape grid area, and we deemed that it detracted minimally from our ability to detect droplet spatter.

Droplet spatter interpretation

Figure 4 shows the initial photograph of the paste tape grid after each simulation with the collection cone opening 4 inches from the incisal edge of tooth no. 9. Table 2 provides the resulting quantification of droplet spatter for all simulations and control experiments. Because experiments were duplicated, statistical comparisons of droplet spatter are not possible. Nonetheless, a clear trend is apparent.

In the absence of extraoral suction, an average of 34% of the total grid area (2 grids at the simulated patient's mouth level and 2 at the dentist's eye level) received droplet spatter, which radiated in all directions from the oral cavity. Spatter detected was reduced to approximately 20% at the dentist's eye level. At vacuum airflow level 4, with the collection cone 4 inches from the oral cavity, these values fell to 16% and 13%, at simulated the simulated patient's mouth and the dentist's eye level, respectively. Average grid area exposed to droplet spatter fell to 8% when ESU vacuum airflow was increased to its maximum (level 10) and spatter at the dentist's eye level dropped to 6% and the simulated patient mouth level exposure was 11%. In spite of the large

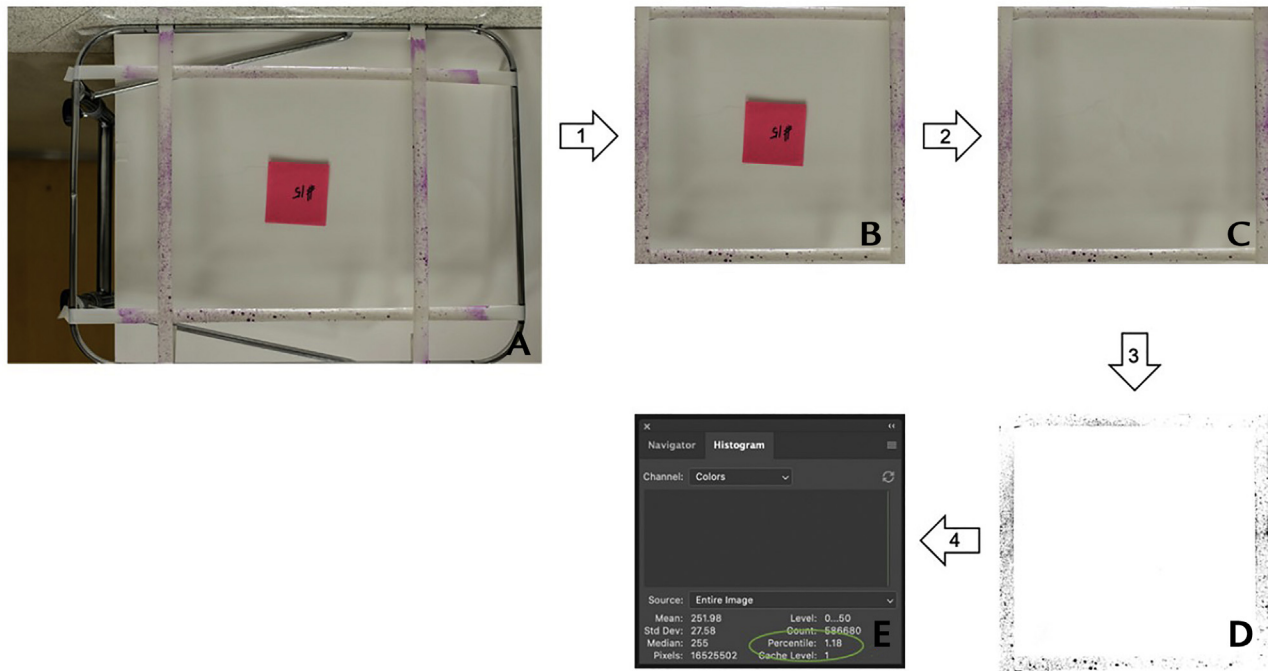


Figure 2. Schematic outline of the image analysis method used quantify aerosol spatter. **A.** Initial photograph. **B.** Cropped. **C.** Label erased. **D.** Threshold adjusted (attributed to aerosol spatter). **E.** Black pixel percentage recorded.

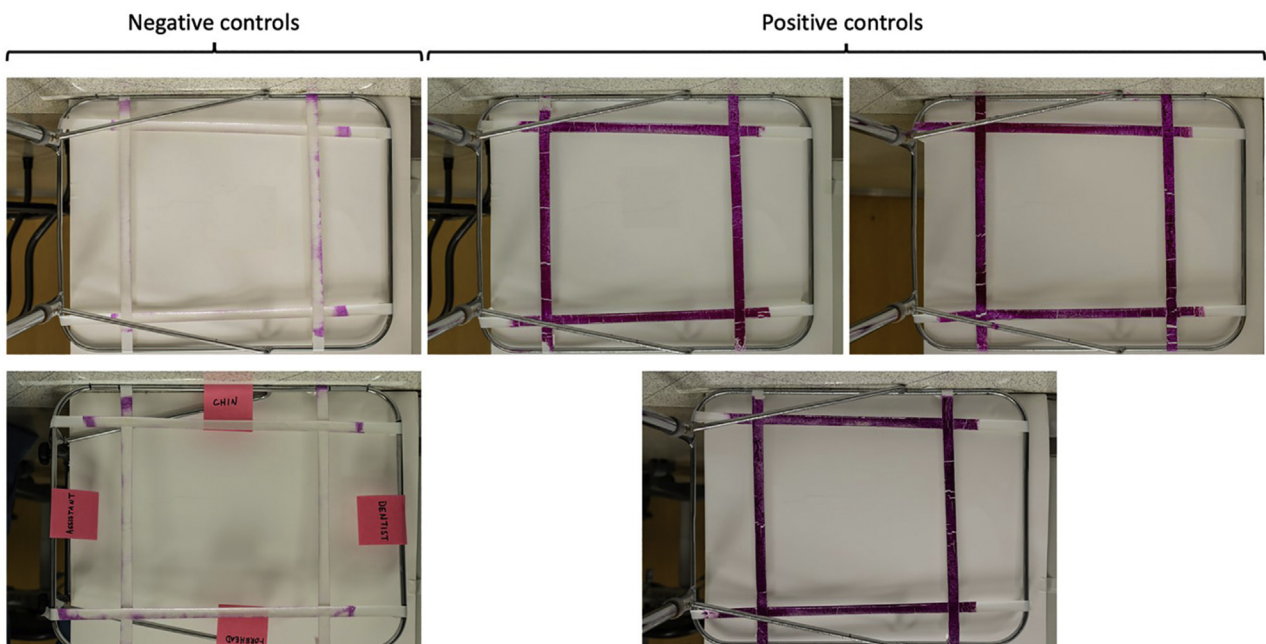


Figure 3. Negative and positive Sar-Gel Water Finding Paste (Arkema)-coated grid control initial photographs. Development of light purple at the edge of the negative controls was attributed to a slightly thinner coating of paste in those regions, which caused it to change to purple more rapidly due to ambient humidity. The distinct white cracks in the positive control photographs were attributed to shrinkage of the hydrophilic paste from the hydrophobic polyvinyl chloride electrical tape.

reductions attributable to use of the ESU, droplets were still detected on all sides of the grid at both the simulated patient's mouth and the dentist's eye level. When the collection cone distance to the oral cavity was increased to 7.5 inches and the vacuum suction remained at its maximum level, the simulated patient's mouth level exposure to droplet spatter remained virtually unchanged (9%).

ESU collection cone 4 inches from oral cavity

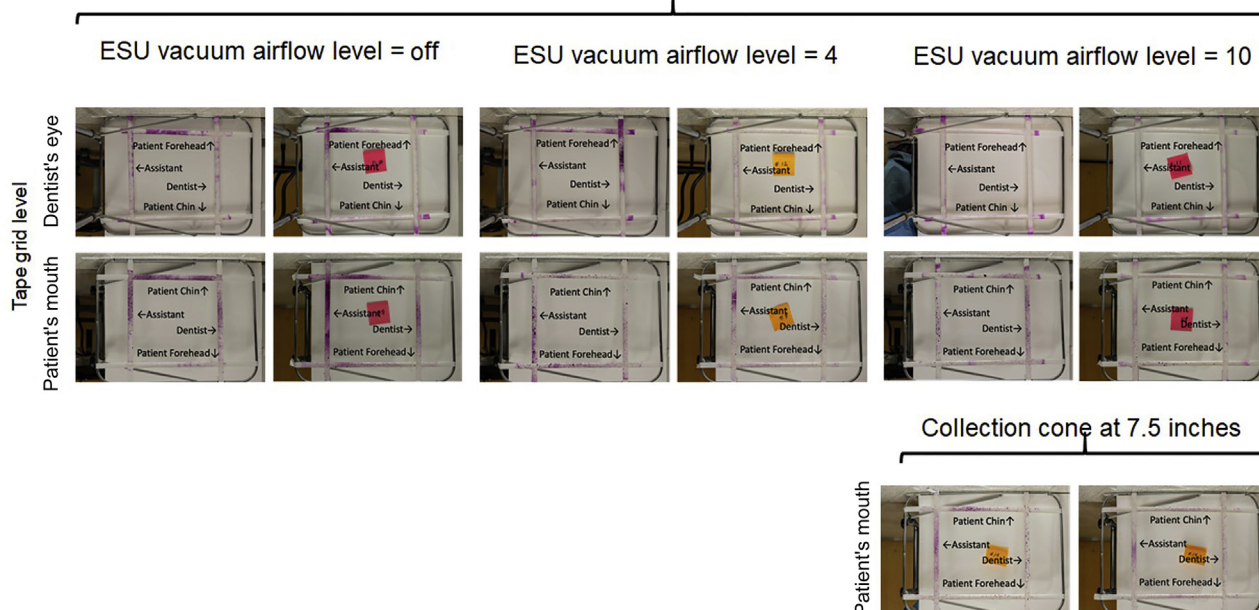


Figure 4. Sar-Gel Water Finding Paste (Arkema)-coated grid photographs corresponding to simulation design parameters outlined in Table 1. ESU: Extraoral suction unit.

Put more simply, the lowest spatter on a grid (2%) for a simulation was detected at the dentist's eye level with the ESU set to level 10, and the collection cone 4 inches from the incisal edge of tooth no. 9. The highest spatter on the grid (58%) for a simulation was detected at the simulated patient's mouth level when the ESU was not deployed. The simulations that yielded the lowest percentage of spatter all used the ADS EOS Extraoral Suction System (Table 2). Of the 8 simulations with the lowest percentage of spatter, 6 were completed with the extraoral suction in use at level 10.

DISCUSSION

Simulations of restorative dental treatment with the ESU in use yielded smaller amounts of droplet spatter. Simulations with the ESU in use at vacuum airflow level 10 (the unit's maximum) resulted in the lowest procedural spatter, but use of the ESU on level 4 (the manufacturer's lowest recommended level for removal of droplets and aerosols) during dental drilling also resulted in less spatter than when the ESU was not used.²³ These findings suggest that using ESUs during dental procedures could reduce the amount of droplet spatter within the active work zone, thereby reducing the oral health care professional's procedural risk of being exposed to SARS-CoV-2. The ESU was efficacious at reducing spatter when the collection cone was used in different positions relative to the manikin's mouth. This is important because its flexibility allows for use in different clinical scenarios. Less droplet spatter was detected at the dentist's eye level, which during the procedure was close to the upper edge of the face shield, where potentially infected biological matter poses a higher risk to clinical staff via ocular mucous membrane exposure.

The primary concerns for SARS-CoV-2 transmission risk are potential infection of clinical staff members during aerosolizing and droplet-producing procedures, as well as potential contact spread from viruses in procedural droplet spatter.²⁴ Therefore, the reduction in procedural spatter achieved using the ESU can mitigate the risk of experiencing viral spread, contamination, and transmission.

Although ESU use helps reduce spatter, it does not eliminate it during procedures and there remains the risk of experiencing potential distribution of biological matter from clinical procedures. Simulations were able to detect water spatter from a handpiece, but this spatter did not include biological materials from saliva, blood, or patient's breath, the potentially virulent component of spatter.²⁵ Handpiece-derived water admixed with contaminated oral and respiratory secretions is the problem, and it is unclear how much microbial contamination would be present in dental

Table 2. Results of image analysis to objectively quantify droplet spatter during each simulated dental procedure.

EXTRAORAL SUCTION UNIT SETTINGS				TAPE GRID EXPOSED TO DROPLET SPATTER (GRID AREA TURNING PURPLE) %		
Vacuum Airflow Level	Distance From Collection Cone to Tooth No. 9, In	Aerosol Detection Position, Replicate No. (control)	Spatter, %	Individual Simulation Result	Simulation Replicates, Mean	Both Aerosol Detection Levels, Mean
Off	4	Simulated patient's mouth, 1	6.83	39.3	48.4	33.8
Off	4	Simulated patient's mouth, 2	10.00	57.5	NA*	NA
Off	4	Dentist's eye level, 1	2.93	16.9	19.2	NA
Off	4	Dentist's eye level, 2	3.75	21.6	NA	NA
4	4	Simulated patient's mouth, 1	2.05	11.8	15.9	14.2
4	4	Simulated patient's mouth, 2	3.49	20.1	NA	NA
4	4	Dentist's eye level, 1	0.47	2.7	12.5	NA
4	4	Dentist's eye level, 2	3.87	22.3	NA	NA
10	4	Simulated patient's mouth, 1	1.18	6.8	10.9	8.4
10	4	Simulated patient's mouth, 2	2.60	15.0	NA	NA
10	4	Dentist's eye level, 1	0.35	2.0	6.0	NA
10	4	Dentist's eye level, 2	1.72	9.9	NA	NA
10	7.5	Simulated patient's mouth, 1	1.31	7.5	8.5	NA
10	7.5	Simulated patient's mouth, 2	1.66	9.6	NA	NA
Off	4	Negative	0.16	0.9	0.8	NA
Off	4	Negative	0.11	0.6	NA	NA
Off	4	Positive	17.58	101.2	100.0	NA
Off	4	Positive	17.71	101.9	NA	NA
Off	4	Positive	16.84	96.9	NA	NA

* NA: Not applicable.

droplet spatter mixed with water from the equipment. In addition, we did not measure the concentration or size of droplets, therefore, we cannot directly address questions about how use of ESUs alters the risk profile compared with the situation in which only masks, respirators, face shields, and other PPE are in use. Guidance from the Centers for Disease Control and Prevention for dental settings recommends use of N95 or higher-level respirators during aerosol-generating procedures.^{18,26} We do know that droplet-borne transmission of SARS-CoV-2 is prevalent, and our work confirms the presence of droplets throughout the immediate work zone.

Even with ESUs in use, additional protections for clinical professionals, staff members, and patients remain essential to reduce the possibility of viral spread. These measures include patient screening before procedures; clinical isolation protocols, such as the use of a rubber dam; facilities controls and environmental measures, such as ambient air purification, infection control disinfection, and sterilization of clinical areas and instruments; and clinical staff PPE. In spite of ESU use, procedural spatter can still potentially reach over or under a provider's face shield, and changes in provider positioning, such as leaning forward, can potentially lead to more facial exposure in spite of PPE. The deposition of droplet spatter was variable during simulations, depending on where drilling was taking place and ESU can mitigate droplet spatter with closer positioning to the oral cavity or to the specific procedural site. The use of ESUs during aerosolizing and droplet-producing procedures is an additional method of reducing potential spatter contaminant and safeguarding clinical staff members and patients from the spread of infected biological matter. The ESU we investigated incorporated a high-efficiency particulate air-purifying filter and a ultraviolet C germicidal irradiation source in its design. These features likely provide an additional level of risk mitigation during use and cleaning of the ESU.

ESU use has limitations, including an increase in ambient noise as the vacuum airflow level is increased. Ambient noise (measured as equivalent continuous sound pressure using a Smartphone app) increased from 69.5 decibels during conversation to 82.3 dB when the dental instruments were

in use to 86.2 dB when the instruments were used in conjunction with the ESU at vacuum level 10. This increased dB level can affect provider communication and patient comfort and could affect safety monitoring for staff.²⁷ ESU use can also require repositioning of the collection cone to optimize procedural suctioning, increasing contact contamination risk. The presence of the ESU can cause potential interference with patient and provider comfort. Surface contamination in the area around and at the simulated patient's mouth level remains present even with the ESU in use.

Restricted staff and facility availability during the pandemic limited the number of experimental replicates to 2, which forced us to present descriptive data only. This is a deficiency in our study that precludes statistical comparisons between experimental conditions. Nonetheless, the duplicated results we present for each condition show a high degree of consistency, and we observed substantial differences between conditions (Table 2). More experimentation is necessary to confirm our results and assess the generalizability of our findings to other dental procedures.

CONCLUSIONS

During the SARS-Cov-2 pandemic, which places increased focus on procedural risk reduction and infection control for dentistry, practical additional means of protection become more critical. The adoption of the use of ESUs for clinical procedures can help reduce procedural spatter, surface contamination, and potential transmission of the SARS-CoV-2 virus in the dental setting.

As the COVID-19 pandemic continues, additional safeguards against the spread of SARS-CoV-2 are critical for the provision of clinical oral health care. ESUs provide an affordable, practical method of reducing aerosols and droplet spatter during clinical procedures. The ESU we evaluated was maneuverable, did not impede workflow, and provided an additional level of protection for clinical providers. However, it did not eradicate spatter and even with the use of an ESU during restorative simulations, spatter was detected projecting in all directions from the procedure site. Patient screening, PPE, proper infection control, and procedural isolation with intraoral techniques like rubber dam, as well as intraoral high-volume evacuation are still necessary to mitigate the risk of experiencing procedural contamination and transmission. ESUs, however, do represent a feasible and practical means of augmenting infection control procedures during clinical oral health care that are particularly important during the COVID-19 pandemic. In addition, because the paste is readily available and provides an immediate visual indication of contact with water, it is a practical tool that allows a practitioner to evaluate the effectiveness of droplet spatter-control precautions implemented in their practice or for use during training sessions. ■

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