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Concise Communication

Spatiotemporal distribution and control measure evaluation of droplets and aerosol clouds in dental procedures

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Abstract

We evaluated the distributions of dental splatters and the corresponding control measure effects with high-speed videography and laser diffraction. Most of the dental splatters were small droplets (<50 μm). High-volume evacuation combined with a suction air purifier could clear away most of the droplets and aerosols.

Keywords: Droplets; Aerosols; Infection control; High-speed imaging; Laser diffraction; COVID-19

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Droplets and aerosols produced during dental procedures may contain pathogens originating from the patient's saliva, blood, or respiratory secretions, which increases the risk of airborne transmission of severe acute respiratory coronavirus virus 2 (SARS-CoV-2), which causes coronavirus disease 2019 (COVID-19).[1–4] Previous studies have reported that the particle size has a great influence on its trajectory in the air and its spreading range.[5,6] To gain insight into the spreading modes and distribution characteristics of splatters, we studied the spatiotemporal particle distributions using high-speed videography and laser diffraction. We also visualized and evaluated the original dental surgery procedure and the effectiveness of common infection control methods

Materials and methods

Operatory and equipment setup

We conducted an experiment to observe the splatter pattern obtained during the simulated preparation of the central incisor (operation mode 1, OM1) and the first molar (operation mode 2, OM2) using a high-speed air turbine handpiece (HSH, T3 SIROBoost, Sirona Dental Systems GmbH, Germany) and an ultrasonic scaler (US, Suprasson P5 Newtron, SATELEC, France). The control measures included a high- and low-volume evacuation (HVE and LVE) in a dental unit (KaVo INTRAmatic LUX 3 25LHA, KaVo Dental, Germany), and a suction air purifier (SAP, AeroVac Pro Dental, E-Maxdent Co., Ltd, China). The splatter pattern was recorded with high-speed videography (Phantom VEO 410 L, Vision Research, USA). The detailed operatory and equipment setup is supplied in the Appendix (online).

Particle size distributions

A spray droplet measurement system (Spraylink, Linkoptic Co., Ltd, China) was used to measure the particle size distributions of splatters by laser diffraction. The focal length of the Spraylink lens used was 100 mm, which allows the measurement of particles of 0.1–2,080 μm. The volume-based particle size distribution was measured, and the software calculated the volume mean diameter ($D_{4,3}$).

Statistical analysis

We qualitatively described the spatiotemporal distributions of the splatters at the oral outlet. The velocity of the presented droplets and aerosols was preliminarily estimated. A trial-and-error thresholding process was used to binarize 3,000 processed images for fully developed aerosols. The number of white points appearing in the same pixel was tallied and divided by the quantity of each test image. A heat map of the splatters for every test case measured was generated from the frequency calculated above at each location in the image.

The mean and standard deviation of the particle size distribution characteristic parameter in each case were calculated. We used the Wilcoxon signed-rank test to evaluate the differences in the size and number distribution.

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Table 1. The Mean and Standard Deviation of the Splatter Velocity Under Different Working Conditions

			X-Axis Velocity (m/s)		Y-Axis Velocity (m/s)		Z-Axis Velocity (m/s)		Total Velocity (m/s)	
Splatter Type	Equipment	Operation Mode	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aerosols	HSH	OM1	1.56	0.68	1.63	0.66	0.63	0.51	2.22	0.73
	HSH	OM2	0.87	0.52	0.92	0.59	1.51	0.95	2.37	0.90
			*		*		*			
	US	OM1	0.25	0.11	0.11	0.09	0.16	0.07	0.31	0.14
	US	OM2	0.14	0.09	0.31	0.18	0.27	0.15	0.46	0.21
			*		*		*		*	
Large droplets	US	OM1	1.60	0.74	1.02	0.72	1.41	0.81	2.63	0.71

Note. OM1, operation mode 1, the simulated preparation of the central incisor; OM2, operation mode 2, the simulated preparation of the first molar; HSH, high-speed air turbine handpiece; US, ultrasonic scaler.
*Wilcoxon signed-rank test, $P < .05$.

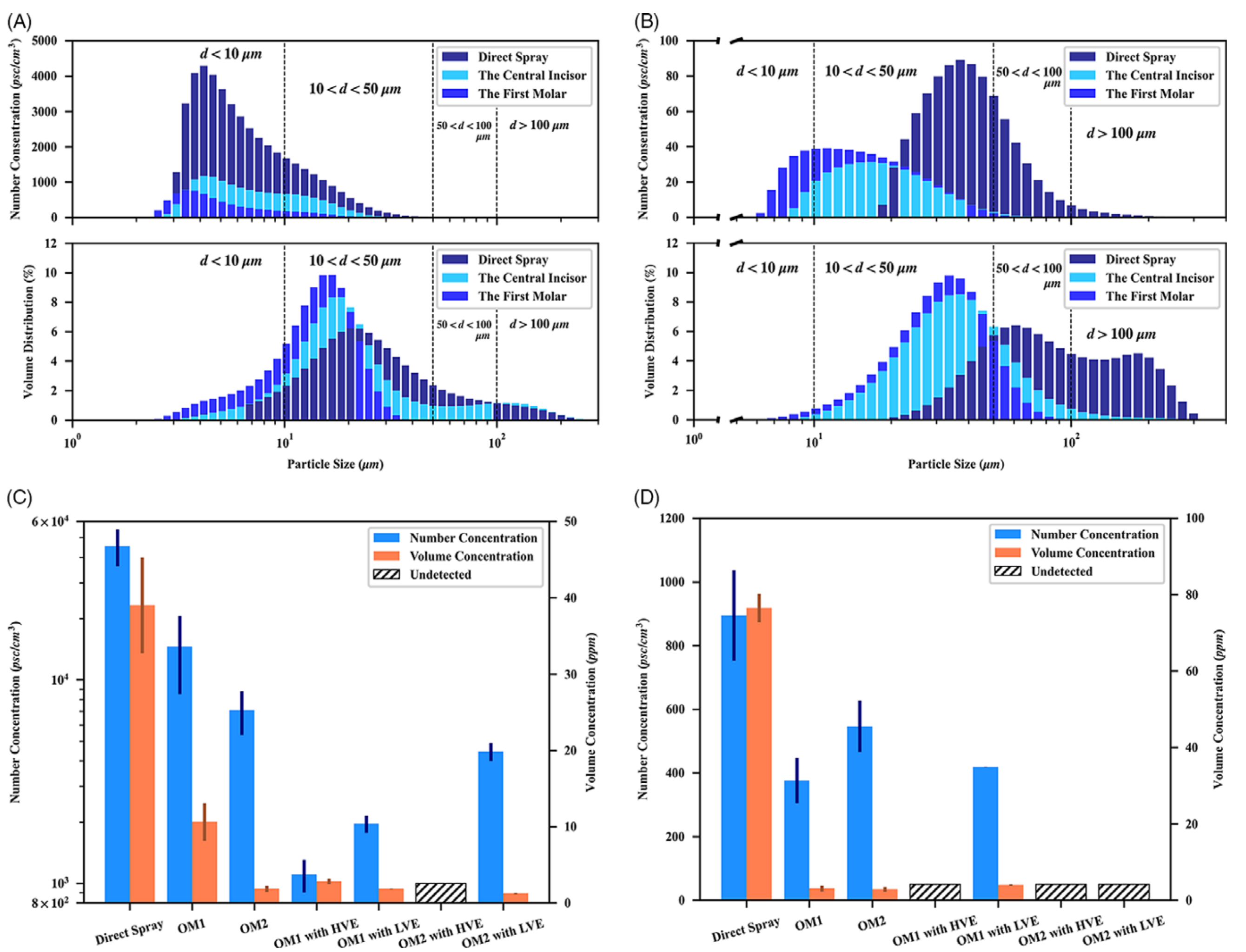

Fig. 1 Particle size distribution in dental procedures by laser diffraction. (A) Particle size distribution of HSH. The volume fraction of the small droplets (diameter <50 μm) was 86.46% in OM1 and 99.99% in OM2. (B) Particle size distribution of ultrasonic scaler. The volume fraction of the small droplets (diameter <50 μm) was 80.94% in OM1 and 92.18% in OM2. (C) Characteristic parameters of HSH with or without control measures. HVE could effectively clear away practically all splatters, except in OM1. Many small droplets still escape to the air while using the LVE. (D) Characteristic parameters of ultrasonic scaler with or without control measures. HVE could effectively clear away practically all splatters. LVE only could effectively eliminate splatters in OM2. Note. OM1, operation mode 1, the simulated preparation of the central incisor; OM2, operation mode 2, the simulated preparation of the first molar; HSH, high-speed air turbine handpiece; HVE, high-volume evacuation; LVE, low-volume evacuation.

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Results

The velocity components (*u*, *v*, *w* and magnitude) are listed in Table 1 of the splatters under different working conditions. At the oral outlet, the speed of large droplets can exceed 2.63 m/s, and the speed of aerosol clouds ranges from 0.31 to 2.37 m/s.

Appendix Figure 2 (online) shows the evolution of splatters from generation to a fully developed state under different working conditions. Overall, larger droplets (with higher mass and momentum) seldomly move along airflow and will rapidly settle to the surfaces due to inertia. In contrast, aerosols are subject to advect along the airflow because the gravitational effect on their trajectories is limited. Different control methods must be adopted according to the characteristics of the 2 kinds of splatters.

As shown in Figure 1A and B, 2 distinct types of sprays were identified, HSH spray (33.44 µm in $D_{4,3}$) and ultrasonic scaler spray (101.38 µm in $D_{4,3}$). The concentration histogram indicates that more large droplets are produced by the ultrasonic scaler spray (41.62% volume fraction with droplet diameter >100 µm) and that aerosols composed of millions of small droplets are produced by the HSH spray (83.84% <50 µm). As shown in Fig. 1C and Fig. 1D, many splatters escape to the surroundings with the use of LVE. Even though HVE can effectively clear away almost all splatters, some smaller droplets could still escape to the surroundings, especially in OM1. The detailed results of the particle size distribution are supplied in Appendix Tables 1 and 2 (online).

Appendix Figure 3 (online) shows the heatmap of splatters under different working conditions. Overall, both LVE and HVE are capable of reducing contamination, but HVE performed better. Regarding the SAP, the quantity of splatters outside the mouth remains unchanged. Most are removed under the suction caused by negative pressure, so the most important role of the SAP is to change the diffusion direction of the splatters, to compress the contamination range, and to control aerosol escape into surrounding air.

Discussion

Qualitative and quantitative analyses of the composition of dental droplets and aerosols are extremely difficult, and the composition of the splatter probably varies with each patient and operative site.[7] In our study, the captured aerosols seem to be stochastically generated by the flow instability and diversity of the reflection interface. The morphology of clouds evolves in a varied and unpredictable way. Therefore, we focused on measuring the size, number, velocity, and spatial probabilistic distributions of the droplets at the oral outlet.

In our study, most dental splatters were small droplets (<50 µm in diameter) and many of the smallest droplets (<10 µm in diameter) were generated using an HSH. Previous studies have indicated that smaller droplets evaporate in 0.027 s and remain suspended meters away from the cougher.[8] Therefore, splatters generated during dental procedures can increase the risk of airborne transmission of diseases such as COVID-19.

Recent developments associated with the current COVID-19 pandemic have already changed the existing protocols regarding personal protective equipment (PPE) and infection control procedures in dental settings.[9] Even when using active ventilation, 10 minutes would be needed to cycle the air between 2 patients' appointments, which restricts the use of and access to dental operatories.[10] Based on our research, we found that the working conditions led to significant differences in the infection control effect. In general, 'point' control measures (HVE and LVE) cannot completely clear all aerosols. With the aid of the 'area' control measure (SAP), one can reduce the scope of pollution and regulate aerosol leakage into the surrounding environment. The evidence should be weighed against the benefits of shortened intervals to ensure the economic viability of the current care provision models and the accessibility of oral health services. Nevertheless, evacuators are needed to protect patients because they are not equipped with appropriate PPE. Even though evacuators reduce dental splatters, providers should also don the appropriate PPE to protect them from being exposed to splatters.

The findings from this study have limitations. Although attempts to replicate a real clinical environment are possible, it is difficult to capture all the variables involved in actual clinical practice through in vitro simulation studies. We hope that the numerical model in computational fluid dynamics will facilitate the extension of experimental conditions and provide guidelines in a relatively qualitative way in future studies.

In conclusion, we believe that studying the spatiotemporal distributions of contaminants and their control methods can contribute to devising more accurate infection control guidelines. We recommend combining 'point' control measure (HVE) and 'area' control measure (SAP) to reduce the scope of contamination and to prevent aerosols from leaking into the surroundings.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/ice.2021.511

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Conflicts of interest. The authors declare that they have no competing interests.

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