Performance of mitigation measures on emitted droplets in dental atomization procedure

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Abstract. Cross-infection risk induced by dental-related droplets and aerosol particles has challenged service providers and patients alike. The dental clinic has been widely treated as one of the most vulnerable healthcare organizations with a high exposure risk to infection. The present study aims to investigate the effect of high-volume evacuation (HVE) on the emitted droplets and aerosol particles during dental atomization procedures. Ultrasonic scaling, one type of atomization procedure, is performed in the dental clinic. The laser light scattering method is employed to visualize the immediate moment with and without the cooperation of HVE on ultrasonic scaling. The Proper Orthogonal Decomposition analysis is employed to investigate the turbulent flow characteristics. The previous hypothesis about the moderate performance of HVE on tiny high-velocity droplets has been proven in the present study. The HVE can be characterized as significantly low-threshold measures to reduce the contaminated region. Besides, a pair of vortexes presented near the facial region of dental professionals will be eliminated when cooperating with HVE. The HVE can significantly reduce the emitted droplets (about 60%) and the airborne lifetime of suspended particles. HVE acting as additional mitigation measures could augment traditional/primary decontamination strategies such as ventilation and personal protective equipment.

1 Introduction

Considerable mitigation measures for COVID-19 transmission have been conducted, and the recurrence of the pandemic is still being reported owing to the presence of new variants. Till November 2022, more than 6.5 million lives and 624 million people infected have been reported. Dental clinics have been treated as one of the most vulnerable institutions for medical services [1]. The cumulative infection rate between dental professionals and patients was found to be about 0.7% based on the case report forms and epidemiological investigations in Israel [2]. Although the infection rate of respiratory disease in dental surgery environments is lower than that in the gathering, further removing the fear and uncertainty associated with the possible airborne transmission of diseases is of critical importance in dental clinic environments.

Droplets and aerosol particles emitted during dental atomization procedures may promote cross-infection between dental professionals and patients, and there is current interest in investigating the performance of mitigation measures in dental clinics [3]. The large droplets are considered difficult to become suspended in the air and will be deposited near the dental treatment region. When the virus-laden droplets are deposited on the human mucus, the direct transmission route would occur. In comparison, small droplets are expelled during the dental atomization procedures, and they would evaporate in a short time and become lighter pathogen-containing particles. With the effect of airflow and diffusion, the particles could suspend in the air for a longer time and spread in a closed indoor environment [4]. Therefore, the emitted droplets and aerosol particles might promote cross-infection between dental professionals and patients when conducting dental atomization procedures.

After the dental atomization procedures, the air in the treatment room should be regarded as contaminated.

Although the viral load in the emitted droplets is not known, whether exceeds the infection dose, the disinfection and cleaning in dental clinics should receive much more attention. Working under negative air pressure is the preferable measure, which could draw clean air to remove possible pathogens from the air. Since retrofitting typical dental clinics with negative pressure rooms is quite expensive and time-consuming, high-volume evacuation (HVE) and portable air purifiers have been promoted to use when outbreaking the pandemic. However, the performance of the aforementioned mitigation measures is not well-investigated. Although several experimental studies have assessed the effect of HVE by investigating the contaminant region [5, 6], they were still limited to the deposited particles and several sampling points. A hypothesis about the moderate effect of HVE on large droplets or high-velocity tiny droplets still has not been fully tested. In addition, the question of how the usage of the HVE modifies cross-infection risk in comparison to the only use of personal protective equipment (PPE)

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remains unsolved. To resolve the aforementioned research questions, the performance of HVE on the droplets in various diameters, velocities, and airflow characteristics has been investigated in the present study.

Plenty of experimental studies have been conducted to further investigate the cross-transmission risk in dental clinics through advanced equipment and methodologies, like luminescent tracers, and bacteria culture methods. Owing to the nature of the aforementioned three research methods, the velocity, the size distribution of emitted droplets, and airflow characteristics cannot be provided. Recently, the laser-light scattering method has been widely employed in various disciplines [7], along with visualization results. Therefore, the visualization method would be adopted to investigate the performance of HVE on droplets in various velocities and diameters generated during ultrasonic scaling. The question about how the use of the HVE modifies the cross-infection risks compared with the condition with only PPEs would also be answered.

2 Experiment and processing methods

2.1 Experimental setup

The experiment was carried out in a single dental surgery environment. As presented in Fig. 1, the patient mannequin lying on the dental chair was located in room central. The air supply and ventilation exhaust (20 cm x 10 cm) are located on the long axis of the ceiling, maintaining the six air changes per hour (ACH). The relative humidity was not controlled but was in the range of 50-70%. Ultrasonic scaling, one type of dental atomization procedure, was conducted on the vestibular side of the mandibular central incisor of the mannequin. The size and velocity distribution of emitted droplets are significantly related to the vibration of the scaler tip and water supply rate. In the present study, the vibration and water supply rates were maintained at 30 kHz and 50 ml/min, respectively. According to the guidelines of dental procedures, the suction attachment of the HVE has been placed 1 cm away from the dental treatment region. The suction flow rate of HVE is variable.

A detailed visualization was performed based on the laser light scattering technique. To quantify the performance of HVE, the study was analyzed from the droplet velocity and diameter distribution, airflow characteristics, and particle removal efficiency. The laser with a pulse energy output of 50 mJ at the wavelength of 532 nm passed through a cylindrical lens. A light sheet was generated with a 2 mm thickness and suspended in the center of the dental clinic. The scattered light generated by the droplet passing through the light sheet would be captured by the high-speed CMOS camera (Lab 140). The room's interior was painted matt black to maximize the scattered light from the particles and reduce the impact of background noise (as presented in Fig. 1).

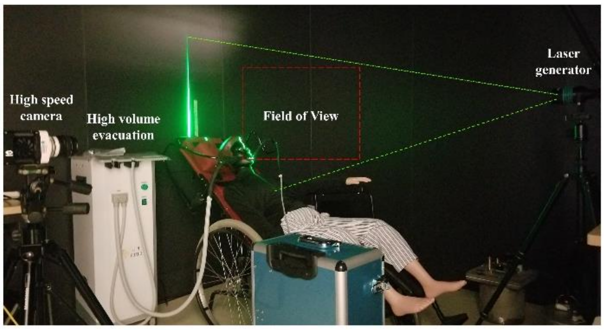

Fig. 1. The real-life photo of the experimental setup.

2.2 Velocity and droplet analysis

During the experiment, the image sequence was recorded by the high-speed camera with an exposure of 144 us per frame at the resolution of 2560 pixels x 1600 pixels. The corresponding field of view was 680 mm and 420 mm, respectively. Firstly, the background noise in the image sequence was removed by the background noise subtraction. Next, the velocity vectors were obtained by the adaptive PIV method, which has been proved with a more precise subpixel interpolation scheme. The aforementioned data processing method acting on the recorded image sequence can reduce the error by less than 3.0% in the velocity field analysis. The identification of emitted droplets was processed frame by frame whose single-pixel intensity exceeded 30 threshold values [8].

2.3 Proper orthogonal decomposition (POD) analysis

To further investigate the turbulent characteristics during ultrasonic scaling, the Proper orthogonal decomposition (POD) analysis was also conducted. Detailed analysis procedures are presented as follows: Firstly, the mean velocity field was calculated from all snapshots, and the fluctuating velocity components were obtained by every snapshot subtracting the mean. Secondly, the time-space matrix would be formed by the aforementioned fluctuating velocity components and further obtaining the autocovariance matrix, corresponding eigenvalue, and eigenvectors. Finally, the POD models can be calculated by combining eigenvalue and eigenvectors with the time-space matrix. Detailed processing procedures can be found in our previously published paper [7]. From the aforementioned analysis, the first mode usually accounts for the largest energy, referring to the large and dominant flow structure. Generally, the POD analysis could act as a 'filter' and reconstruct the airflow with specific turbulent kinetic energy, with the help of identifying the vortexes [9].

3 Results

3.1 Performace of HVE on droplets in various velocities

Fig. 2 presents the airflow characteristics on the scenarios whether the cooperation of HVE. The flow structures in the central plane were found to be similar: strong airflow in an upward direction was issued from the dental treatment region. The maximum velocity of emitted droplets is also about 3.0 – 3.5 m/s, which is located near the dental operation region. However, the cooperation of HVE (shown in Fig. 2b) can help to remove the high-velocity region at the top of FOV, significantly reducing the contaminated region on the patient's chest. The above findings represented that the effect of HVE cannot eliminate the emitted droplet and aerosol particles during ultrasonic scaling. But the droplets deposited and contaminated regions are significantly reduced.

To quantitatively investigate the performance of HVE on high-velocity droplets, the droplets' velocities were extracted at Point M to make a comparison (shown in Fig. 3). The peak velocity (3.0 – 3.5 m/s) was generally in the same location (Point M at about X/D=0.1) on the FOV (670 mm × 418 mm), where the D = 670 mm refers to the X-length of FOV. The above finding can be described by the moderate effect of HVE on the high-velocity droplets, which further help to prove the previous hypothesis about the effect of suction. Notably, considering that suction can bring remarkable effects on the airflow, they should be defined as cost-efficient equipment to bring significant benefits to reduce the deposited and contaminated region. The employment of HVE and other precautionary measures like air purifiers can further help to reduce cross-infection risks.

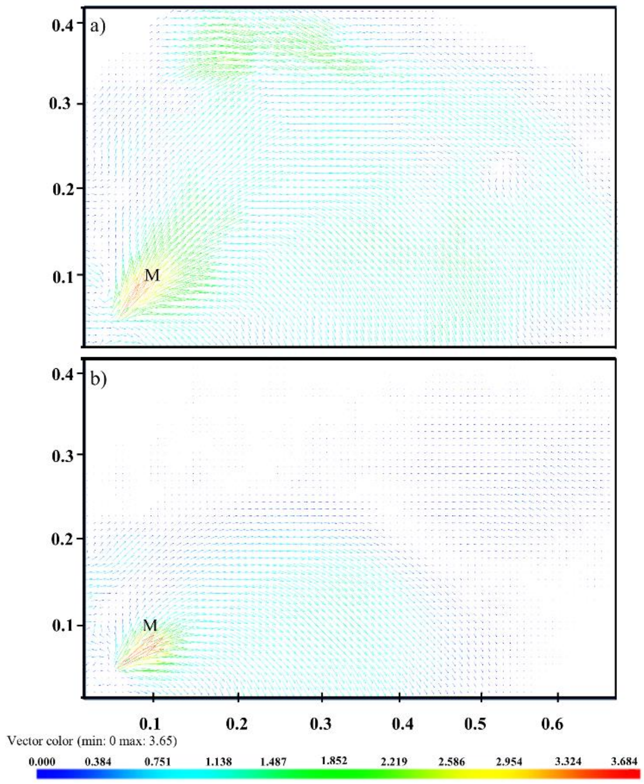

Fig. 2 The effect of HVE on the airflow characteristics: a) without the cooperation of HVE; b) HVE with a suction flow rate of 300 L/min.

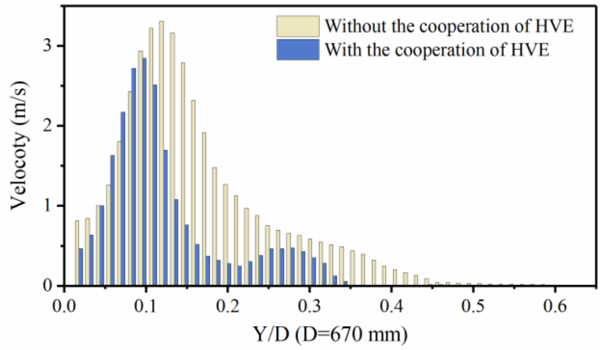

Fig. 3 The performance of HVE on high-velocity droplets at Point M (X/D= 0.1), where the Y refers to the changes in Y-length, the D is 670 mm, representing the X-length of FOV

3.2 Performance of HVE on airflow characteristics

The POD analysis was used to analyze the performance of HVE on the general airflow through the domain structure of complex instant flow characteristics. Since the POD analysis was based on the fluctuating parts of velocity components (subtracting the mean velocity field), the lower modes contributed more energy in the flow field. To cover 90% of the total energy, the first 136 and 131 modes were employed for the flow reconstruction for the scenario without and with the cooperation of HVE, respectively. Owing to more models being required for the scenario without HVE cooperation, more small-scale vortexes were in the airflow. Detailed POD analysis can be found in our previous study [7]. As presented in Fig. 4, selected POD models are extracted for comparison under the scenario with and without the cooperation of HVE. A remarkable difference in velocity distribution is noticed between the different modes. In the condition without HVE, a pair of large vortexes was presented at the top of FOV. The observation of the conjugated turbulence structures is in line with the previous study [1]. Notably, the presence of a pair of vortexes was at the same height as dental professionals' breathing zone, which may induce a high cross-infection risk. In comparison, the conjugated turbulence structures disappeared in the condition with HVE.

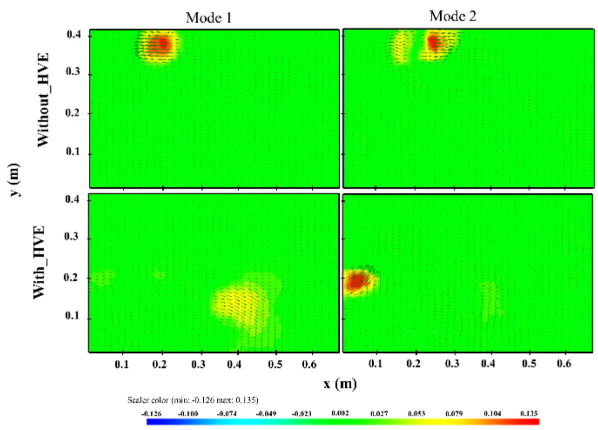

Fig. 4 First two POD modes from flow reconstruction under the condition with and without the cooperation

of HVE, which indicate the fluctuating parts of velocity components.

3.3 Particle removal characteristics

Based on the identified particle numbers, particle removal efficiency can be obtained by comparing the conditions with and without HVE (as presented in Table 1). To avoid the fluctuation of particle number in each recorded image, every forty images are extracted as one group.

Table 1. Particle removal efficiencies in different frames.

Frame	Particle removal efficiency
0 - 40 frames	60.2±4.1%
40 – 80 frames	58.7±3.0%
80 – 120 frames	59.2±3.3%
120 – 160 frames	57.3±2.4%
160 – 200 frames	55.7±3.7%
Overall	58.2±3.3%

4 Discussion

Plenty of high-velocity droplets are emitted during dental atomization procedures, which may induce the cross-infection risk between dental professionals and patients. Both dental professionals and patients have been significantly affected by the fear and uncertainties associated with the possible airborne transmission of SARs-CoV-2. Based on the Israel case report forms and epidemiological investigations, the cumulative infection rate between dental professionals and patients was found to be about 0.7% [2]. The SARS-CoV-2 cross-infection rate in dental clinics was much lower in comparison with the gathering. Further removing the fear and uncertainty associated with the possible airborne transmission of diseases is of critical importance in dental clinic environments.

Owing to the lack of quantitative evaluation of the recommended mitigation measures, the present study aims to evaluate the performance of HVE on the emitted droplets and aerosol particles during ultrasonic scaling. The question about how the use of HVE modifies the cross-infection risks compared with the situation in only PPEs has been answered. Although several previous studies used the luminescent tracer, the microbiological method, and particle sampling in dental clinics, the laser light scattering method can directly resolve the spatial-temporal distribution of the emitted particles. The HVE has a moderate effect on high-velocity droplets, it still can act as cost-efficient equipment, significantly reducing the contaminated region in dental clinics. The HVE has been significantly recommended by the Hong Kong Center for Health Protection during dental atomization procedures. Notably, the cooperation between HVE and air purifiers may further reduce the risk.

The study is limited to the absence of dental atomization procedures in real patients. The properties of saliva and mouthwash are different from those of cooling water, which may lead to differences in the velocity and size distribution of the emitted droplets. Since the present study is focused the perforamce of HVE rather than the size identification, the diameter distribution was not considered. The short-term exposure events in dental clinic should receive much more attention [10]. Different dental procedures should be considered owing to their different atomization mechanisms.

Conclusion

In summary, the present study quantitatively evaluates the performance of HVE on emitted droplets during ultrasonic scaling. The corresponding particle removal efficiency and airflow characteristics were analyzed. The obtained results can provide scientific evidence for dental procedure guidelines.

The previous hypothesis about the moderate performance of HVE on tiny high-velocity droplets has been proven in the present study. The HVE can be characterized as significantly low-threshold measures to reduce the contaminated region. Besides, a pair of vortexes presented near the facial region of dental professionals will be eliminated when cooperating with HVE. The HVE can significantly reduce the emitted droplets (about 60%)

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