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Restoration of dental services after COVID-19: the fallow time determination with laser light scattering

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Declaration of Competing interest

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Abstract:

In time, dental health care has slowly expanded beyond emergency treatment to treat oral diseases. How to reduce the cross-transmission risk in dental surgery has raised much more attention. Considering the lack of consistency of fallow time (FT) in its necessity and duration, the highly sensitive laser light scattering method has been proposed to visualize the airborne lifetime and decay rate of suspended particles in the dental surgery environment. The FT is defined as when the number of suspended particles drops to the level that the next patient can safely enter after the aerosol-generating procedures (AGPs). The ultrasonic scaling was performed in the mock-up experimental dental clinic with 6 air changes per hour (ACH), and the instantaneous moments of the droplets were recorded by a high-speed camera. Without any mitigation measures, the estimated FT in the single dental surgery environment with 6 ACH was in the range of 27-35 minutes, significantly affecting the number of daily dental services. Despite the cooperation of high-volume evacuation (HVE [IO]) cannot eliminate the FT to zero minutes, the equipment could reduce the required FT by 3-11 minutes for the suspended particles reducing the baseline levels. Owing to the longer airborne lifetime of suspended particles, the relevant protection equipment, especially respiratory protection, is quite essential in dental surgery. The obtained results of this study will provide evidence to establish the revised FT in dental surgery guidelines and

protect the health and wellbeing of urban dwellers.

Keywords: COVID-19, fallow time, laser light, dental clinic, suspended particles.

1. Introduction

The ongoing COVID-19 pandemic has forced the governments to undertake emergency measures to combat the transmission of SARs-CoV-2 (Megahed and Ghoneim 2020, Sun and Zhai 2020). This pandemic has impacted economic development and also significantly affected the provision of medical and dental services (Rahmani and Mirmahaleh 2020, Chen, Cao et al. 2021). In Hong Kong, the routine dental services were ceased, and the aerosol-generating procedures (AGPs) were postponed in January late 2020 (Kong 2020). The above disruption has caused negative effects on patient care and face-to-face dental teaching (Cao, Ding et al. 2020, Long and Corsar 2020), and also significantly affected the health and well-being of urban dwellers (Lee and Mak 2019, Li, Wei et al. 2019, Sun and Zhai 2020). With the restoration of dental services worldwide, the guideline of dental procedures should be provided with sufficient evidence.

In the dental surgery operation room, the aerosols and droplets contaminated with saliva or blood could be a high-risk transmission mode of SARS-CoV-2 (Ge, Yang et al. 2020). It was common to choosing water coolant during various dental procedures, like tooth preparation, oral prophylaxis, and dental surgery (Farah 2018). When the water coolant was in combination with saliva and blood, the bioaerosols and fluid droplets were generated. The high-viral loads of SARS-CoV-2 had been detected in the oral fluids of the COVID-19 positive patients (Chan, Yip et al. 2020, To, Tsang et al. 2020) and asymptomatic ones (Wolfel, Corman et al. 2020, Wyllie, Fournier et al. 2020). Besides, a study showed that experimentally generated aerosols containing the SARS-CoV-2 virus were with only a slight reduction in infectivity during a 3-hour period of observation (Van Doremalen, Bushmaker et al. 2020). Since the built environment characteristics significantly affect the infection of COVID-19 (Megahed and Ghoneim 2020, Li, Peng et al. 2021, Li, Ma et al. 2021), how to create sustainable spaces and reduce the exposure risk of dental professionals and patients is quite critical for the restoration of dental services.

Current existing solutions are inapplicable or not cost-efficient to solve the generated aerosols and droplets. The recommended negative pressure room for AGPs is quite expensive, not available in all community dental clinics (Jia, Lee Baker et al. 2021). The airborne isolation measures for 60 minutes in the non-negative pressure room seriously affect the number of daily dental services. Some devices have been suggested to reduce airborne dispersion in the medical area through simulation and experiments (Canelli, Connor et al. 2020, Jia, Lee Baker et al. 2021). Nevertheless, the specialty of dentistry, such as good visualization of the field of view and constant suction (Ma, Wong et al. 2017), for an accurate and gentle dental surgery has never been considered (Ai, Mak et al. 2017). Besides, timely communication could reduce the noise effect on patients' dental anxiety (Wong, Mak et al. 2011, Wong, Mak et al. 2015).

The fallow time (FT) is defined to settle down the suspended particles generated from AGPs. One challenge in the dental surgery environment is to estimate the duration of FT, which is quite critical for mitigating the exposure risks of dental professionals and patients. However, the necessity and duration of FT still lack consistency. A recent review revealed that FT was not referred to most countries' dental guideline documents, and the recommended FT ranged from 2 to 180 minutes (Clarkson, Ramsay et al. 2020). Some researchers also provided their suggestions on the duration of FT. A recommended FT of 60 minutes was published by the Office of the Chief Dental Officer England (England 2020), which was not widely adopted by other organizations. Hurley also recommended a 60-minute FT with ventilation rates of 6 air changes per hour (ACH) (Hurley 2020). In contrast, Allison detected whether fluorescein contamination of the filter paper in the post-procedure duration and suggested that the FT of 30-40 minutes with 6.5 ACH was more proper than the recommended 60-minute (Allison, Currie et al. 2020). A recent research paper stated that less than 10-minute FT might be more proper in the hospital's mechanically ventilated environment (Shahdad, Hindocha et al. 2021). Considering the current evidence in dentistry cannot support a defined and appropriated FT after AGPs during the COVID-19 pandemic, the measurement of the airborne lifetime and decay rate of suspended particles needs to be carried out to provide sufficient evidence of the value.

The lack of robust evidence about the lifetime or persistence of suspended particles will be the barrier to reopen routine dental services. Even though the number of virus particles in the air of the dental surgery operation room exceeds the infectious dose is unknown, the dispersion in the dental clinic should be avoided. However, many previous experimental methods in dentistry only focused on the settled particles, like the microbiological method and luminescent tracer (Allison, Currie et al. 2020, Hurley 2020, Zemouri, Volgenant et al. 2020). The lack of research on suspended particles in dental surgery may lead to a misunderstanding of the FT. Recently, theoretical modeling of airborne particles had been proposed to recommend the FT according to the actual air changes per hour, the length of procedures, and various mitigation measures (SDCEP 2021). However, the modeling was based on a series of unrealistic assumptions, like the same particle emission rate of procedures, removing droplet particles only by dilution measures.

Since the FT of suspended particles could be affected by many parameters, like the flow-field characteristics, size distribution, and even the evaporation rate of droplets, it is of paramount importance to conduct experiments to measure the decay rate of the suspended particles directly and calculate the FT after AGPs. Recently, several methods have been proposed to investigate the transmission of droplets and aerosols like luminescent tracer (Allison, Currie et al. 2020), bacteria culture method (Zemouri, Volgenant et al. 2020), and even the visual chromatic change detection (Chavis, Hines et al. 2021). However, the above three methods only focused on the settled particles rather than the suspended droplets and flow-field details. Recently, the laser light scattering method has been widely adopted in various disciplines. The detailed measurement and analysis, including the turbulent cloud and particle velocity characteristics, are of great significance for COVID-19 control and environmental design (Anfinrud, Stadnytskyi et al. 2020, Bahl, de Silva et al. 2020).

During the beginning of the pandemic outbreak, only providing emergency dental health care was adopted in many regions and countries (Izzetti, Nisi et al. 2020, Peng, Xu et al. 2020). In time, dental health care has slowly expanded beyond emergency treatment to treat oral diseases. The objectives of this study were to investigate the decay rate of the suspended particles and provide evidence for the revised FT in dental surgery guidelines. In Section 2, the experimental methodologies were briefly described. The FT determination with the estimated decay curves of suspended particles and exposure risk sources were analyzed in Section 3. Section 4 and Section 5 were presented the discussion and main conclusion of the experiment, respectively.

2. Experimental design

The study was performed in a mock-up dental clinic (dimension: $3.6\,m$ length x $2.7\,m$ width x $2.3\,m$ height) with the indoor room temperature and the relative humidity maintained at $23℃$ and 52%, respectively. The dental clinic in this study was in ceiling ventilation with 6 ACH. The generated laser light sheet was suspended in the center of the mock-up dental surgery with a pulse energy output of 50mJ. When the suspended particles passed through the light sheet, the scattered light was captured by a high-speed CMOS camera (Lab140). The operation of the laser and camera were synchronized to capture light spots rather than steaks (Anfinrud, Stadnytskyi et al. 2020), and the capture of light spots was much more convenient to analyze the diameter of suspended particles. The structure of the experiment platform was presented in Fig. 1. The image sequences were recorded with a $2560\ pixel\ x\ 1600\ pixel$ resolution, at a frame rate of $6\ Hz$.

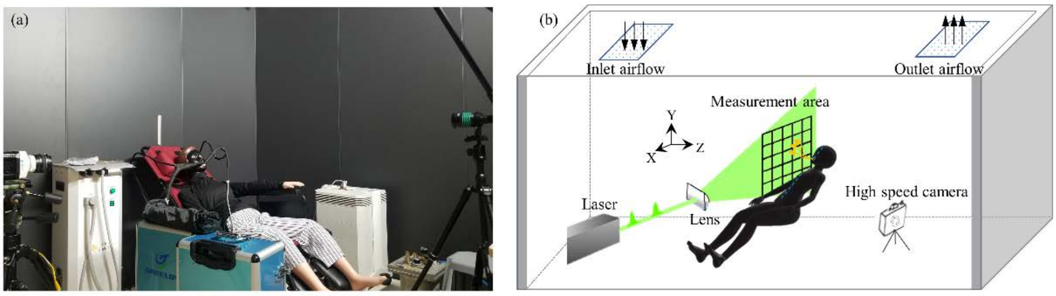

Fig.1(a) The Photo of the experiment platform; (b) The structure of experimental setup

The study was conducted in two groups, the control and intervention groups. The study mimicked the situation of a single surgery environment, where the mandibular central incisor of a mannequin or a patient was under ultrasonic scaling. The difference between the control group and intervention group was whether the high-volume evacuation HVE [IO] cooperated with ultrasonic scaling. In the control group, there were not any mitigation measures. In contrast, the intervention group was in the same experimental condition as the control group, except for the cooperation of HVE [IO]. The evacuation device was with an $3\ cm^2$ aspirator tip and at the high flow rate, 300 l/min of air.

Each experiment comprised a two-minute AGP (ultrasonic scaling), followed by a 40-minute post-procedure duration (after the cessation of procedure) to monitor the decay of suspended particles. Before the experiment, the air in the dental clinic had been filtered by a high-efficiency particulate air filter. The image sequences were recorded from 30 seconds before the end of the ultrasonic scaling. In the post-procedure duration, the 12 double-frame images were recorded in every 1 minute, and the recorded image sequences would be analyzed by the Image J particle counter (National Institutes of Health) to evaluate the suspended particle counts. The recorded image sequences in 40 minutes were analyzed frame by frame to determine the number of particles which single-pixel intensity exceeded 30 threshold values (Stadnytskyi, Bax et al. 2020). To avoid the fluctuation of particle numbers in one minute, the 12 consecutive images were extracted to form a one-minute image sequence. Then, the cumulative particle counts identified from the 12 images were employed to investigate the airborne lifetime and decay rate of suspended particles. The detailed analysis methods were presented in our previous study (LI, Ming et al. 2021).

The FT estimation in both control and intervention groups was studied by the linear and exponential regressions of the particle counts in the post-procedure duration. The FT was calculated as the time by the particle counts decreased below the baseline levels. Since the image sequences recorded by the high-speed camera were not stored in real-time, there were no new images during the interval of 3-7 minutes. Considering that the current recommendations for FT are larger than 10 minutes, the missing interval has little effect on the regression errors.

3. Results and analysis

3.1 Fallow time (FT) determination in the control group

The recorded image sequences were analyzed frame by frame to determine the number of particle spots. Fig. 2 presented the time-dependent decrease in the particle counts of the control group without HVE [IO]. The red rectangular points were referred to the total detected particles, and the blue triangular points were referred to the top 60% of particle diameter (large particles). In the control group, the total particle counts remained above the background level for a long duration after ultrasonic scaling. In order to estimate the range of FT for particles reducing to the baseline levels, the two estimated decay curves of the linear regression model were plotted in Fig. 2 (a) with 95% confidence intervals, and two exponential estimated decay curves were presented in Fig. 2 (b). The two yellow horizontal dashed lines were referred for the baseline levels: 4 for 12-frame of total particles and 1 for 12-frame of large particles, respectively.

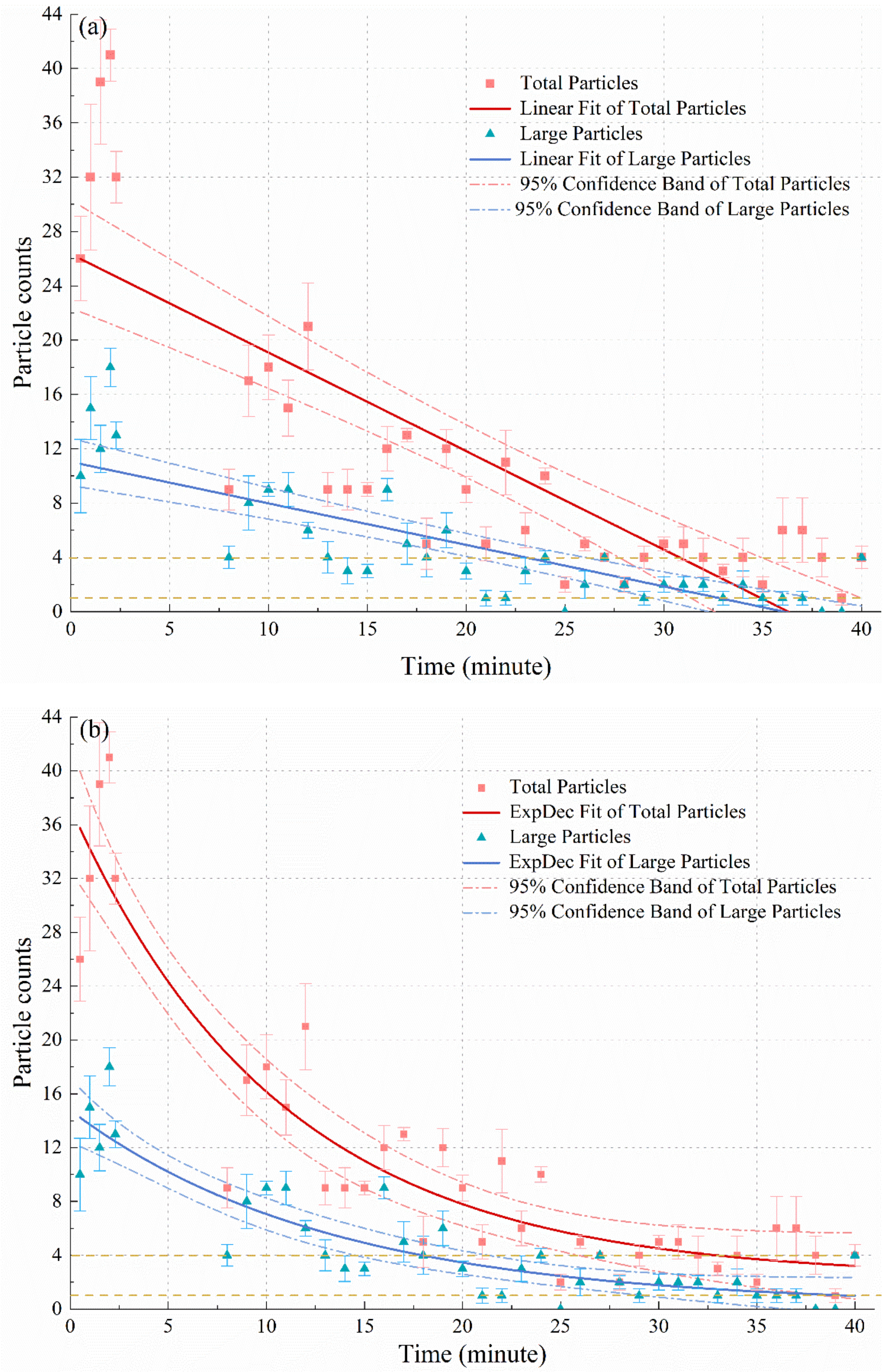

Fig. 2 The particle counts and four estimated decay curves of regression models in the post-procedure duration of 40 minutes in the control group: (a) the linear estimated curves; (b) the exponential estimated curves.

The particle count decay curves were estimated by two regression models (linear and exponential models) with the post-procedure duration as the independent variable (see Table 1). The larger R-square, the better the estimated curves. For the linear estimated curves (Linear Fit 1 and Linear Fit 2) in Fig. 2 (a), the estimated median of FT was 30.6 minutes (range 27-35 minutes) after the ultrasonic scaling. In comparison, for the exponential estimated curve (ExpDec Fit 1) in Fig. 2 (b), the total particles (red curve) decreased exponentially in time, with a time constant of 10.7 minutes, and the estimated median of FT was 32.9 minutes. The larger particle estimated curve (ExpDec Fit 2) decreased with a time content of 13.1 minutes. In all, without any intervention measures during ultrasonic scaling, the estimated FT for total particles to return to baseline level was in the range of 27-35 minutes.

Table 1 The four estimated curves of regression models in the control group

Name	Regression model	y	x	Estimated regression curve	R-Square
Linear Fit 1	$y \sim ax + b$	C_{all}	T	$C_{all} = -0.73 * T + 26.34$	0.680
Linear Fit 2	$y \sim ax + b$	C_l	T	$C_l = -0.31 * T + 11.04$	0.663
ExpDec Fit 1	$y \sim y_0 + ae^{-x/b}$	C_{all}	T	$C_{all} = 2.36 + 34.97e^{-T/10.75}$	0.855
ExpDec Fit 2	$y \sim y_0 + ae^{-x/b}$	C_l	T	$C_l = 0.30 + 14.48e^{-T/13.13}$	0.784

Note: $y =$ dependent variable of the regression, $x =$ independent variable of the regression, $C_{all} =$ total particles, $C_l =$ large particles. $T =$ post-procedure duration.

3.2 Fallow time (FT) determination in the intervention group

In comparison with the control group, the HVE [IO] was employed to cooperate with ultrasonic scaling in the intervention group. The time-dependent decrease and four estimated decay curves of regression models in the particle counts were presented in Fig. 3. The two estimated decay curves of the linear regression were plotted in Fig. 3 (a) with 95% confidence intervals, and two exponential estimated decay curves were presented in Fig. 3 (b). The particle size distribution generated in the intervention group was in line with that in the control group, but a marked difference was observed in the particle counts. Since the main function of HVE [IO] was to suck the saliva in the oral cavity and ejected droplet particles, the total detected particle counts decreased significantly in this group. The red rectangular points and blue triangular points were referred to the same meanings with Fig. 2. The yellow dash lines were also presented as the baseline levels.

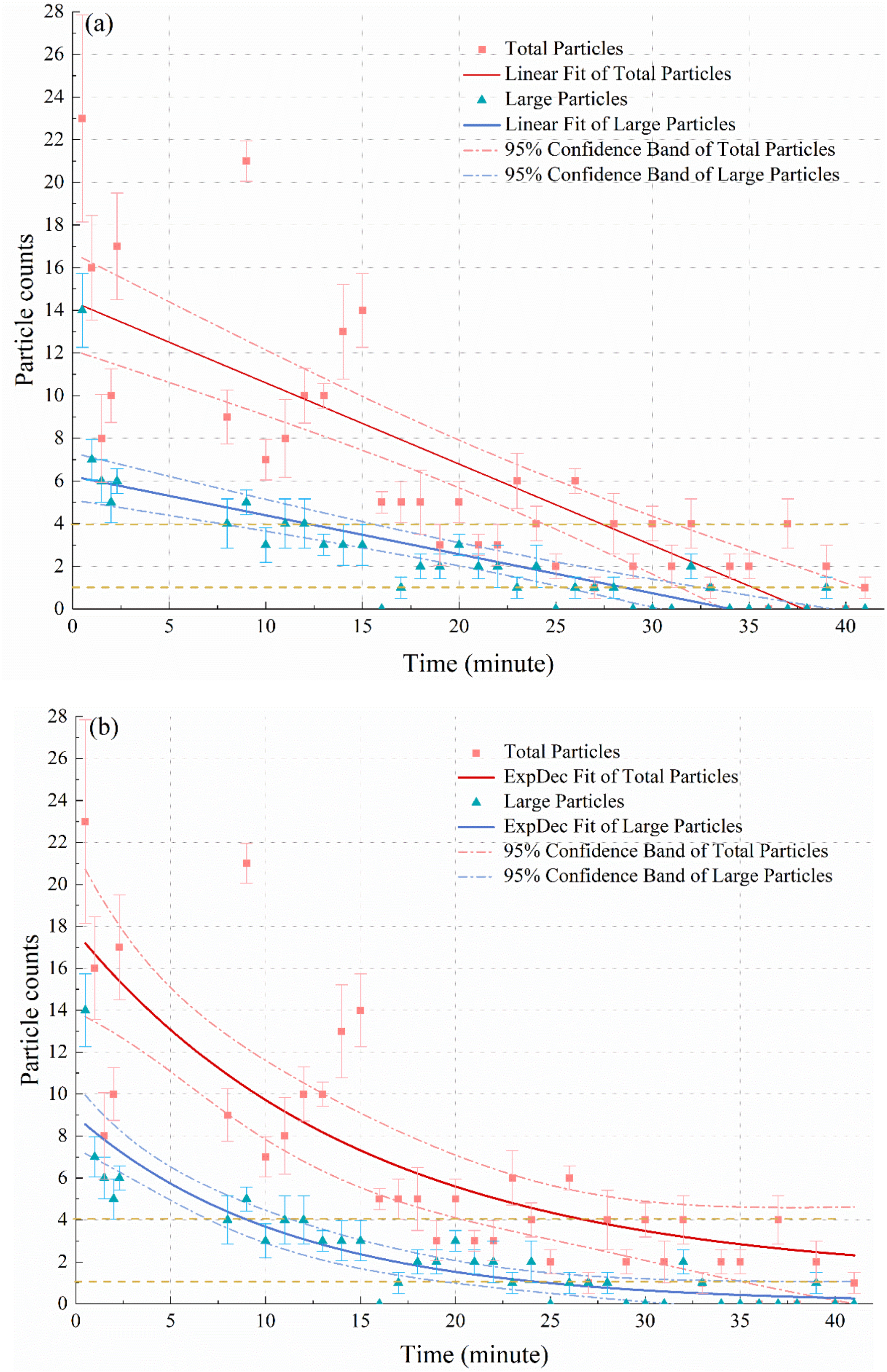

Fig. 3 The particle counts and four estimated curves of regression models (two linear and two exponential) in the post-procedure duration of 40 minutes in the intervention

group: (a) the linear estimated curves; (b) the exponential estimated curves.

In the intervention group, the particle count decay curves of regression models were estimated, and the detailed parameters were shown in Table 2. The performance of HVE [IO] on FT was analyzed below. For the linear estimated curves (Linear Fit 3 and Linear Fit 4) in Fig. 3 (a), the estimated median of FT to baseline level was 27.4 minutes (range 24-30 minutes). By comparison, the exponential estimated curve (ExpDec Fit 3) in Fig. 3 (b), the total number of particles (red curve) decreased exponentially in time, with a time constant of 15.0 minutes, and the larger particles (ExpDec Fit 3) decreased with a time content of 11.1 minutes. The estimated median of FT for the exponential curve in the intervention group was 26.8 minutes. In all, the estimated FT for total particles to return to baseline level was in the range of 24-30 min, when the HVE [IO] cooperated with ultrasonic scaling.

The cooperation of HVE [IO] could save the FT by 3-11 minutes for suspended particles reducing to the baseline levels. Considering the residual standard error of the estimated curves in the intervention group was slightly larger than that in the control group, the more detailed measurement should be carried out in future research by increasing the sampling frequency.

Table 2 The four estimated curves of regression models in the intervention group

Name	Regression model	y	x	Estimated regression curve	R-Square

Linear Fit 3	$y \sim ax + b$	C_{all}	T	$C_{all} = -0.38 * T + 14.41$	0.643
Linear Fit 4	$y \sim ax + b$	C_l	T	$C_l = -0.18 * T + 6.22$	0.638
ExpDec Fit 3	$y \sim y_0 + ae^{-x/b}$	C_{all}	T	$C_{all} = 1.24 + 16.50e^{-T/15.02}$	0.643
ExpDec Fit 4	$y \sim y_0 + ae^{-x/b}$	C_l	T	$C_l = 0.03 + 8.91e^{-T/11.17}$	0.775

Note: $y =$ dependent variable of the regression, $x =$ independent variable of the regression, $C_{all} =$ total particles, $C_l =$ large particles. $T =$ post-procedure duration.

3.3 Exposure risk source analysis

Although whether the amount of virus particles in the dental surgery operation room exceed the infectious dose is unknown, the dispersion of virus-laden droplets and aerosols should be controlled (Ge, Pu et al. 2020, Agarwal, Meena et al. 2021). According to the application of the Independent Action Hypothesis (IAH) in SARs-CoV-2 speech droplets transmission analysis (Stadnytskyi, Bax et al. 2020), each virion had an equal and non-zero probability of causing diseases. As for the asymptomatic carrier of COVID-19, the average virus RNA load in the saliva was about 7×10^6 copies per milliliter, maximum of 2.3×10^9 copies per milliliter (Wolfel, Corman et al. 2020). The probability that a 50-μm-diameter droplet containing a virion was about 1.3%, which scaled with its initial hydrated volume. However, the probability dropped to about 0.001% for the 5 μm aerosol.

Although the fluid droplets would evaporate in the falling trajectories, as shown in Fig. 4, the probability of containing a virion still scaled with the initial diameter of the patient droplet. Fig.4 referred to the overlaying of instant images in the intervention group. Besides, the proportion of liquid droplets dehydration depended on the ratio of nonvolatile substances in saliva. Traditionally, the high normal stimulated salivary flow was about $1.5\ ml/min$ (Llandro, Allison et al. 2020). The pure saliva contained 99.5% water, and the weight fraction of nonvolatile substances was within the range of 1 to 5% (Stadnytskyi, Bax et al. 2020). Commonly, the water coolant was chosen during various dental procedures, and the ultrasonic scaler with 26.5 psi water supply (flow rate of $40.6\ ml/min$) was employed in this study. Assuming that the density of nonvolatile substances was $1.3\ g/ml$, the saliva and cooling water were evenly mixed. The weight fraction of nonvolatile substances in miscible liquids of the oral cavity would be within the range of $0.03\ to\ 0.1\%$. In this study, if all water was lost by evaporation, the diameter of emitted droplets would shrink to about $10\%\ to\ 20\%$ of its patient droplets and the settling velocity would slow down (Wells 1934, Xie, Li et al. 2007). For example, if the patient droplet with an initial diameter of 50 μm shrinks to 10 μm, the falling speed would decrease from $6.8\ cm/s$ to about $0.35\ cm/s$. In all, the traveling distance and suspending time of expelled droplets from the patient's mouth is dominated by the flow velocity, evaporation rate and turbulence gas characteristic. Therefore, except for the small droplets circulated in the turbulence cloud (LI, Ming et al. 2021), the droplet nuclei generated by dehydration is one of primary sources of suspended particles, which should be the basis of the FT determination.

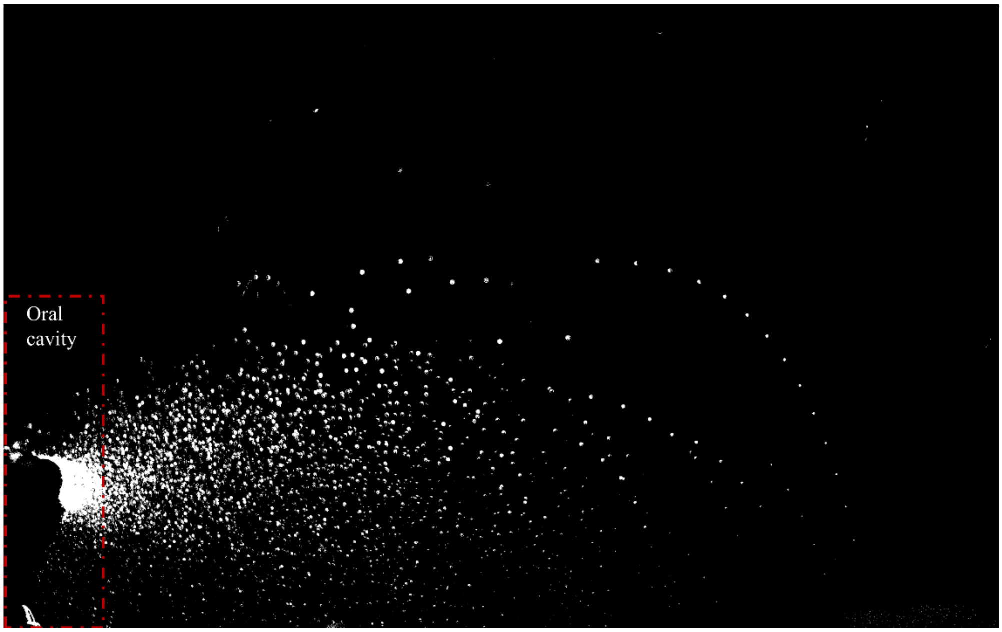

Fig. 4 The visualization of the droplet nuclei generated by dehydration and their trajectories in the intervention group

4. Discussion

Considering that the necessity and duration of FT still lacked consistency, the highly sensitive laser light scattering method has been proposed to visualize the airborne lifetime and decay rate of suspended particles generated by ultrasonic scaling. The obtained results of this study were intended to contribute to providing evidence for establishing the revised FT in dental surgery guidelines. During the COVID-19 pandemic, several methods have been proposed to investigate the transmission of droplets and aerosols like luminescent tracer (Allison, Currie et al. 2020), bacteria culture method (Zemouri, Volgenant et al. 2020), and even the visual chromatic change detection (Chavis, Hines et al. 2021). However, the above three methods only focused on the settled particles rather than the suspended ones and flow-field details. Although the concentration of suspended particles could be complemented by the aerodynamic particle sizer (APS) or the particle counter, the sampling tubes would interfere with the flow field and particle distribution. Besides, the above two techniques also limited the number of sampling points and device calibration. However, the laser light scattering method used in this study could complement the above shortcomings.

The comparison between the laser light scattering and particle counter had already been conducted in a previous study and the correlation coefficient between the results of the two techniques was always better than 0.97 (Somsen, van Rijn et al. 2020). But the technique could only give a rough indication of the particle size distribution. Currently, the APS method with sampling tubes and fluorescein tracer dye method were widely adopted to measure the FT after AGPs (Allison, Currie et al. 2020, Ehtezazi, Evans et al. 2021, Shahdad, Hindocha et al. 2021). The estimated FT from the above studies, about 30 minutes in 6 ACH, was in line with the results in our control group study. Besides, the estimated FT in this study by the exponential estimated curves performed much better than that previously by linear estimated curves (Ehtezazi, Evans et al. 2021).

Although the difference between the exponential and linear regression models was very small in the intervention group, the apparent gap with the actual particle count scatter was observed. The reason was that the influence of background noise led to some identification errors in particle counts. Notably, the cooperation of HVE [IO] in ultrasonic scaling could save the required FT by 3-11 minutes for the suspended particles reducing to the baseline levels. It demonstrated that the HVE [IO], one of the aerosol-management interventions, was relatively effective in controlling the expelled droplets in the dental surgery environment. Since the main function of HVE[IO] was to suck the saliva in the oral cavity and ejected droplet particles, the total detected particle counts decreased significantly. Although the HVE[IO] had a marked effect on reducing contamination in practice, the performance on removing large droplets was relatively medium (around 40% removal rate) in this study. Recently, a recommended combination of high-volume intraoral suction (HVS[IO]) with an Air Cleaning System (ACS) in 24 air changes per hour could reduce the FT to zero minutes (Ehtezazi, Evans et al. 2021). Considering the less detailed information about the performance and effectiveness of HVE and other mitigation measures, future quantitative research should be carried out in these aspects.

The FT could be influenced by many factors, like the surgery environment, duration of dental treatment, the dental procedures, the ventilation type, the air change rate, the number of dental professionals, and so on. As for the factor of surgery environment, although previous studies focused on the different single surgery environment (Ehtezazi, Evans et al. 2021, Shahdad, Hindocha et al. 2021), the measured FT, about 30 minutes in 6 ACH, were generally in line (Holliday, Allison et al. 2020). However, more research should be encouraged to perform in the open-plan clinic due to the many other influencing factors like more movement. Secondly, since the duration of the procedure generally depended on the individual treatment plan, this parameter varied widely in different studies. Thirdly, among the various dental procedures, the most spatter was generated during the operation of ultrasonic scaling, 3-in-1 syringe, and air-driven high-speed handpiece (Bentley, Burkhart et al. 1994). The above three AGPs were widely studied in the FT measurements of other studies (Holliday, Allison et al. 2020, Shahdad, Hindocha et al. 2021). Fourthly, the ventilation system in the hospital operating room can be designed to reduce the surgery site infection (McHugh, Hill et al. 2015). Due to the specificity of the dental surgery environment, personalized ventilation may further contribute to reducing the exposure risks on dental professionals and patients. Fifthly, although the ACH was recommended from 6 to 12 ACH by the current clinical practice guidelines in dentistry, the relationship between the FT and ACH value was not well-investigated (Clarkson, Ramsay et al. 2020). How to further reduce the FT in the conditions without negative pressure room should be studied. Sixthly, four-handed dentistry is widely adopted during the COVID-19 pandemic (Villani, Aiuto et al. 2020), more number and movement of dental professionals could significantly affect the airflow and further influence the contaminated region.

Compared with the aerosols emitted from the oral cavity, the volume of fluid droplets accounts for a much larger total fluid volume. Although the fluid droplets would dehydrate in the trajectories, the probability of droplet which contains a virus scales with its initial hydrated volume. So, in the dental surgery operation room, one of the major exposure risk sources from the droplet nuclei generated by evaporation, which should receive much more attention. The risk profile analysis should not only consider the virus load, and other parameters include, but not limited to the transmission routes, the number of particles, and so on. Although the minimal infection dose of SARS-CoV-2 is not clear, the mitigation measures, like HVE, should be recommended to reduce the number of droplets emitted from the oral cavity. Owing to the lack of reliable experimental data in the current dental surgery environment, the results of this study could be used in numerical validation. For example, the droplet velocity could act as the boundary condition. The numerical simulation in the dental surgery environment could give a detailed risk profile analysis and future research will be conducted in this aspect. Thus, the collaborations among dental professionals, building environmental and occupational health experts play a critical role in the design, construction, and even renovations of the dental operating room. Ensuring safe and flexible spaces for dental professionals and patients can make the dental operation room more sustainable, with the ability to minimizing the exposure risks.

Due to the limitation of the experimental method, the laser light scattering, the particles smaller than 10 μm were not investigated in this study. Although the particles smaller than 10 μm were the majority that can be suspended in air, the small particles were usually derived from the dehydration of large droplets in the dental surgery environment. Besides, the droplets with a size range from 10 μm to 50 μm pre-evaporation had been identified as having the highest infection probability(Chaudhuri, Basu et al. 2020). Currently, the APS method is widely used to perform real-time aerosol analysis and is best suited for particles ranging from 0.05-10 μm. The majority (99%) of detected AGP particles are < 0.3 μm diameters, well outside the range observed by laser light scattering. The high sensitivity of the laser light scattering method can be used to investigate the medium-sized (10-100 μm) droplets and larger (>100 μm) droplets. Considering the estimated FT obtained by this study was in line with that by the APS method (Ehtezazi, Evans et al. 2021), the laser light scattering, and the APS method could form a perfect complement to investigate the emitted droplets during AGPs. Considering the laser hazards, the ultrasonic scaling was limited to perform on the mannequin. Further confirmatory studies on patients should be carried out after improving laser safety. Besides, only one type of AGPs was a clear limitation of this study, and the actual individual treatment plan always included a sequence of AGPs. Such work should include more dental procedures in different surgery environments (single surgery room and open plan clinic) to validate the recommendation of FT.

5. Conclusion

Considering the lack of consistency of FT in its necessity and duration, there are no detailed studies on the airborne lifetime and decay rate of suspended particles generated during AGPs. Therefore, the laser light scattering method in this study was proposed to field the research gap. Besides, the cooperation of HVE[IO], one recommended mitigation measure, played a critical role in reducing FT. The measurement results of this study would provide evidence to establish the revised FT in dental surgery guidelines.

1) Without any mitigation measures, the estimated FT in the single dental surgery environment with 6 ACH is in the range of 27-35 minutes The key to restoring the number of daily dental services is to further reduce the FT.

2) Despite the cooperation of high-volume evacuation (HVE [IO]) cannot eliminate the FT to zero minutes, the equipment could reduce the required FT by 3-11 minutes for the suspended particles reducing the baseline levels. Owing to the longer airborne lifetime of suspended particles, the relevant protection equipment, especially respiratory protection, is quite essential in dental surgery.

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