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Spatiotemporal distribution of aerosols generated by using powder jet handpieces in periodontal department

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Abstract:

This study performed an on-site measurement of the spatiotemporal distribution of aerosols, at the range of 0-10.0 μm, generated during the use of the powder jet handpieces in a periodontal department. The mass concentration and number of aerosols were monitored within 1.0 m away from the patient's mouth at three vertical heights from the floor, namely 0.8 m (the height of the patients' mouth), 0.9 m, and 1.1 m (the height of the doctors' mouth). Overall, the concentration aerosols during the dental treatments, mostly more than 1000 μm, is much higher than the allowed thresholds in the area within 1.0 m away from the patient's mouth, putting a high exposure risk to the dental doctors and other nearby persons. Vertically, the concentration and number of aerosols are mostly comparable among on the three measured heights. Horizontally, the concentration and number of aerosols show a non-uniform distribution around the patient's mouth, especially for larger aerosols at the area closer to the mouth. This is an important characteristic of the dental spattering, which is due to the high momentum of the generated aerosols and randomness of their spattering direction. The results indicate that the present control measures, including particularly the suction system, are not effective to prevent the spattering of high-momentum aerosols generated by using dental instruments. The high risk of cross-infection in dental hospitals and clinics calls for the advancement of control measures.

Keywords:

Hospital; dental treatment, cross infection, respiratory infectious diseases, aerosols

1. Introduction

The use of instruments, such as powder jet handpieces and ultrasonic scalers, during dental treatments generates a large number of particles that may contain saliva, blood, stones, tooth fragments and so on. These particles, probably with a high initial momentum, spatter from the patient's mouth to the air of the clinic and put a high risk to the health of people in the same shared space. Studies have shown that pollutants spattering from a patient's mouth led to an increase of bacteria concentration in the surrounding air [1-2]. In addition, the spattering particles may contain metals such as silver, barium, zirconium, strontium and ytterbium [3-4], or metal oxides such as ZnO, MgO, and TiO_2 [5-6]. Inhalation of these particles may cause lung inflammation and chronic obstructive pulmonary diseases, increasing the risk of lung cancer, cardiovascular diseases and other diseases in atopic patients [7-9]. COVID-19 leads to a global outbreak due to the fact that people are generally susceptible to infection [10]. High viral load of SARS-CoV-2 were detected in oral fluids of COVID-19 symptomatic patients [11-12] and asymptomatic patients [13-14]. It has been confirmed that the infectivity of SARS-CoV-2 viruses was only slightly reduced within 3 hours under experimental conditions [15], though the environmental parameters had a great influence on their infectivity [16-18]. Implementation of effective prevention and control measures is therefore important to reduce the risk of infection for dental health-care workers and patients in a shared space.

Medical and engineering measures play important roles in reducing the pollution generated during dental treatments. The use of mouthwash such as chlorhexidine

(0.12%-0.20%) before dental treatments can reduce the number of bacteria in the clinic by more than 60% [19-22]. High volume suction systems are able to reduce the number of aerosols by more than 90% [23]. Evidently, the combination of mouthwash and high volume suction system is more effective than using one of them alone [24-25]. Xu et al. [26] reported that a combination of mouthwash and high volume suction system could effectively reduce the air pollution during ultrasonic scaling. However, the number of bacterial colonies in the air was still higher than the recommended limit of 500 CFU/m^3. To deal with the particles released into the air, dilution ventilation through either mechanical or natural means is an important method. In addition, properly located air cleaners with high-efficiency filters can effectively reduce the particle concentration in the air [2,27]. However, none of these measures are effective to remove the spattering aerosol generated during the dental treatments, especially those with a high momentum. Before developing new control measures and technologies that are aimed for these high-momentum aerosols, it is necessary to understand their distribution characteristics.

As early as 1998, Discacciati et al. [28] observed the spatter during dental treatments by adding dye to the water supply of the dental chair, and the results showed that, the patient, doctor, and the surrounding area of dental chair were all within the spattering range. In addition to simulation experiments, petri dishes were often placed in a fixed position around the clinic to study the contamination [29-30]. Since there are many kinds of bacteria in the mouth, the levels and extent of contamination of each indoor surface can be determined by comparing the number of bacterial colonies in the culture dish [31]. In order to further reveal the extent to which a doctor's surface is contaminated by spattering particles during dental treatments, there were studies applying fluorescein and other substances to a dummy's mouth, so that people can clearly observe the severely polluted area with naked eyes. However, the experimental results were different due to different operation modes and habits of doctors [32-33]. Fluorescein labeling materials are generally prohibited from real person's treatment. It has been documented that those aerosols with an equivalent diameter of less than 10 μm (also called aerosols) can suspend in the air for a prolonged period. Limited by the natural sedimentation methods, petri dishes and sterilized headbands collect rarely such airborne aerosols.

During dental treatments, airborne transmission by suspended aerosols is a great threat to dental health-care workers [34]. The size of suspended aerosols is almost the most important parameter determining their properties [35-36]. Grenier [37] suggested that the aerosol pollution could cover a whole closed dental clinic. There are three common approaches to study suspended particles (aerosols) produced during dental treatments. First, six-stage viable particle impactor was used to collect aerosols and then the environment was evaluated based on the number of bacterial colonies in the aerosols [38]. Second, the (Particle Image Velocimetry) PIV system was used to study the flow field and droplet distribution in the ultrasonic descaling process [39]. Third, aerodynamic particle sizer (APS) was used to record the mass concentration of inhalable aerosols at one or two locations [40]. Overall, past studies focused mainly on the settling time of aerosols in the air or the change of particle concentration at a few sampling locations. There is still a lack of understanding on the spatial and temporal distribution of aerosols around the site of dental treatment.

The objective of this study is to reveal the spatial and temporal distribution of aerosols near the site of dental treatment. The process of using powder jet handpieces that is a widely used instrument was selected as a research target. On-site measurements of the concentration and number of spattering aerosols were performed in the periodontal department of a dental hospital. The findings of this study would increase our understanding of the characteristics of spattering aerosols during dental treatments and provide information for the development of control measures.

2. Experimental methods

2.1. Experimental site and subjects

The on-site measurements were performed in a periodontal department in the Changsha Stomatological Hospital located in Changsha city, Hunan province, China, during the period from Jan 24, 2021 to Jan 31, 2021. The measurements covered the dental treatments of 63 patients. The clinic was equipped with a wall-mounted air cleaner, which was in operation from 12:10-14:10 and 17:30-19:30 every day. As shown in Figure 1, there were windows in the dental treatment area, which were usually opened slightly during the business hours. There was a mechanical ventilation system in the dental treatment room, which, however, was not in operation during the experimental period.

As shown in Figure 1, the dimensions of the periodontal department selected for performing the measurements were 18.0 m × 12.0 m, and it contained 12 dental chairs in 12 semi-separated units. The dimensions of each unit were 4.8 m × 3.0 m.

The main treatment projects of the periodontal department included dental cleaning, periodontal basic treatment, and periodontal surgeries. Among others, powder jet handpieces and ultrasonic scraping machine were used intensively during the dental cleaning process. Dental cleaning procedures include supragingival scaling and subgingival scaling. During supragingival scaling, powder jet handpieces were often used to remove pigments from the patient's teeth.

The mixture from the powder jet handpieces includes water and sand powder that is mainly composed of sodium bicarbonate. The mixture is contaminated when contacted with patient's teeth or the mucous surfaces of the mouth. Some of the contaminants left in the mouth were sucked out by a low volume suction system. The rest of the contaminants spatter from the mouth into the air.

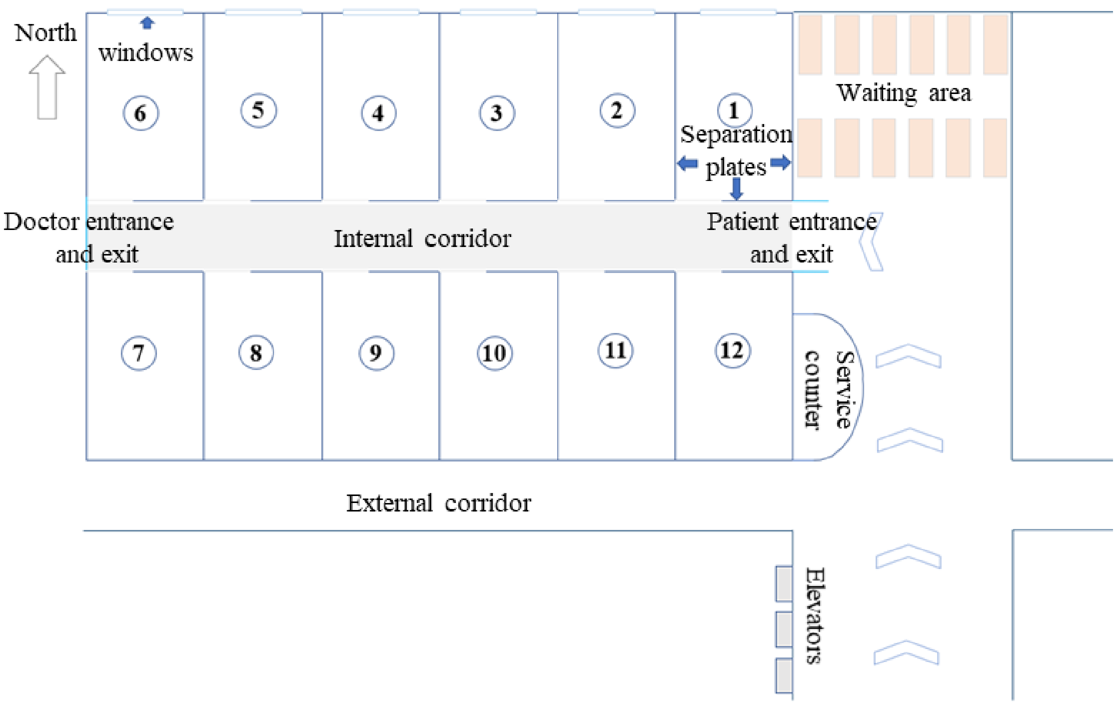

Figure 1 Distribution of the dental treatment units in the periodontal department.

2.2. Experimental condition and procedures

During the measurements, only one medical staff was performing the cleaning of the patient's teeth (see Figure 2 (a)). During the cleaning, a low volume suction system was used to remove liquid contaminants in the oral cavity and the inner diameter of its nozzle was 6 mm. It is known that aerosol with a diameter of less than 10 μm can enter the bronchioles and alveolus of human lung [41], causing a great harm to human health. In order to reveal the distribution characteristics of this range of aerosol, a handheld IAQ particle counter was used, as shown in Figure 2 (c). Monitoring parameters of this instrument include the concentration and number of PM0.3, PM0.5, PM1.0, PM2.5, PM0.5, and PM10.0. In order to study the distribution of aerosols around the patient's mouth, dozens of sampling points were arranged (see Figure 3). In addition, measurements at three different heights were performed, namely, the height of the patient's mouth (0.8 m), the height of the medical staff's mouth while sitting (1.1 m), and the height in between these two heights (0.9 m), as shown in Figure 3. During the dental treatment, the medical staff moved around in the area between the line 45° and the line 270°.

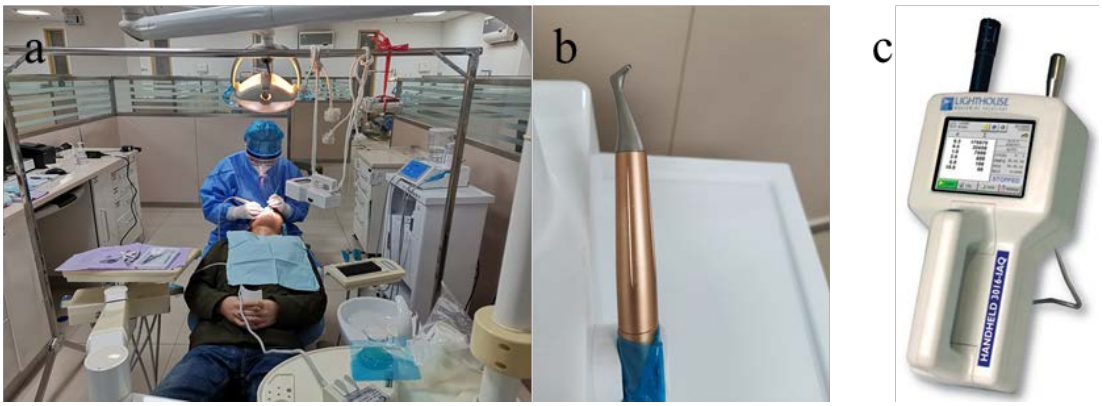

Figure 2 (a) Photo of the on-site measurement, (b) The nozzle of the powder jet

handpieces, and (c) Handheld 3016 IAQ particle counter

The measurement duration at each sampling point was the time used for the dental treatment of one patient. Due to the differences between patients' oral health condition, oral structure, and tooth distribution, the treatment time (namely the measurement duration) for the 63 patients was between 17 and 56 minutes. It is obvious that the treatment could include many procedures. The sampling durations that correspond specifically to the durations of using powder jet handpieces on each patient were extracted and presented in Table 1. They were between 2 minutes and 13 minutes, indicating the complexity and diversity of the actual dental treatment processes. This provides basic information for future experimental and numerical simulations of dental treatments.

Table 1 The sampling durations (minutes) at the sampling points on the height of 0.8 m and 1.1 m (see the yellow dots in Figure 3).

Height (m)	0°	45°	90°	135°	180°	225°	270°	315°
0.8	6	2	5	7	11	5	12	-
1.1	5	4	11	2	5	4	6	13

The sampling location of the background concentration in the periodontal department was located in the middle of dental treatment unit No. 5, 0.9 m away from the floor. The measurements of background concentration were performed for 3 minutes before the admission of the first patient in the morning. The mean background concentrations during the period of Jan 24-27 were presented in Table 2. As can be seen from Table 2, the mass concentrations of aerosols were higher than the limits recommended by Chinese IAQ standard [42].

Table 2 The mean background concentrations (μg/m³) in the department during the measurement period from January 24 to 27, 2021.

Date	PM0.3	PM0.5	PM1.0	PM2.5	PM5.0	PM10.0
Jan 24 to 27	25.2	67.2	101.5	130.6	165.5	193.8

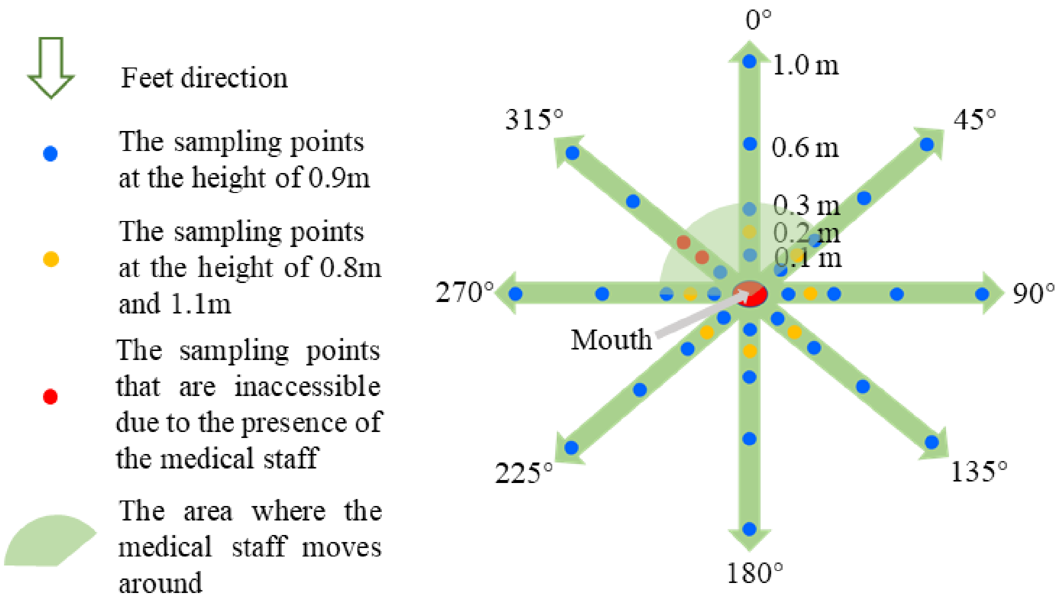

Figure 3 Distribution of sampling points.

3. Results and analyses

In order to investigate the spattering characteristics of aerosols generated by using powder jet handpieces during dental treatments, the concentration and number of aerosols surrounding the patient's mouth and their variations over time were analyzed.

3.1. Distribution of aerosols along height

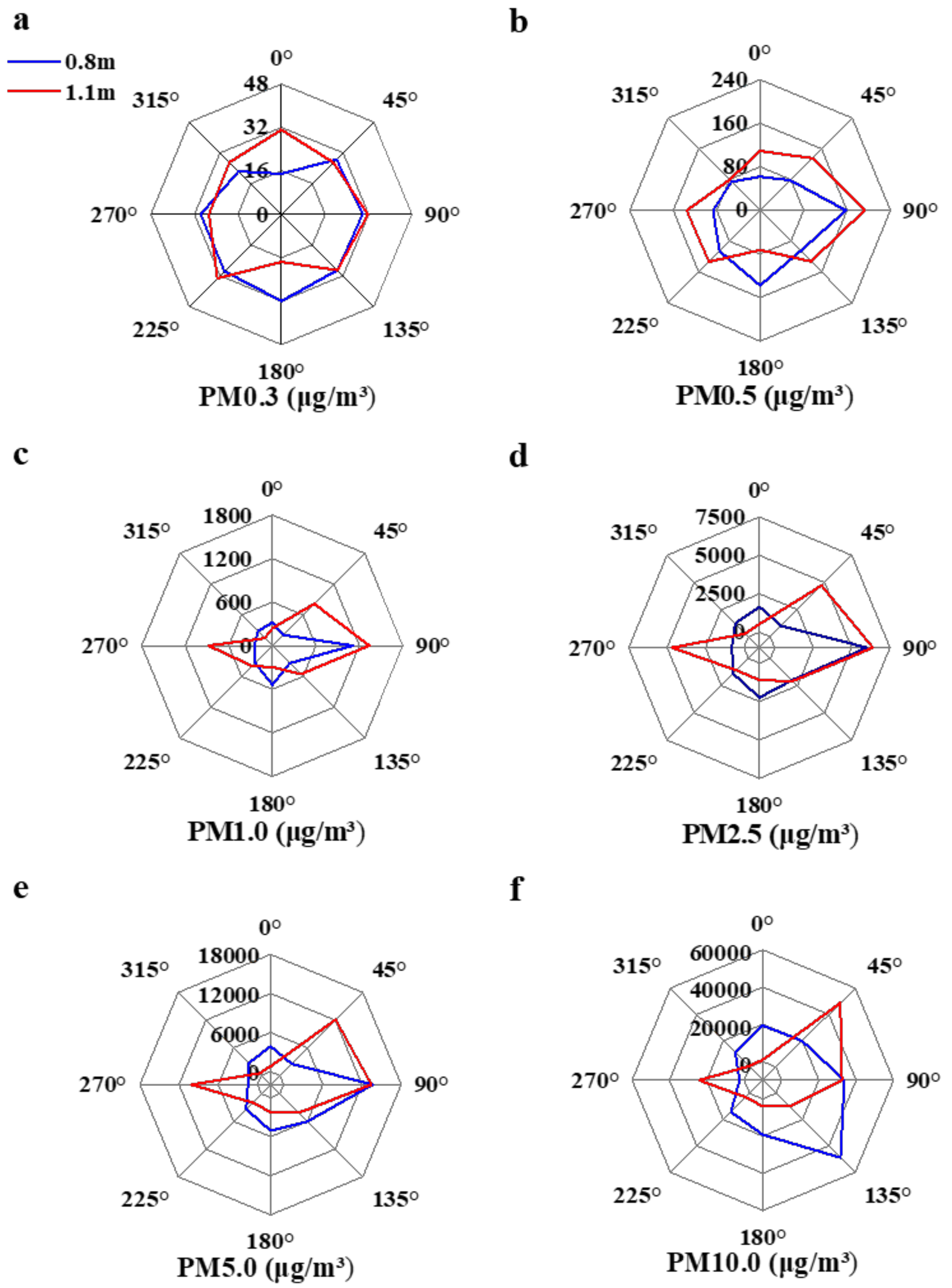

Figure 4 Mass concentrations distribution of aerosols with different particle sizes: (a) PM0.3, (b) PM0.5, (c) PM1.0, (d) PM2.5, (e) PM5.0, and (f) PM10.0 at the heights of 0.8 m and 1.1 m from the floor and 0.2 m from the mouth. Note: the value of the point on the line 315° at the height of 0.8 m from the floor was not measured (due to the presence of the medical staff) but calculated to be the average of the two points on the

lines 0° and 270° at the height of 0.8 m.

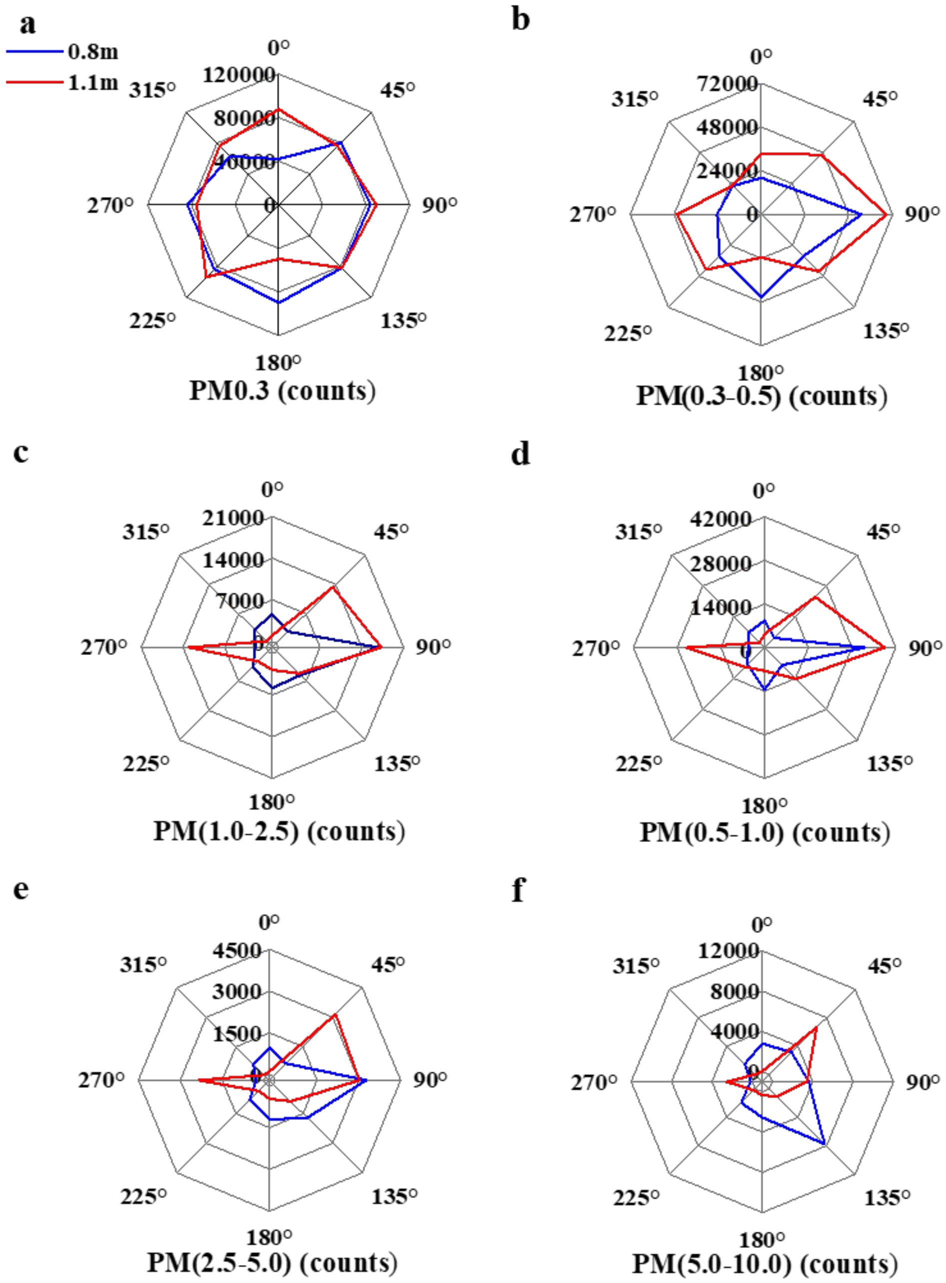

Figure 5 Distribution of number of aerosols with different particle sizes: (a) PM0.3, (b) PM (0.3-0.5), (c) PM (0.5-1.0), (d) PM (1.0-2.5), (e) PM (2.5-5.0), and (f) PM (5.0-10.0) at the distance of 0.2 m away from the mouth and at the heights of 0.8 m and 1.1 m from the floor. Note: the value of the point on the line 315° at the height of 0.8 m from the floor was not measured (due to the presence of the medical staff) but

calculated to be the average of the two points on the lines 0° and 270° at the height of 0.8 m.

In order to analyze the vertical distribution, the mass concentrations of aerosols measured at the points with 0.2 m away from the patients mouth at the heights of 0.8 m and 1.1 m were presented in Figure 4. From this figure, the following major observations can be made. First, the mass concentration distribution of aerosol with different sizes was different, though the concentrations of PM0.3 and PM0.5 were relatively similar at each sampling point. The mass concentrations of PM1.0, PM2.5, PM5.0, and PM10.0 were relatively small in the area (counter-clockwise between the lines 45° and 270°) where the doctors are often present and relatively large in the remaining area. Second, on the 0.8 m height from the floor, the mass concentrations at the sampling points in the left side and in front of the doctor (sampling points on the lines 90°, 135° and 180°) were relatively high; on the height of 1.1 m from the floor, the left and right sides of the patient's mouth (sampling point on the lines 90° and 270°) and the sampling points on the line 45° had higher concentrations than others. The reasons for this distribution should include the blocking effect of the doctor’s body and the use of right hand for dental treatments. Third, the mass concentrations did not necessarily decay along height. In general, mass concentrations on the height of 1.1 m were larger than those on the height of 0.8 m at the left side of the doctor, namely on the line 45°, but this was opposite in front of the doctor, namely on the line 180°. According to the Technical Standard for Isolation in Hospitals issued by China's Ministry of Health, airborne transmission refers to the 4spread of disease caused by airborne movement of micro aerosol (≤ 5 μm) carrying pathogenic microorganisms [43]. The mean concentrations of PM5.0 at all sampling points were more than 1000 μg/m³ except for the sampling points on the line 315°. This level of concentration was much higher than the healthy threshold, suggesting that a high exposure risk faces doctor and other persons around the patient under dental treatments.

Figure 5 presents the distribution of the average number of aerosols at the height of 0.8 m and 1.1 m. The number of aerosol smaller than 0.3 μm is the largest, and that between 2.5 μm and 5.0 μm is the least. The number of PM0.3 is two orders of magnitude higher than PM (2.5-5.0).

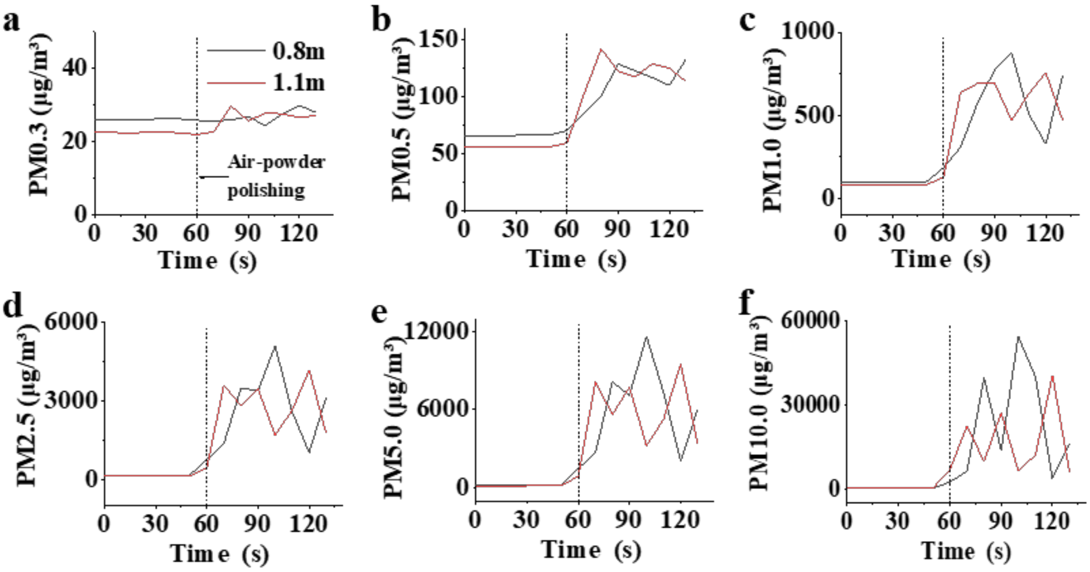

Figure 6 Distribution of mean mass concentrations of all sampling points at the distance of 0.2 m away from the mouth and at the heights of 0.8 m and 1.1 m.

In Figure 6 and Figure 7, the measured data during 60 seconds before the air-powder-polishing process and 70 seconds at the beginning of the air-powder-polishing process were selected for comparative analysis. From Figure 6, the following analyses can be made. First, the mass concentrations increased considerably after the start of the process of air-powder-polishing. Second, for both PM0.3 and PM0.5, the concentrations at the heights of 0.8 m and 1.1 m are quite close. However, the peak value of PM1.0 at the height of 0.8 m was higher than that at 1.1 m, and the greater the particle size is, the more obvious it is. This should be due to the gravitational effect of aerosol. Third, taking PM5.0 as an example, the mean concentration of aerosol within the 1.0 minutes before the air-powder-polishing process was 218.56 $\mu g/m^3$, and over the process of air-powder-polishing was much more than 1000 $\mu g/m^3$. Compared with the concentration before the air-powder-polishing process, the concentration was increased by one order of magnitude in the process of air-powder-polishing. Note that the indoor background concentrations were relatively high even before the treatment and the breaks between two dental treatments on different patients were not long enough for the indoor concentrations to fully decay. The relatively low concentrations before air-powder-polishing were measured after stopping the ultrasonic scaling and when the doctor was changing the instrument. The large fluctuation in concentrations during the process of air-powder-polishing should be attributed to that the air-powder-polishing process was not a continuous, but an intermittent, process. Aerosols released during the process of air-powder-polishing mostly had a high momentum, which can quickly pass through the sampling points and move to the indoor environment. If air-powder-polishing treatment was terminated, a rapid reduction of the concentrations occurs.

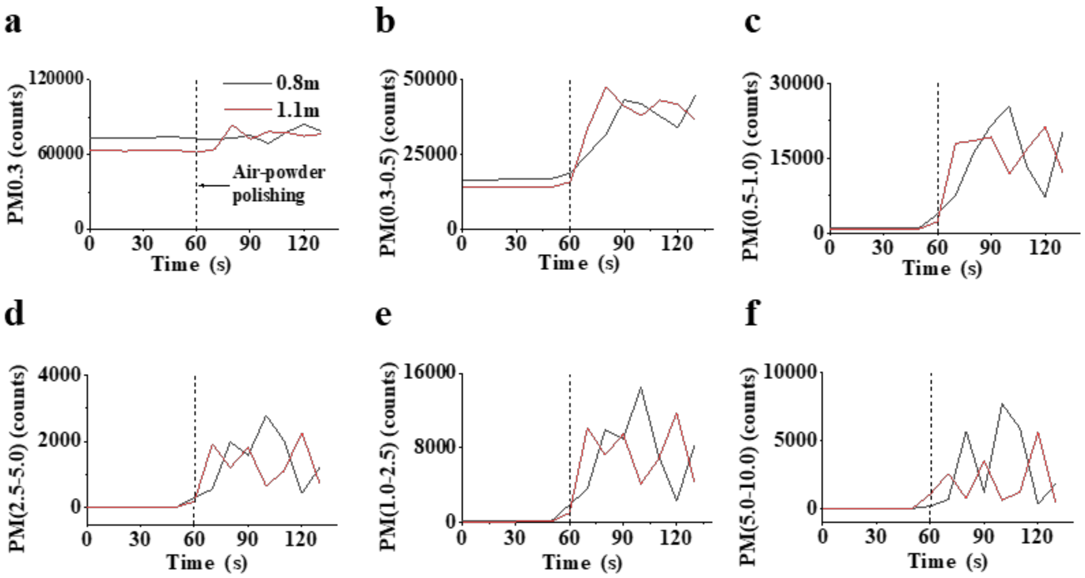

Figure 7 Distribution of mean number concentrations of all sampling points at the distance of 0.2 m away from the mouth and at the heights of 0.8 m and 1.1 m.

3.2. Distribution along horizontal direction

Figure 8 and Figure 9 presents the horizontal distribution of the concentration and number of aerosols with different sizes at the height of 0.9 m from the floor. First, the mass concentrations of aerosol showed a decreasing trend along the horizontal distance from the mouth. The area that was farther away from the mouth had a more uniform distribution towards different horizontal directions. For example, the distribution at the distance of 1.0 m away from the mouth was quite uniform, but it was heterogeneous at 0.1 m. Second, the mass concentration of PM0.3 was relatively uniform in the horizontal direction and did not have an obvious difference in the region from 0.1 m to 1.0 m away from the patient's mouth. With the increase of particle size, the concentration gradually decreased with the increase of the distance in the horizontal direction. The distribution of PM1.0, PM2.5 and PM5.0 was very similar, indicating their similar aerodynamic characteristics. Third, PM (0.5-5.0) had certain similarities in horizontal distribution, that was, most values of sampling point were larger along the direction on the lines 0° and 225°. The lines 0° and 225°correspond to the directions along the patient's head and the right front of the doctor, which were roughly at the left and right sides of the doctor's movement area. This finding does not completely comply with that analyzed in the Section 3.1. The possible reason is that the data presented in the two sections is different, as it was obtained at different times with different patients treated by different doctors. Fourth, the concentration of PM10.0 sharply decays from 0.1 m to 0.3 m away from the mouth, and then didn’t show obvious change until 1.0 m away. Fifth, for PM5.0, the concentrations at 1.0 m from the patient's mouth decreased to the lowest, but still had on average 717.0 $\mu g/m^3$, indicating the high risk of exposure.

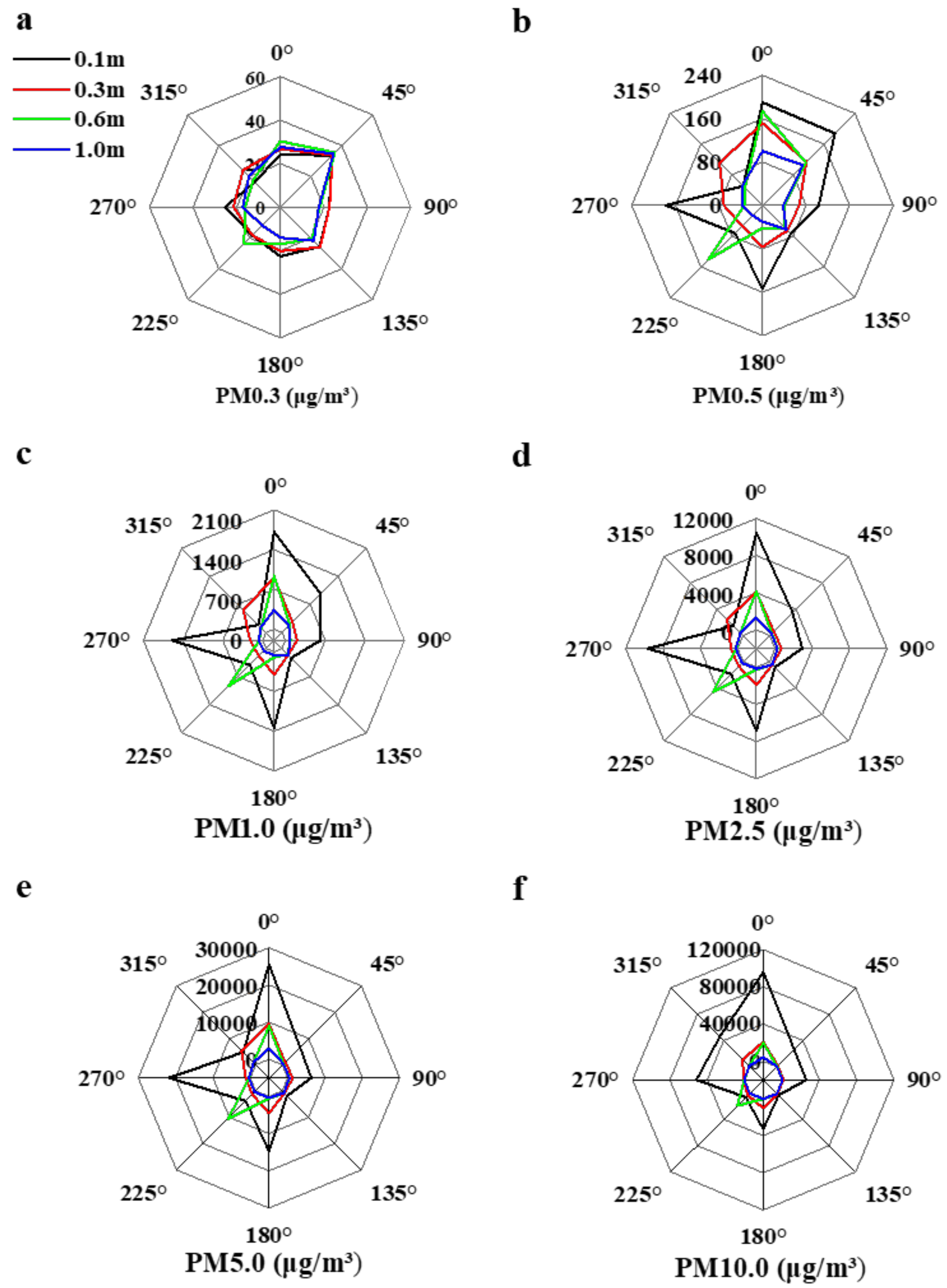

Figure 8 Distribution of mass concentrations of aerosols with different particle sizes: (a) PM0.3, (b) PM0.5, (c) PM1.0, (d) PM2.5, (e) PM5.0, and (f) PM10.0 at the distances of 0.1 m, 0.3 m, 0.6 m, and 1.0 m away from the mouth and at the height of 0.9 m from the floor. Note: the value of the point at the distance of 0.3 m away from the mouth on the line 315° was not measured (due to the presence of the medical staff) but calculated to be the average of the two points at the distance of 0.3 m away

from the mouth on the lines 0° and 270°.

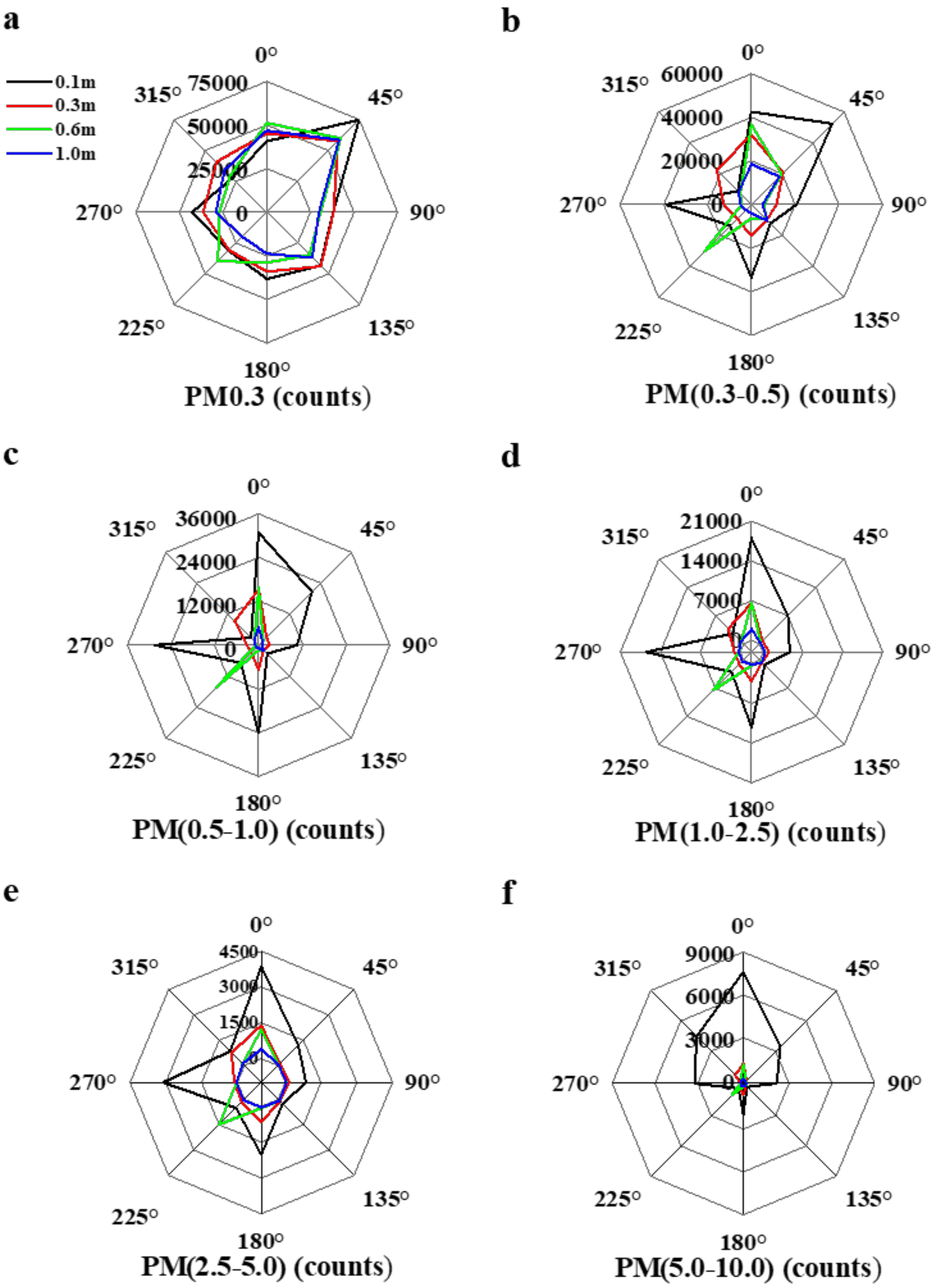

Figure 9 Distribution of number of aerosols with different particle sizes: (a) PM0.3, (b) PM (0.3-0.5), (c) PM (0.5-1.0), (d) PM (1.0-2.5), (e) PM (2.5-5.0), and (f) PM (5.0-10.0) at the distances of 0.1 m, 0.3 m, 0.6 m, and 1.0 m away from the mouth and at the height of 0.9 m from the floor. Note: the value of the point at the distance of 0.3

m away from the mouth on the line 315° was not measured (due to the presence of the medical staff) but calculated to be the average of the two points at the distance of 0.3 m away from the mouth on the lines 0° and 270°.

Figure 10 and Figure 11 presents the variation of mean mass concentration and number of aerosols at different distances away from the patient's mouth on the height of 0.9 m during a 1.0-minute process of air-powder-polishing. As can be seen, larger aerosols generally had higher fluctuations in concentration over time, especially in the area closer to the patient's mouth. This should be attributed to that the smaller aerosols have weaker gravitational and momentum effects and do not have an obvious dispersion direction.

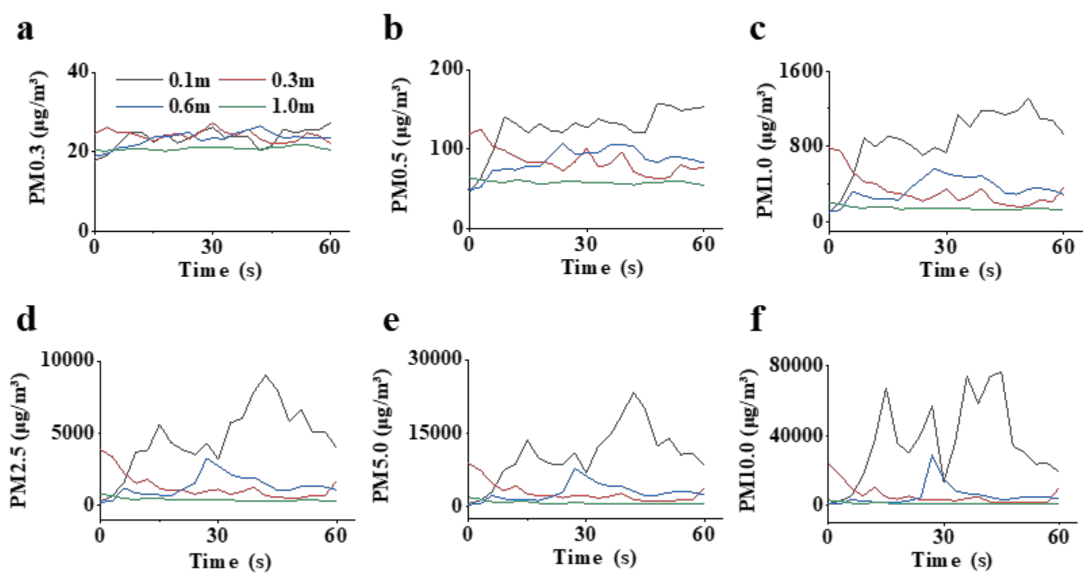

Figure 10 Distribution of the mean mass concentration of aerosols of all sampling points at the distances of 0.1 m, 0.3 m, 0.6 m, and 1.0 m away from the mouth and at the height of 0.9 m from the floor.

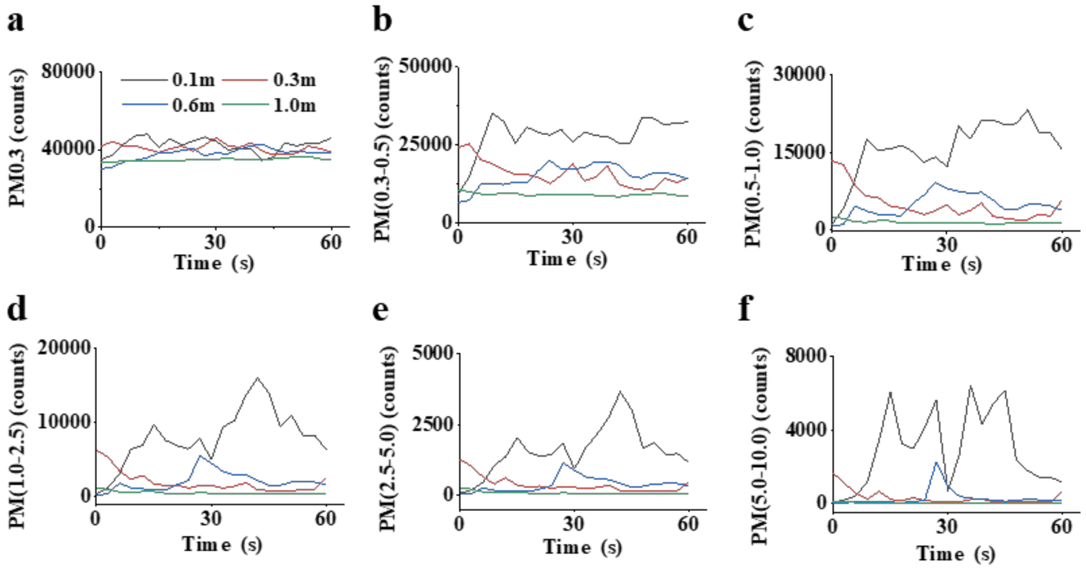

Figure 11 Distribution of the mean number of aerosols of all sampling points at the distances of 0.1 m, 0.3 m, 0.6 m, and 1.0 m away from the mouth and at the height of 0.9 m from the floor.

4. Discussion

Since the aerosols stay around the dental treatment units for more than 30 minutes after dental cleaning [34], it was suggested that the interval between two consecutive patients should be more than 30 minutes. According to the actual situation during the measurements, the interval was mostly less than 5 minutes. During this period, doctor dealt with the medical waste generated by the operation, replaced the instruments, and simply disinfected the surfaces around the dental chair. The very short interval times should be attributed to the relatively large number of patients and relatively shortage of medical resources. It should be noted that the breaks between two consecutive patients were usually less than 5 minutes, which means that the indoor concentration of aerosols generated during the dental treatment of a former patient was still very high when the dental treatment of a latter patient started. Though this was a real condition, such a high background concentration during the business hours did have considerable influences on both the exposure of the medical staffs and patients as well as on the measurements.

The experimental results of the concentration and number of aerosols (PM0.3-10.0) within the area not farther than 1.0 m away from the patient's mouth during the process of air-powder-polishing have been analyzed. They in general show that the concentration in this area is quite high and thus the exposure risk of persons near the treatment site is high. Although the mouthwash can reduce the number of viable pathogens in the mouth, it does not reduce the number of aerosols generated during the dental treatments. The present prevention and control measures aiming for reducing the spattering aerosols during the dental treatments include mainly the suction equipment and the ventilation. As the spattering aerosols are generated by the interaction between the dental instruments and the teeth, they have a high initial momentum. Most such high-momentum aerosols are impossible and ineffective to be captured by the present measures. In order to reduce the effect of spattering aerosols, the following suggestions may be considered. The dental treatments should be conducted with four or six hands instead of two hands. Except for low volume suction, an additional high volume suction system with the head larger than 0.8 mm in diameter should be used by the newly added assistant to absorb the spatter. In order to improve the cleaning and disinfection efficiency, the air cleaner should be placed as close as possible to the site of dental treatment. The air cleaner should always be in operation during the working hours. If possible, dental treatments should be carried out in an independent space, rather than a shared space, to limit the affected area of the spattering aerosols. Considering the falling of a large number of aerosols, the surfaces near the site of dental treatment should be disinfected regularly. The intervals between the treatments on two consecutive patients should be enlarged or two treatment spaces may be allocated to a same team of dental staffs for alternate use.

The affected scope of the spattering particles during the process of dental treatments is an important concern. Veena et al. [32] simulated the ultrasonic scraping process in the mouth of a dummy. Several sampling points were set up near the dummy's mouth, and the degree of pollution was judged according to the distribution of fluorescent dye on the paper placed at the sampling points. The pollution that could be observed was mostly caused by large particles. The simulation showed a maximum contamination area of 1.2 m, which means that the main contamination area was within a 0.6 m radius. The most severe contamination occurred at about 0.3 m near the left side of the dummy’s mouth, followed by at about 0.3 m in front of the mouth, and then at about 0.3 m overhead. The present study that was based on the inhalable aerosols generally agrees with this study on the scope of the high-contamination area. However, for inhalable aerosols, the present study found that the maximum concentration appeared at around the mouth and then decreased with distance. In addition, the distribution of concentration and number of aerosols was quite scattered around the mouth, especially for larger particles at a distance closer to the patient’s mouth. In general, the maximum concentration appeared towards the head and feet directions of the patient as well as towards the left hand and right hand of the doctor.

The data in the present study was collected during the actual dental treatment of 63 different patients. Restricted by the number of instruments and the limited space for sampling, the sampling at different points was performed at different times and probably based on different patients. This is a limitation of the present study, though the data obtained reveals the general condition of the distribution of aerosols during the use of powder jet handpieces.

5. Conclusions

Distribution of inhalable aerosols generated by using powder jet handpieces was measured during the air-powder-polishing treatment, which allows the following conclusions to be drawn.

Overall, the concentration and number of aerosols during the dental treatments are much higher than the allowed thresholds in the area within 1.0 m away from the patient's mouth, putting a high exposure risk to the dental doctors and other nearby persons.

Vertically, the concentration and number of aerosols do not necessarily decrease from the height of the patient's mouth to the height of the doctor's height. Horizontally, the concentration and number of aerosols mostly decrease with the increase of distance away from the mouth, but their distribution around the mouth is quite scattered. In terms of particle size, the distribution of smaller aerosols tends to be more uniform around the patient's mouth. In terms of distance, the area that is farther away from the mouth has a more uniformly distributed concentration of aerosols. Relatively high concentration and number appear towards the head and feet directions of the patient as well as towards the left hand and right hand of the doctor.

The concentration and number of aerosols increase quickly after the start of the air-powder-polishing process, fluctuate over the process. The fluctuation is generally higher for larger aerosols at a shorter distance on the height of the patient's mouth. The reason should be that the dispersion of a larger particle is more influenced by the gravitation and initial momentum and less influenced by the mixing effect of indoor air.

The results of this study can provide a theoretical basis for the research and development of new measures and technologies on removing and controlling the spattering aerosols generated during dental treatments.

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Highlights

The range and level of aerosol pollution caused by the powder jet handpieces were quantified.

The mass concentration and number of particulates in the aerosol were quantified.

It provides a theoretical basis for proposing new devices to control the spatter of pollutants.