



## Research article

## Ultrafine particles exposure is associated with specific operative procedures in a multi-chair dental clinic



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## ABSTRACT

Air quality in dental clinics is critical, especially in light of the severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) pandemic, given that dental professionals and patients are at risk of regular exposure to aerosols and bioaerosols in dental clinics. High levels of ultrafine particles (UFP) may be produced by dental procedures. This study aimed to quantify ultrafine particles (UFP) concentrations in a real multi-chair dental clinic and compare the levels of UFP produced by different dental procedures. The efficiency of a high-volume evacuator (HVE) in reducing the UFP concentrations during dental procedures was also assessed. UFP concentrations were measured both inside and outside of a dental clinic in Shanghai, China during a 12-day period from July to September 2020. Dental activities were recorded during working hours. The mean ( $\pm$ standard deviation) concentrations of indoor and outdoor UFP during the sampling period were 8,209 ( $\pm$ 4,407) counts/cm<sup>3</sup> and 15,984 ( $\pm$ 7,977) counts/cm<sup>3</sup>, respectively. The indoor UFP concentration was much higher during working hours (10,057  $\pm$  5,725 counts/cm<sup>3</sup>) than during non-working hours (7,163  $\pm$  2,972 counts/cm<sup>3</sup>). The UFP concentrations increased significantly during laser periodontal treatment, root canal filling, tooth drilling, and grinding, and were slightly elevated during ultrasonic scaling or tooth extraction by piezo-surgery. The highest UFP concentration (241,136 counts/cm<sup>3</sup>) was observed during laser periodontal treatment, followed by root canal filling (75,034 counts/cm<sup>3</sup>), which showed the second highest level. The use of an HVE resulted in lower number concentration of UFP when drilling and grinding teeth with high-speed handpieces, but did not significantly reduce UFP measured during laser periodontal therapy. We found that many dental procedures can generate high concentration of UFP in dental clinics, which may have a great health impact on the dental workers. The use of an HVE may help reduce the exposure to UFP during the use of high-speed handpieces.

## 1. Introduction

Air quality in dental clinics has become an important concern. This concern has become alarming under the light of the severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) pandemic (Cherrie et al., 2020). Previous studies have found that the indoor dental environment is

particularly subject to bioaerosols air pollution (Nejatidanesh et al., 2013; Sotiriou et al., 2008). Dental professionals and patients may be constantly exposed to a clearly visible aerosol cloud of particulate matter and fluid during dental treatment. This ubiquitous aerosolized cloud can be produced by many dental procedures, such as tooth preparation with a rotary instrument or air abrasion, the use of an air-water syringe, using ultrasonic

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scaling or air polishing (Micik et al., 1969; Miller et al., 1971; Bennett et al., 2000). It has been proven by several studies that a great variety of infectious agents and toxic substances such as microorganisms and viruses, allergenic substances, solvent fumes and fine particulate matter can be transported by aerosols and bioaerosols generated in the dental clinic environment, which may be a risk factor for cross-infection for dental professionals, staff, and patients (Bennett et al., 2000; Kedjarune et al., 2000; Harrel et al., 2004; Kimmerle et al., 2012; Yamada et al., 2011). An increased prevalence of respiratory infections among dental personnel and a direct relationship between bioaerosols produced during dental procedures and respiratory system infections has been demonstrated (Harrel et al., 2004).

Additionally, existing studies provide evidence that the dental healthcare workers and patients are also exposed to large amounts of abiotic particles, which are generated from different dental procedures, such as drilling teeth (Sotiriou et al., 2008; Helmis et al., 2008; Liu et al., 2019), removing the old restorations and grinding/polishing dental materials with high/low speed turbine handpieces (Nayebzadeh et al., 1998; Collard et al., 1989; Helmis et al., 2007; Van Landuyt et al., 2012). In addition to the disease transmission through bioaerosols, exposure to abiotic aerosol particles in dental clinics and laboratories adversely affects human health (Taira et al., 2009). To date, various studies have reported the health effects caused by exposure to particulate matter, such as particulate matter less than 10  $\mu\text{m}$  ( $\text{PM}_{10}$ ) and 2.5  $\mu\text{m}$  ( $\text{PM}_{2.5}$ ) in aerodynamic diameter, during dental procedures (Sotiriou et al., 2008; Brunekreef et al., 2009; Cassee et al., 2013; Kadaifciler et al., 2013). Godwin et al. (2003) found that  $\text{PM}_{2.5}$  levels in the dental office exceeded ambient standards (by a factor of 2–6) throughout the building. In addition, a previous study showed that the drilling activities in the operating room are associated with the smallest particles ( $<0.5 \mu\text{m}$ ), which is significantly higher than the background level (Sotiriou et al., 2008). Particulate matter may contain potential toxic trace elements such as Al, Si, Zr, and Ba. The aerosolized particles may be deposited in certain regions of the respiratory tract, with deposition amounts and areas dependent on particulate size and concentration (Day et al., 2008). Particles of a certain size may further enter the bloodstream, causing respiratory and cardiovascular diseases and increasing mortality (Burnett et al., 2014; Lelieveld et al., 2015).

Recently, increasing attention has been focused on ultrafine particles (UFP) with aerodynamic diameters less than 0.1  $\mu\text{m}$ . Existing evidence indicates that UFP may have a greater potency to cause adverse health effects compared with larger particles (Ferreira et al., 2013; Kumar et al., 2013, 2014). An important property of UFP is the large surface-area to mass ratio that allows them to act as carriers of toxic chemicals (Wichmann and Peters, 2000). The large variety of compounds that attach to these particles is likely to be a major cause of their toxicity (Schraufnagel, 2020). However, limited attempts have been made to assess the air quality status of dental clinics by measuring UFP with diameter below 100 nm (Van Landuyt et al., 2014; Polednik, 2014; Ochsmann et al., 2020). In dental practice, UFP are abundant and are mainly produced by intra-oral grinding/polishing dental resin material containing nano-sized particles, such as pyrogenic silica ( $\text{SiO}_2$ ) or zirconium dioxide ( $\text{ZrO}_2$ )– $\text{SiO}_2$  (Schmalz et al., 2018; Van Landuyt et al., 2014; Polednik, 2014; Rupf et al., 2015; Ochsmann et al., 2020). These nano-sized particles may deposit in the alveoli of the lungs (Donaldson et al., 2005; Day et al., 2008). Substances such as silica or the other nanoparticles generated during grinding dental materials have a fibro-genic potential and may cause lung fibrosis (Hoffmeyer et al., 2007). They might further cross the biological barriers and enter the bloodstream, either through mobile cells or freely in the vasculature and lymph to directly harm distal organs causing lung cancer, pulmonary and cardio-vascular diseases, neurodegenerative diseases, asthma, increased mortality (Sotiriou et al., 2008; Lelieveld et al., 2015; Cokic et al., 2020a; Schraufnagel, 2020; Calder'on-Garciduñas et al., 2004; Von Klot et al., 2002; Maher et al., 2016; Tian et al., 2019) or even occupational disability in dental health care workers (Leggat et al., 2007). The exposure to nanoparticles in the dental laboratories is addressed by legal regulations (Schmalz et al., 2018). Another key issue, mostly studied using animal experiments is the potentially carcinogenic effect of UFP,

which depends on the underlying substances and is still under scrutiny (Ostiguy et al., 2008; Simko et al., 2010). Hence, more attention should be paid on air quality in dental clinics.

The objective of this study was to quantify UFP concentrations in real multi-chair dental clinics and to compare the levels of UFP produced by different dental procedures. We also assessed the efficiency of an HVE in reducing the UFP concentration during dental procedures.

## 2. Material and methods

### 2.1. Measurement site

UFP concentrations were measured in the dental department of Shanghai Tenth People's Hospital, a comprehensive hospital in Shanghai, China. The dental clinic is a 4-story building, located in the downtown area of Shanghai. The endodontics, periodontics and operative dentistry (EPOD) and prosthodontic Clinics are located on the first floor of the building. The clinic operates in two shifts (08:00–12:00 and 13:30–17:00) from Monday to Saturday, with a maximum of 35 occupants in every shift.

Before the main experiment, preliminary measurements were performed in several areas of the dental clinic. According to the results, the EPOD and prosthodontic clinic, on the first floor of the building, was selected for the experiment because of their characteristics and high pollution levels. The clinic on the first floor has 13 separate office spaces for dental treatments and procedures. The indoor ventilation conditions were controlled by a heating ventilation air conditioning (HVAC) system (cooling mode: 25–26 °C) which was used during the working hours, and were closed after working time. The area of the first floor is approximately 800m<sup>2</sup>. The rooms have the same dimensions of 3.2 × 3.8 × 2.7 m (W×L×H). A partition wall with 2.2 m height separates the adjacent rooms into separate spaces. There are approximately 260–280 outpatient visits per day on the first floor. The layout of the first floor is illustrated in Figure 1.

### 2.2. Data collection

A 12-day monitoring campaign was conducted between July and September of 2020. Consecutive 24-h measurements (8:00 a.m.–8:00 a.m.) were performed to collect indoor and outdoor UFP concentrations and climatic factors (i.e., temperature and relative humidity) simultaneously. Indoor measurements were conducted in the operating rooms on the ground floor, where the 13 operating rooms were connected by an internal corridor and separated from the waiting region. Each room has no window but two doors, one with only a doorframe open towards the corridor, and the other with a glass sliding door to the outside. The sampling equipment was placed next to the dental unit (approximately 0.5 m from the patient's head and 0.85 m above the floor) to collect the air in the patients' and dentists' breathing zone. The outdoor sampling equipment was placed on the balcony of the fourth floor.

We measured the number concentrations of UFP using NanoTracer (XP, Oxilixity, Netherlands), which records the real-time (every 10 s) concentration of particles within the range of 10–300nm using the diffusion charging method. Temperature and relative humidity were measured using HOBO loggers (UX100-003, Onset Computer Corporation, Pocasset, Massachusetts), with 1-min time intervals of data logging.

During the working hours, we also recorded information that may influence the concentration of UFP, including the number of patients and the dental procedures (type, time, instruments, etc.). We calculated the average concentration during off-hours (5:00 p.m.–8:00 a.m.) as the “background concentration” (Helmis et al., 2007) and the averaged concentration during the 10 min prior to dental procedures as the “baseline concentration”.

### 2.3. Statistical methods

SPSS software (version 22.0; SPSS, Chicago, IL, USA) was used for statistical analyses, and the significance level was set to 0.05. GraphPad

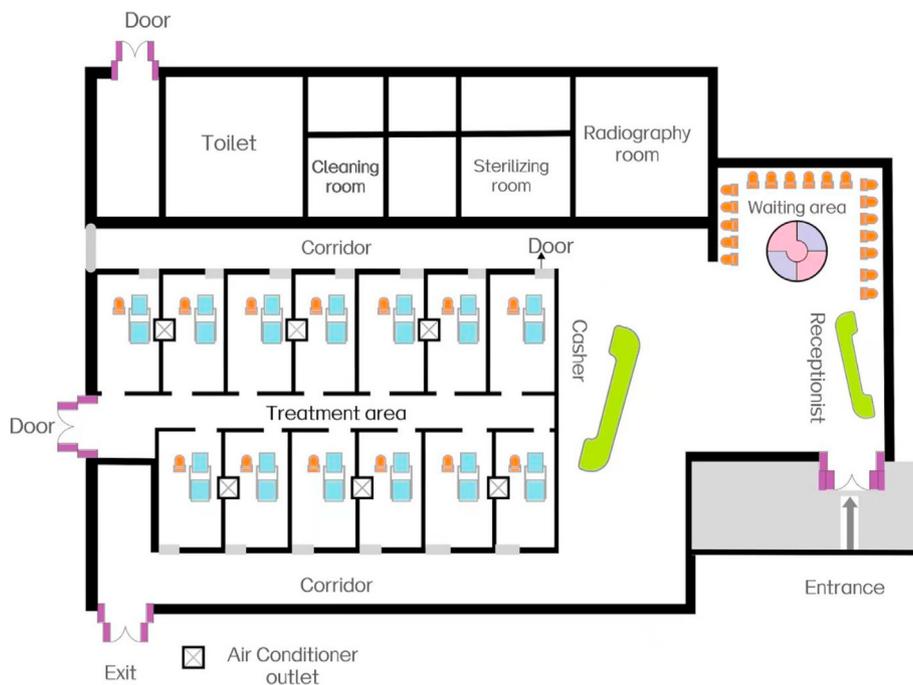


Figure 1. The layout of the dental clinic on the first floor.

Prism software (version 6.0; GraphPad Software, Inc., USA) was used for the graph data. Descriptive statistics were used to characterize the concentrations and compositions of the indoor and outdoor UFP. Student's t-test was applied ( $p < 0.05$ ; two-tailed) to compare the indices of UFP generated with or without an HVE during high-speed handpiece or laser periodontal treatment. A one-way ANOVA was conducted to compare the particle concentrations generated by power drilling, piezo-surgery, and simple extraction.

### 3. Results

Table 1 summarizes the descriptive statistics of UFP, temperature, and relative humidity during working hours, nonworking hours, and the entire sampling period. During the 12-day period, the mean concentrations ( $\pm$ SD) of indoor and outdoor UFP were 8,209 ( $\pm$ 4,407) counts/cm<sup>3</sup> and 15,984 ( $\pm$ 7,977) counts/cm<sup>3</sup>, respectively. The indoor UFP concentration was much higher during working hours (10,057  $\pm$  5,725 counts/cm<sup>3</sup>) than during non-working hours (7,163  $\pm$  2,972 counts/cm<sup>3</sup>).

Table 2 presents the main dental procedures performed during the monitoring campaign. Extraction, drilling teeth using a high-speed rotary handpiece were the most frequently procedures during the study period,

followed by root canal filling, grinding composites, and laser periodontal therapy.

The time-dependent changes in the concentrations of the indoor UFP are shown in Figure 2, and the peak UFP concentrations during the procedures are presented in Table 3. Overall, the UFP concentrations varied during the days and generally increased during the following dental procedures: drilling (D), grinding (G), root canal filling (R), laser periodontal treatment (L) and tooth extraction with power drilling (P), extraction with piezo-surgery (PS), and simple extraction (SE) (Figure 2A). Examples of UFP concentration profiles in the operating room on the seventh day are shown in Figure 2B. We identified peaks during dental procedures ranging from 11,602 counts/cm<sup>3</sup> to 241,136 counts/cm<sup>3</sup> (Table 3). The highest concentration (241,136 counts/cm<sup>3</sup>) was observed during laser periodontal treatment on the eighth day, which was 32.90 and 26.52 times their background and baseline levels, respectively (Table 3). The second highest level (75,034 counts/cm<sup>3</sup>) was produced by root canal filling treatment and was 9.75 and 7.24 times their background and baseline levels, respectively (Table 3). We found that drilling, grinding, and extraction with a power drill can also generate high concentrations of UFP (Figure 2A and Table 3). On average, the concentrations of UFP produced by grinding increased by

Table 1. Descriptive statistics of temperature, relative humidity, and UFP during the working hours<sup>a</sup>, non-working hours<sup>b</sup>, and the entire sampling day.

Environments	Variables	Working hours		Nonworking hours		The entire sampling day	
		Mean (SD)	Median (IQR)	Mean (SD)	Media (IQR)	Mean (SD)	Median (IQR)
Indoor	T, °C	24.27 (1.18)	24.15 (1.52)	25.00 (1.00)	25.22 (1.16)	24.69 (1.11)	24.80 (1.45)
	RH, %	56.99 (7.00)	56.71 (8.93)	59.70 (8.19)	58.13 (14.47)	57.4 (10.14)	57.19 (13.04)
	UFP, counts/cm <sup>3</sup>	10,057 (5,725)	9,196 (4,875)	7,163 (2,972)	6,602 (3,425)	8,209 (4,407)	7,444 (4,270)
Outdoor	T, °C	30.65 (4.15)	30.76 (7.17)	27.19 (2.76)	27.68 (3.54)	28.77 (3.84)	28.67 (4.51)
	RH, %	49.01 (13.69)	50.09 (21.79)	60.60 (13.28)	60.26 (19.15)	57.24 (15.33)	59.06 (23.06)
	UFP, counts/cm <sup>3</sup>	20,249 (9,116)	18,717 (11,033)	13,872 (6,366)	12,130 (8,247)	15,984 (7,977)	14,236 (10,445)

a: The working hours were between 8:00 and 17:00; b: The non-working hours were between 17:00 and 8:00.

Definition of abbreviations: SD, standard deviation; IQR, interquartile range; T, temperature; RH, relative humidity; UFP, ultrafine particles.

**Table 2.** Dental activities for each sample day in working hours (List of the main dental procedures for each sample day).

Day	Time	Dental procedures
Day 1	8:00–12:00	DX2, GX1, LSHX1, UX1
	13:30–17:00	DX2, RCFX2, GX1, LSHX1, UX1
Day 2	8:00–12:00	DX2, RCFX2, GX2
	13:30–17:00	DX2, RCFX1, GX1
Day 3	8:00–12:00	PX3, SEX3, UX2
	13:30–17:00	PX1, PSX1, UX1
Day 4	8:00–12:00	LX2, DX1, UX1
	13:30–17:00	LX2, DX1, UX1
Day 5	8:00–12:00	PX2, PSX1, SEX2
	13:30–17:00	PX2, PSX2, SEX1
Day 6	8:00–12:00	SEX7, PX1, PSX2
	13:30–17:00	SEX6, PX1, PSX2
Day 7	8:00–12:00	PX3, PSX2, SEX1, DX3, RCFX3, GX3, LSHX1
	13:30–17:00	PX2, PSX1, SEX3, DX3, GX3, RCFX1, LSHX1
Day 8	8:00–12:00	LX2, PX3, PSX3, DX2, GX2
	13:30–17:00	LX2, RCFX1, DX1, PX3, PSX1, GX1
Day 9	8:00–12:00	LX2, UX2, RCFX2, GX2, LSHX2
	13:30–17:00	LX2, UX1, GX1, RCFX1, LSHX1
Day 10	8:00–12:00	LX2, DX1, LSHX1, PX4, PSX2, SEX1
	13:30–17:00	LX2, DX1, GX1, LSHX1, PX3, PSX2
Day 11	8:00–12:00	DX1, RCFX1, GX2, LSHX1, PX4, PSX1
	13:30–17:00	RCFX3, DX3, GX3, UX2, PX4, PSX2, SEX1
Day 12	8:00–12:00	DX3, RCFX3, GX3, UX1
	13:30–17:00	DX2, RCFX2, GX2, UX1

Definition of abbreviations: D, drilling; U, ultrasonic scaling; RCF, root canal filling; G, Grinding; P, extraction with power.

drill; PS, extraction with piezo-surgery; S, simple extraction; L, laser periodontal treatment; LSH, low-speed handpiece.

1.91 ( $\pm 0.53$ ) times, and the maximum could reach 5.47 times the corresponding background level.

During ultrasonic scaling, we did not observe a significant change in UFP concentrations, which were about 1.32 (0.39) and 0.99 (0.12) times higher than the background and the baseline level, respectively. Among the three extraction methods, the highest levels of UFP (mean = 11,941 counts/cm<sup>3</sup>, peak = 36,015 counts/cm<sup>3</sup>) were generated by extraction with the power drill, which was 1.87 and 6.67 times their background level, respectively (Table 3 and Fig. 5A, B). While during extraction with piezo-surgery, the UFP levels were much lower than power drill (mean = 8,986 counts/cm<sup>3</sup>, peak = 17,092 counts/cm<sup>3</sup>,  $p < 0.05$ ) (Table 3), which was 1.49 and 2.49 times their background level (Fig. 5A, B) and 1.01 and 1.18 times the baseline level, respectively (Fig. 5C, D). During simple tooth extraction the increase in UFP concentration was the smallest. The average and peak values were only 5,688 counts/cm<sup>3</sup> and 11,692 counts/cm<sup>3</sup> respectively (Table 3), which was 0.96 and 2.23 times the background (Fig. 5A, B), and 1.02 and 1.28 times the baseline level (Fig. 5C, D).

Figure 3 shows the comparison of the UFP concentrations when using an HVE or low vacuum evacuator (LVE) while drilling and grinding teeth with a high-speed handpiece. The concentration of UFP with an HVE (mean = 11,024 counts/cm<sup>3</sup>, peak = 29,817 counts/cm<sup>3</sup>) was lower than that with LVE (mean = 14,178 counts/cm<sup>3</sup>, peak = 62,233 counts/cm<sup>3</sup>,  $p < 0.05$ ) (Fig. 3A, C). In addition, during drilling and grinding with an HVE, the ratio of mean or peak concentration to its background level (1.62 and 1.87) was significantly lower than that with the LVE (2.16 and 3.09,  $p < 0.01$ ) (Fig. 3B, D).

Figure 4 shows the comparison of the UFP concentrations during laser periodontal treatment with an HVE or LVE. Although not statistically significant ( $p > 0.05$ ), the mean concentrations of UFP during laser periodontal therapy with an LVE (26,125 counts/cm<sup>3</sup>) were much higher

than those with HVE (14,488 counts/cm<sup>3</sup>) (Figure 4A). Similar results were found for the peak levels of UFP concentrations (Figure 4C). The ratio of the mean or peak UFP concentration to its background level with HVE (2.06 and 3.57) and LVE (3.57 and 7.17) also showed no difference between the two conditions ( $p > 0.05$ ) (Fig. 4B, D).

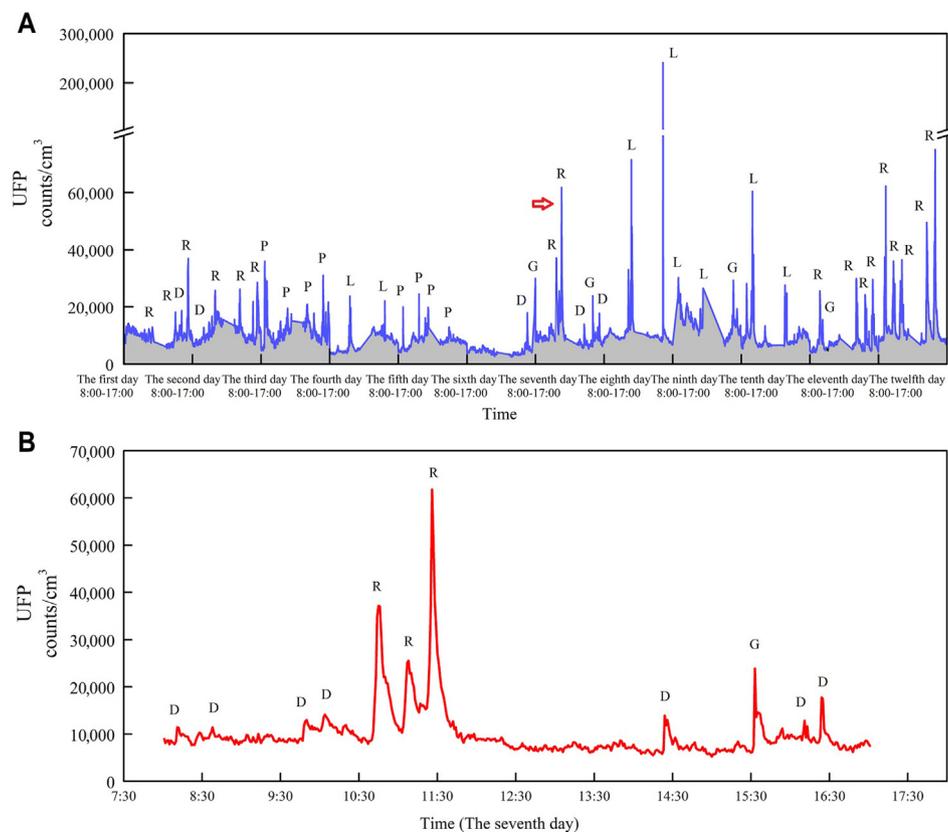
#### 4. Discussion

Numerous studies have shown that dental procedures can generate bioaerosols (Harrel et al., 2004; Micik et al., 1969; Miller et al., 1971). In this study, we conducted a monitoring campaign to measure variations of UFP number concentrations with various operative procedures in a real multi-chair dental clinic in Shanghai Tenth Hospital, China. Dental care professionals are exposed to higher levels of UFP, which may contain hazardous substances during dental procedures in daily practice. We assessed high-level indoor UFP concentrations in the dental clinic and found that the increased UFP concentrations were associated with specific dental procedures. A significant increase in the level of UFP was encountered during laser periodontal therapy, root canal filling, drilling, and grinding of dental composites. Additionally, our results suggest that the use of HVE can efficiently reduce the level of UFP during the use of high-speed handpieces. The main significance is that this is a clinical study with patients not a simulation.

The study showed that the mean concentration of outdoor UFP was significantly higher than that inside the dental clinic. There may be two reasons for the result. First, the high concentration of outside UFP was due to the heavy traffic pollution because the clinic was located at the crossroad of two arterial roads with great amounts of traffic. Furthermore, the emergency building of the hospital which is situated at the west of the dental clinic was under construction every day during the sample periods.

In the present study, we found that the UFP concentrations may vary with dental treatments. Previous studies have found that laser-generated airborne contaminants may contain bacteria, viruses, cellular debris, particulate matter, noxious and toxic aerosols, gases, vapors, or fumes such as hydrocarbons, acrylonitrile, fatty acids, and phenols (Hensman et al., 1998; Bargman et al., 2011; Pierce et al., 2011). It has been documented that laser-related dental treatments may produce UFP (Irene et al., 2008), which could be inhaled into the air tract, deposited in the alveoli, and further be transferred into the blood and lymph circulation through epithelial and endothelial cells (Li et al., 2003; Penttinen et al., 2001; Peters et al., 1997; Heinsohn et al., 1993; Nemmar et al., 2006). In the present study, the highest levels of UFP was observed during laser periodontal therapy with laser erbium, chromium: yttrium-scandium-gallium-garnet (Er,Cr:YSGG). This finding is consistent with the results reported by Irene et al. (2008), who measured the amounts of generated particulates in 'surgical smoke' during different surgical procedures and quantified the particle concentration in the surgical operating room. They found a peak concentration of 490,000 counts/cm<sup>3</sup> particles in the diameter range of 10 nm to 1  $\mu$ m. However, the peak values found in this study were not as high as those reported by Irene et al. (2008), which could be due to the use of different types of lasers and different types of surgical procedures. Lasers are a beneficial tool and are widely used in dentistry for soft and hard tissue treatment, even in the SARS-Cov-2 era (Arnabat-Dominguez et al., 2021). Based on the results, the authors suggest that high levels of exposure to UFP may increase the potential risk of using lasers during the daily dental practice.

To the best of our knowledge, this is one of the first studies to quantify the exposure to UFP generated during root canal filling during actual dental work. We observed the second highest levels of UFP concentration (75,034 counts/cm<sup>3</sup>) during root canal filling, which was 9.75 and 7.24 times the background and baseline concentration, respectively. During the process of root canal filling, a combination of core material with a composition of 20% gutta-percha (GP), 56% zinc oxide filler, 11% radio-pacifier (barium sulfate), and 3% plasticizers



**Figure 2.** Time series of the indoor UFP concentrations in the dental clinic during working hours. A. The concentrations of UFP in the twelve-day period; B. Example of indoor UFP concentration profile on the seventh day, as shown by the arrow in panel A. L, laser periodontal treatment; R, root canal filling; D, drilling; G, grinding; P, power drilling.

(waxes or resins) (Al-Afifi et al., 2016; Belsare et al., 2015; Monteiro et al., 2011) is obturated to the root canals. Heating the core material above 130 °C is necessary to remove the excess material, which can cause physical changes or degradation of GP and UFP is emitted (Friedman et al., 1977). The operation of heating often lasts for 3–30 min, depending on the number of root canals and GP points obturated in the canals. Hence, dentists may be exposed to the relatively high concentrations of UFP multiple times per day in daily practice. Because of the limitations of the experimental conditions, we did not measure the chemicals in the smoke generated during heating of the GP. Further studies are needed to measure the composition of UFP during the operation of root canal filling.

Dental composites typically contain high amounts (up to 60 vol.%) of nano-sized filler particles (Van Landuyt et al., 2014), which may be a source of UFP exposure for dental personnel, particularly during grinding, finishing, and polishing composites. Evidence suggests that dental drilling and grinding of composites fillings both with and without the use of water results in increased particle concentrations, which could far exceed the background levels (Liu et al., 2019; Van Landuyt et al., 2012; Polednik et al., 2014; Lang et al., 2018; Ireland et al., 2003) with sizes ranging from 0.01 to 0.3  $\mu\text{m}$ . During grinding, the average and the maximum concentrations of  $\text{PN}_{0.01-0.3}$  increased by 6.2 and 31.8 times on average, respectively, while during drilling, they increased by 3.2 and 9.7 times, respectively (Polednik, 2014). However, the levels of UFP generated by grinding and drilling in the present study were lower than that Polednik (2014) reported. There are four possible reasons for these differences. First, we used water-cooling spray systems during using grinding and drilling. Consistent with previous studies (Nimmo et al., 1990; Van Landuyt et al., 2012, 2014), we observed that the use of water spray and high-velocity evacuation significantly reduced patient

exposure to particles. Cokic et al. (2020b) found that grinding with water spray greatly reduced UFP concentrations compared to those produced when grinding without water-cooling spray. In any case, the amounts of particulate matters generated in dental clinics should be kept to a minimum during dental procedures. Cooling with water spray and effective suction whenever possible are recommended when drilling and grinding dental materials (Van Landuyt et al., 2012, 2014; Schmalz et al., 2018). Second, the different result may be due to the different monitors and their lower cut for PM size. Third, in the present study, an assistant was present to assist with saliva suction during the entire treatment period. The use of four-handed dentistry helps to reduce the intensity of aerosol contamination (Shahdad et al., 2020). The author suggested that the four-handed approach to all dental procedures would enhance protection during aerosol-generating procedures, which is particularly important during the SARS-Cov-2 pandemic. Finally, this difference may also be partially explained by the varied indoor air relative humidity, seasons, and background levels of UFP.

The present study also found that ultrasonic scaling produced relatively low levels of UFP compared to drilling and grinding. This result was consistent with the finding of Polednik (2014), who found that the use of an ultrasonic scaler produced the lowest levels of the measured particle concentrations ( $\text{PN}_{0.02-1}$ ). However, some other previous studies have found that ultrasonic cleaning can produce large amounts of aerosols. Micik et al. (1969) found that air-turbine hand pieces, when used with air-water spray coolant, generated 20 times more bacteria than air spray alone. Harrel et al. (1996) found that the use of an ultrasonic scaler produced the highest levels of airborne contamination with regard to scaling. Inconsistent findings might be due to the different objectives and methods among studies. These previous studies focused on the colony forming unit (CFU) in bioaerosols during dental treatments; however, the

**Table 3.** The mean and peak concentrations of UFP during different dental procedures, and the corresponding ratios over baseline<sup>a</sup> or background<sup>b</sup> concentrations.

Dental procedures	Number	Mean (SD) counts/cm <sup>3</sup>	Peak counts/cm <sup>3</sup>	Baseline conc. <sup>a</sup> counts/cm <sup>3</sup>		Ratio of mean conc./ Baseline		Ratio of peak conc./ Baseline		Background conc. <sup>b</sup> counts/cm <sup>3</sup>		Ratio of mean conc./ Background level		Ratio of peak conc./ Background level	
				Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max
Drilling (D)	30	9,832 (3,329)	28,916	7,387	1.33 (0.37)	1.00–2.58	1.61 (0.69)	1.01–4.19	6,068	1.63 (0.58)	0.92–3.37	1.98 (1.03)	1.01–5.47		
Grinding (G)	27	13,695 (5,518)	62,233	9,793	1.43 (0.41)	0.94–2.25	1.87 (1.07)	1.00–6.13	7,449	1.91 (0.53)	0.95–3.16	2.45 (1.21)	1.15–7.04		
Laser periodontal treatment (L)	16	20,176 (16,618)	241,136	9,915	2.1 (1.82)	0.93–8.92	4.05 (5.83)	1.04–26.52	8,455	2.79 (2.42)	0.98–11.07	5.37 (7.46)	1.06–32.90		
Ultrasonic scaling (U)	12	10,556 (3,495)	20,088	10,818	0.99 (0.12)	0.86–1.26	1.09 (0.13)	0.96–1.36	7,147	1.32 (0.39)	0.91–2.01	1.45 (0.42)	0.98–2.07		
Low-speed handpiece (LSH)	10	11,129 (6,939)	30,902	10,088	1.08 (0.14)	0.80–1.25	1.17 (0.18)	0.81–1.41	8,093	1.46 (1.33)	0.84–2.58	1.57 (0.58)	0.85–2.74		
Root canal filling (RCF)	22	20,347 (5,036)	75,034	10,625	1.98 (0.58)	1.09–3.29	3.22 (1.37)	1.47–7.24	7,522	2.87 (0.82)	1.04–4.38	4.66 (1.9)	1.26–9.75		
Power drill (P)	32	11,941 (3,517)	36,015	9,244	1.33 (0.41)	0.91–2.49	1.72 (0.9)	1.05–4.64	6,608	1.87 (0.71)	0.94–3.90	2.41 (1.21)	1.00–6.67		
Piezo-surgery (PS)	22	8,986 (2,803)	17,092	8,895	1.01 (0.07)	0.89–1.18	1.10 (0.14)	0.93–1.46	6,261	1.49 (0.49)	0.71–2.22	1.62 (0.55)	0.74–2.49		
Simple extraction (SE)	23	5,688 (1,965)	11,692	5,580	1.02 (0.09)	0.81–1.29	1.08 (0.11)	0.87–1.39	5,663	0.96 (0.43)	0.47–2.11	1.02 (0.47)	0.49–2.23		

a: baseline concentrations: the mean concentrations of UFP during 10 min prior to the dental procedures.

b: background concentrations: the mean concentrations of UFP during non-working hours.

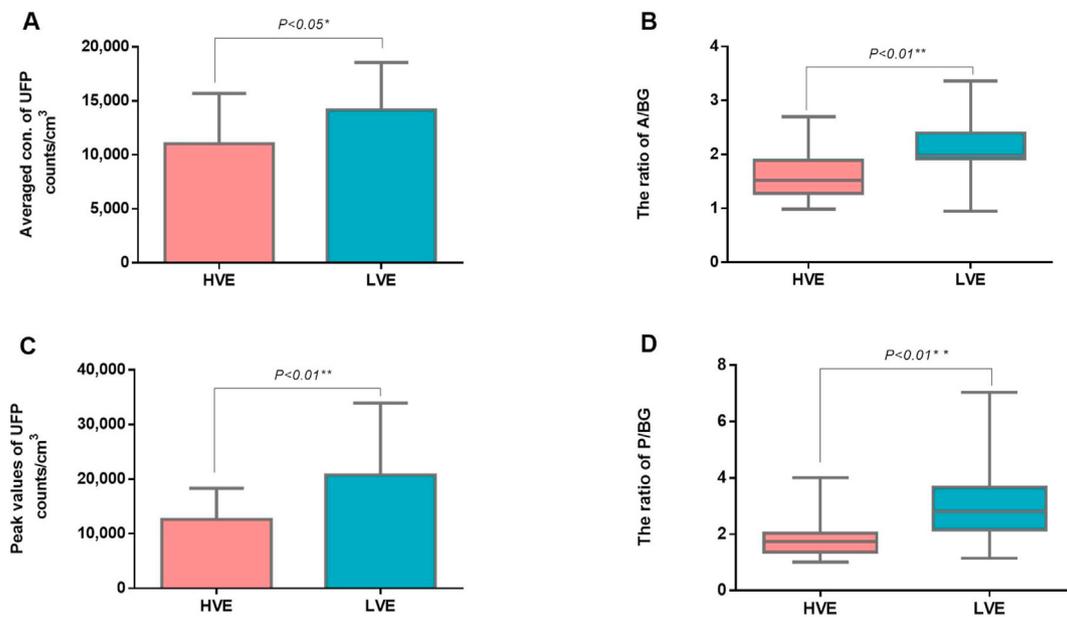
Definition of abbreviations: SD, standard deviation; conc., concentration; Min, minimum; Max, maximum.

present study measured the concentration of abiotic aerosols, especially PM<sub>0.1</sub>, during ultrasonic scaling.

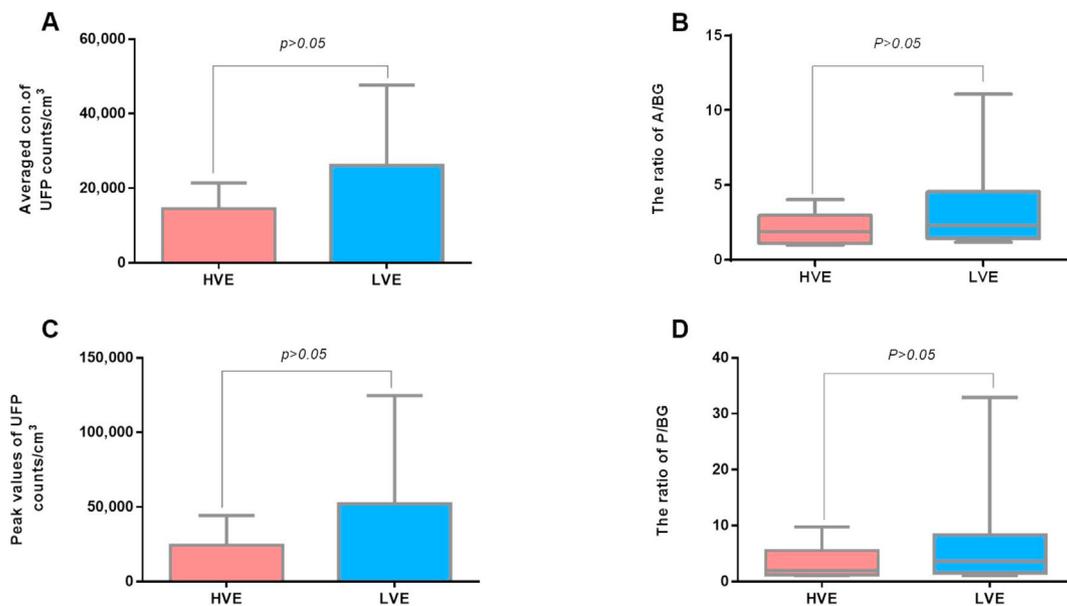
Inhalation of UFP may pose significant human health risks due to their nanometer size range which allows UFP to relatively efficiently penetrate the deeper parts of the lungs, cross the biological barriers to get deeper into the body to directly harm distal organs (Sotiriou et al., 2008; Cokic et al., 2020a; Schraufnagel, 2020). Occupational exposure to high UFP levels can cause airway inflammation, impaired lung function (Wichmann and Peters, 2000), even cardiac events, neurodegenerative diseases and cancer (Fang et al., 2010; Devlin et al., 2014; Downward et al., 2018; Kawanaka et al., 2011; Tian et al., 2019). Previous researches have revealed that some pathogen such as Sars-CoV-2 virus can be transmitted via particulate matters, especially in the light of COVID-19 pandemic (Kimmerle et al., 2012; Yamada et al., 2011; Guo et al., 2020). Therefore, protection methods are constantly emphasized. It is extremely essential for dental workers to reduce the aerosols during routine dental procedures.

The removal of suspended particles during dental procedures by using an effective vacuum system and selecting optimal high-level personal face masks for dentists and other medical staffs are important safety measures (Liu et al., 2019). The use of saliva ejectors with low or high volume was shown to reduce the production of droplets and aerosols in the study of Yadav et al. (2015). Harrel et al. (1996) discussed that an HVE device operated by an assistant or attached to the instrument being used can decrease the level of dental aerosols. Harrel (2004) also found that an HVE can reduce the aerosol by more than 90%. In the present study, we observed that an HVE was more effective in removing UFP than an LVE during drilling and grinding, which is consistent with previous studies (Harrel et al., 2004; Liu et al., 2019; Nulty et al., 2020; Rupf et al., 2015). Nulty et al. (2020) observed a statistically significant difference in the levels of PM<sub>2.5</sub>- and PM<sub>10</sub>-sized particulate with and without an external HVE. Their study suggested that an HVE should be used along with a high-speed handpiece. Moreover, Rupf et al. (2015) recommended HVE to reduce patients' and dental staffs' exposure to fine and ultrafine airborne particles when using scanning sprays.

However, the results of this study showed no statistically significant difference between the levels of UFP in using HVE and using LVE during laser periodontal treatment. The result is in contrast to that of Grzech-Leśniak (2021) who found a significantly lower aerosol quantity generated during crown removal using Er:YAG lasers, compared to that in using the high-speed turbine with both HVE and saliva ejector (SE). The present study is a clinical study in a real setting, not a simulation study. In addition, different laser treatments were used in the two studies. These may explain the difference. However, the result of the current study is consistent with those of Desarda et al. (2014) and Holloman et al. (2015). Desarda et al. (2014) found no statistically significant difference for aerosols reduction with and without HVE either at 12 or 20 inches from patient's oral cavity. Holloman et al. (2015) found that neither saliva ejectors nor HVE devices could reduce the aerosols and splatter effectively. Recently, Balanta-Melo (2020) measured the volume fraction of aerosol particles less than 10 μm in the dental operating room, and found that HVE could reduce the generated particles, but not for all of them. Holliday (2021) found that the HVE device, as other mitigation measures, cannot completely eliminate the risk profile to dental professionals, with around 60% of particles removal efficiency. The differences in the results might be attributed to the differences in experimental design, HVE type, observation indicators and dental procedures. Additionally, the size of particles generated during the dental procedures should be considered in evaluating the efficacy of HVE (Koch et al., 2021). Although the difference was not statistically significant, the results showed a lower level of UFP in using an HVE during laser periodontal therapy, compared to the levels observed in using an LVE. More samples are needed in additional studies under controlled experimental conditions. Furthermore, randomized clinical trials concerning the effect of HVE on aerosols reduction are needed during laser dental procedures.



**Figure 3.** Comparison of UFP concentrations under drilling or grinding the teeth with a high-volume evacuation (HVE) or low-volume evacuation (LVE): A. the averaged concentrations of UFP with HVE or LVE; B. the ratios of A/BG with HVE or LVE; C. the peak concentrations of UFP with HVE or LVE; D. the ratios of P/BG with HVE or LVE. Definition of abbreviations: A, averaged concentrations of UFP; BG, the background levels of UFP concentrations; P, the peak concentrations of UFP; \*:  $p < 0.05$ , significant; \*\*:  $p < 0.01$ , much significant.

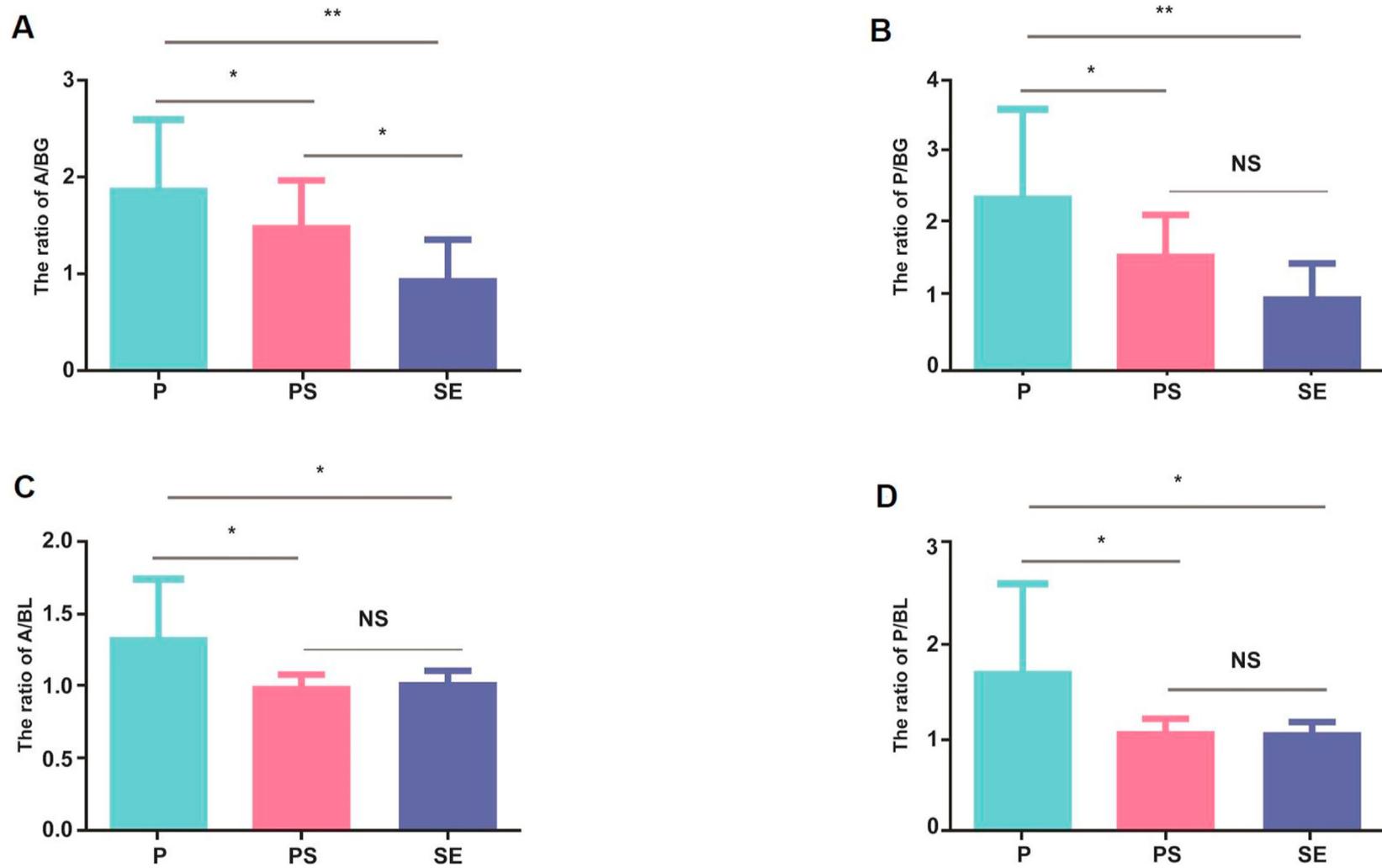


**Figure 4.** Comparison of UFP concentrations under laser periodontal treatment with an HVE or LVE: A. the averaged concentrations of UFP with HVE or LVE; B. the ratio of averaged concentrations of UFP to the background level of UFP with an HVE or LVE; C. the peak concentrations of UFP with an HVE or LVE; D. the ratio of peak concentrations of UFP to the background concentrations of UFP with an HVE or LVE. Definition of abbreviations: A, averaged number concentrations of UFP; BG, the background levels of UFP concentrations; P, the peak concentrations of UFP.

Therefore, besides an HVE, a plume scavenging system (suction nozzle within 5 cm from the treatment site) with high-efficiency particulate air filters (HEPA) or ultra-low penetration air filters (ULPA) should also be warranted (Sullivan et al., 2021; Liu et al., 2020; Bargman et al., 2011). In addition, a laser-related N95/P2 mask should be considered during the dental procedures, especially during the pandemic of SARS-CoV-2 (Sullivan et al., 2021).

Some limitations should be considered when interpreting of findings. First, this study may not cover all types of dental operative procedures

(i.e., polishing) which may also generate UFP. Second, we did not assess the bioaerosols levels simultaneously. Thus, we could not assess the risk of exposure to microorganisms as well as the high levels of UFP. Third, notice that our measurement might miss the portion of UFP less than 10nm, given that the instrument of NanoTracer measures the particles ranging from 10nm to 300nm. Finally, the study did not consider the influence of air conditioner and ventilation to the levels of UFP. We suggest future studies on aerosols reduction in larger areas with HVE efficacy evaluation.



**Figure 5.** Comparison of the averaged concentrations of UFP to the background concentrations with different extraction methods; A. the A/BG ratio of the UFP concentration; B. the P/BG ratio of the UFP concentration; C. the A/BL ratio of the UFP concentration; D. the P/BL ratio of the UFP concentration; Definition of abbreviations: P, power drilling; BL, the baseline levels of UFP concentrations; PS, piezo-surgery; SE, simple extraction; \*:  $p < 0.05$ , significant; \*\*:  $p < 0.01$ , much significant; NS, not significant.

## 5. Conclusions

In this study, we found that many dental procedures can generate high concentrations of UFP in dental clinics, such as laser periodontal treatment, root canal filling, drilling, and grinding dental composites. Exposure to the high concentrations of particulate matter may have a significant health impact on the dental workers and patients. HVE can be used to help decrease the concentrations of UFP.

## Declarations

### Author contribution statement

Fengqin Tang, Xueyun Wen, Xu Zhang: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Shengcai Qi, Xiaoshan Tang, Jieying Huang, Chenjie Zhu, Guangwei Shang: Performed the experiments; Contributed reagents, materials; analysis tools or data.

Jing Cai, Yuanzhi xu, Raorao Wang: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials; analysis tools or data.

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### Data availability statement

Data will be made available on request.

### Competing interest statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

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