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Original article

PM2.5 and PM10 Compound Emissions in a Dental Clinic During Clinical Procedures

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Abstract
This study assessed PM2.5 and PM10 concentrations and associated indoor environmental conditions during routine dental procedures in four dental clinics in Alzahraa, Tripoli, Libya. Measurements were obtained with a PCE-MPC 10 particle counter at baseline, 15 minutes, and 30 minutes. Using SPSS Statistics version 29.0.10, mean ± standard deviation, One-way ANOVA, and paired t-tests at a statistical significance level of $p < 0.05$ were applied to analyse the data. Across complete monitoring positions, mean PM2.5 increased from 426.88 µg/m^3 at baseline to 454.62 µg/m^3 at 15 minutes and 817.21 µg/m^3 at 30 minutes, producing a significant time effect ($F = 16.02$, $p < 0.001$, partial $\eta^2 = 0.411$). Mean PM10 similarly increased from 19.29 to 20.04 and 36.12 µg/m^3 ($F = 18.57$, $p < 0.001$, partial $\eta^2 = 0.447$). The major differences were mainly seen during the 30 minutes of testing. The temperature varied significantly but within a narrower range ($F = 7.06$, $p = 0.002$), while humidity did not change at all ($F = 0.69$, $p = 0.508$). Clinic 2 had the highest particulate loads among the clinics. It is clear from the data that there is particulate loading due to some procedures in dental clinics and the importance of improving particulate source removal.
Keywords. *PM2.5, PM10, Dental Clinics, Indoor Air Quality, Ventilation, Occupational Exposure, ISO 16000-40:2019.*

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Introduction

The issue of air quality is becoming increasingly prominent in healthcare facilities, including contemporary dental clinics, as many dental procedures generate aerosols and particulate matter. Aerosols and splatter from high-speed handpieces, ultrasonic scalers, air-water units, and air-polishing devices disperse into the environment [1,2]. The problem has become especially acute in recent times during the COVID-19 pandemic due to the generation of aerosols in dental procedures, which posed a risk of exposure and infection transmission to dental professionals and patients [3]. Particulate matter (PM2.5 and PM10) is known to have negative impacts on health [4]. Therefore, proper air quality within dental practice needs to be provided through ventilation, air filtration, and monitoring of the environment. Studies show that physical ventilation and air purification can help to reduce PM2.5, PM10 and volatile organic compounds in dental practice [1,5]. ISO 16000-40:2019 standard describes requirements for the development, implementation, maintenance and continual improvement of the indoor air quality management system [6]. Besides, the PCE-MPC 10 is a portable particulate matter counter intended to monitor the concentration of PM2.5 and PM10, temperature and relative humidity [7].

There have been previous studies where the effect of dental procedures has been shown to be able to significantly increase the levels of PM2.5 and PM10, especially in case there is no adequate ventilation [5]. Particles created in a dental office could also include material and metallic components in addition to being different from other ambient particles [1]. Besides, some recent research has revealed the impact of PM2.5 on gingival fibroblast viability and functioning, pointing out to possible adverse effects on oral tissue [8]. Nulty et al. conducted a comparative clinical experimental study in the UK to determine the concentrations of PM1, PM2.5, and PM10 generated during dental aerosol-generating procedures, as well as the efficiency of external high-volume extraction (HVE). In total, 10 dental restorations were assessed using the industrial Trotec PC220 particle counter, placed about 420 mm away from the working site – the distance at which the operator works. Maximum levels reported during the experiments amounted to 11 µg/m^3 for PM2.5 and 24 µg/m^3 for PM10. Concentration of particles was much higher when dental aerosol-generating procedures were done without external HVE, whereas use of HVE lowered the number of particles of all types [9]. Prospective clinical observation was done by Lahdentausta et al. in Finland to determine the aerosol concentrations and aerosol particle size distribution generated in the course of routine dental procedures. This included 84 subjects who underwent 253 dental procedures which involved air-turbine handpieces (n=8), high-speed handpieces (n=6), low-speed handpieces (n=30), ultrasonic scaling (n=31), manual periodontal procedures (n=60), endodontic treatment (n=12), intraoral radiography (n=24), and local anaesthesia (n=31). Aerosol concentration in the form of airborne particles in a size range of 0.3 to 10 µm was measured using an Optical Particle Sizer. Use of air turbine handpieces caused a significant increase in the median concentration of particles less than 1 µm ($p=0.013$) and peak concentration ($p=0.016$), and in aerosol particle mass concentrations ($p=0.046$ and $p=0.006$). It was

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therefore concluded that air turbines generated the highest level of aerosols and that high-speed, low-speed, and ultrasonic instruments are important [10]. In a study carried out by Tang et al., the concentration, morphology, elemental composition, and the health hazards associated with the produced PM2.5 in a multi-chair dental clinic in Shanghai, China, were investigated. The study employed the use of the environmental observational technique on 19 working days in clinical areas where the dental procedures were being done. PM2.5 was measured using a MicroPEM real-time monitor and the chemical composition was analyzed using a scanning electron microscope, energy-dispersive X-ray spectrometry, and X-ray fluorescence spectrometry. The indoor mean concentration of PM2.5 ranged between 2.01 and 114.59 µg/m^3, with a mean value of 23.31 µg/m^3, while the outdoor mean value was 30.98 µg/m^3.
Calcium, phosphorus, silicon, and zirconium were some of the compounds in the dental-clinic particles, whereas toxic elements such as cadmium, arsenic, and nickel were also present; the estimated carcinogenic risks for Cd, As, and Cr were 3.68×10^{-5}, 1.10×10^{-5}, and 5.52×10^{-6}, respectively [11]. Islam et al. carried out a field study on occupational exposure in three dental clinics in Oslo and Asker, Norway. This study aimed to measure the airborne particles generated during dental work and occupational exposure to such particles in dental practitioners. This study consisted of 17 dental workers, such as dentists, dental health secretaries, and a dental hygienist, with 43 person-borne respirable particle samples. Respirable particles were continuously measured by use of a Scanning Mobility Particle Sizer (SMPS 3938) measuring 16.8-593 nm in diameter and an Aerodynamic Particle Sizer (APS 3321) measuring 0.542-19.8 µm in diameter. The geometric means of respirable-particle concentrations in Clinics 1, 2, and 3 were 0.04 mg/m^3, 0.06 mg/m^3, and 0.03 mg/m^3, respectively, without a statistically significant difference between the clinics (p=0.1988). Even though these levels are far lower than the occupational exposure level in Norway, which is 5 mg/m^3, many ultrafine particles were found during working hours [12].
The problem that needs to be solved with the current research is connected to the everyday generation of PM2.5 and PM10 from different types of dental procedures, especially when high-speed handpieces and ultrasonic scalers are used, since that would result in deterioration of air quality and increased exposure of both dentists and their patients. Measurement of the concentration of these pollutants in different areas of the dental office and during processes of different durations would help to evaluate the effectiveness of the ventilation system and the generation of particulates. Therefore, this study was conducted to assess and evaluate PM2.5 and PM10 concentrations during routine dental procedures and the exposure of dental staff to these particles, and to provide recommendations for improving indoor air quality in dental clinics in accordance with relevant Libyan requirements and international ISO specifications.

Materials and Methods

The study includes a specific area within defined administrative boundaries. This is Alzahraa/Tripoli/Libya. The scope area has five dental clinics; one of these clinics was temporarily closed, so we excluded from this study. The study was in four dental clinics with different numbers of rooms. It was in nine different rooms in different locations in the building, and variation in window diameters. The measurements were in all dental clinic rooms in addition to the reception area where the receptionist stay in there shifts and where patients wait. The measurements were done in three fixed areas, they were: thedentist's breathing zone, theassistant's breathing zone, and the reception area. The measurements were also in fixed times: zero time, after fifteen minutes and after half an hour during routine dental work. This type of measurement makes the comparison more qualified and reliable; also, it's from real dental procedures and dental clinics. The device used was (PCE MPC 10, PCE Instruments, Germany). This device measures 10 Particulate Matter and 2.5 Particulate Matter in the air; the result showed in electronic screen. The device also measures the temperature and humidity. The main principle of this device is laser scattering; the accuracy of the device can be ±10%, detection ranges from 0-9999 µg/m^3. But this device does not follow the ISO standard.

Figure 1. PCE-MPC 10 particle counter used for measuring PM2.5 and PM10 concentrations in clinical settings, specifically within the assistant area.

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Data Analysis Methods

By using SPSS Statistics version 29.0.10, the measurements at baseline, 15 minutes, and 30 minutes were summarised as mean ± standard deviation. Because the same monitoring positions were followed over time, repeated-measures ANOVA was used to test temporal change within each clinic and across all complete positions. PM2.5 and PM10 were natural-log transformed before ANOVA; temperature and humidity were analysed on their original scales. Significant overall time effects were followed by Bonferroni-adjusted paired t-tests. Differences among the four clinics at each time point were assessed with Welch one-way ANOVA, which is robust to unequal variances. Statistical significance was set at $p < 0.05$.

Results

Particulate Matter (PM2.5) and (PM10) Concentrations (μg/m^3)

Table 1 illustrated that there was a significant overall time effect for PM2.5, $F = 16.02$, $p < 0.001$, partial $\eta^2 = 0.411$. Bonferroni-adjusted comparisons showed no change from baseline to 15 minutes ($p = 1.000$), but PM2.5 was significantly higher at 30 minutes than at baseline ($p = 0.001$) and 15 minutes ($p = 0.001$). Clinic 2 had the highest mean concentrations at all three times and reached 1,977.17 μg/m^3 at 30 minutes. Time effects were significant in Clinics 1 ($p = 0.001$) and 4 ($p < 0.001$), but not in Clinics 2 or 3, reflecting large within-clinic variability in those clinics.

Table 1. PM2.5 descriptive statistics and repeated-measures ANOVA

Clinic	Baseline	15 min	30 min	F-ratio	p-value	Result
	M ± SD	M ± SD	M ± SD			
Clinic 1	188.83 ± 23.19	219.50 ± 30.86	395.00 ± 151.62	13.40	0.001	Significant
Clinic 2	987.17 ± 198.20	1152.67 ± 197.54	1977.17 ± 1923.79	0.99	0.404	Not significant
Clinic 3	335.83 ± 72.92	267.00 ± 36.37	468.50 ± 379.03	1.78	0.217	Not significant
Clinic 4	195.67 ± 24.12	179.33 ± 44.87	428.17 ± 142.59	43.02	<0.001	Significant
Overall	**426.88**	**454.62**	**817.21**	**16.02**	**<0.001**	**Significant**

Table 2 illustrated that PM10 also changed significantly over time overall, $F = 18.57$, $p < 0.001$, partial $\eta^2 = 0.447$. Baseline and 15-minute values did not differ, whereas 30-minute values were significantly higher than baseline ($p < 0.001$) and 15 minutes ($p < 0.001$). Clinic 2 again showed the greatest particulate burden, with a mean of 82.17 μg/m^3 at 30 minutes. Significant time effects occurred in Clinics 1 ($p = 0.001$) and 4 ($p < 0.001$).

Table 2. PM10 descriptive statistics and repeated-measures ANOVA

Clinic	Baseline	15 min	30 min	F-ratio	df	p-value	Result
	M ± SD	M ± SD	M ± SD				
Clinic 1	9.83 ± 1.33	11.33 ± 2.07	20.33 ± 6.35	14.76	(2, 10)	0.001	Significant
Clinic 2	40.33 ± 4.08	46.33 ± 8.50	82.17 ± 79.16	1.30	(2, 10)	0.314	Not significant
Clinic 3	16.50 ± 3.89	13.33 ± 1.63	20.50 ± 12.29	1.79	(2, 10)	0.216	Not significant
Clinic 4	10.50 ± 1.64	9.17 ± 1.83	21.50 ± 5.32	78.23	(2, 10)	<0.001	Significant
Overall	**19.29**	**20.04**	**36.12**	**18.57**	**(2, 46)**	**<0.001**	**Significant**

Temperature (°C)

Table 3 illustrates that the temperature showed a significant overall time effect, $F = 7.06$, $p = 0.002$, partial $\eta^2 = 0.235$. The principal change was a decrease from baseline to 15 minutes (Bonferroni-adjusted $p = 0.002$); the baseline-to-30-minute difference was not significant ($p = 0.331$). Clinic 2 started with the highest mean temperature (22.55°C) and decreased to approximately 21°C, whereas Clinic 4 increased to 21.02°C at 30 minutes. Each clinic showed a statistically significant time effect (all $p < 0.05$).

Table 3. Temperature descriptive statistics and repeated-measures ANOVA

Clinic	Baseline	15 min	30 min	F-ratio	df	p-value	Result
	M ± SD	M ± SD	M ± SD				
Clinic 1	20.27 ± 0.08	19.88 ± 0.42	19.65 ± 0.26	5.68	(2, 10)	0.022	Significant
Clinic 2	22.55 ± 0.58	20.92 ± 0.13	20.98 ± 0.22	26.61	(2, 10)	<0.001	Significant
Clinic 3	19.95 ± 0.08	19.77 ± 0.34	20.05 ± 0.14	5.84	(2, 10)	0.021	Significant
Clinic 4	20.25 ± 0.05	20.08 ± 0.13	21.02 ± 0.16	92.92	(2, 10)	<0.001	Significant
Overall	20.75	20.16	20.42	7.06	(2, 46)	0.002	Significant

Humidity (%)

Table 4 illustrates that the humidity was not significantly different over time, F = 0.69, p = 0.508, partial $\eta^2 = 0.029$. Humidity level remained relatively constant across clinics; however, Clinics 2 (p = 0.009) and 3 (p = 0.003) exhibited a significant change in humidity level over time. Clinic 4 had the lowest humidity level throughout, which was 51-52%, whereas Clinic 1 had the highest humidity level at baseline (65.13%).

Table 4. Humidity descriptive statistics and repeated-measures ANOVA

Clinic	Baseline	15 min	30 min	F-ratio	df	p-value	Result
	M ± SD	M ± SD	M ± SD				
Clinic 1	65.13 ± 1.08	64.43 ± 0.73	64.48 ± 0.86	1.09	(2, 10)	0.374	Not significant
Clinic 2	61.68 ± 0.72	63.57 ± 1.25	63.32 ± 0.51	7.89	(2, 10)	0.009	Significant
Clinic 3	62.40 ± 0.63	62.18 ± 0.87	61.35 ± 0.58	10.81	(2, 10)	0.003	Significant
Clinic 4	51.20 ± 0.57	51.45 ± 0.57	51.60 ± 1.65	0.58	(2, 10)	0.578	Not significant
Overall	**60.10**	**60.41**	**60.19**	**0.69**	**(2, 46)**	**0.508**	**Not significant**

Comparison among Clinics

Table 5 illustrated that the four clinics differed significantly for all four environmental measures at every time point (all p < 0.05). The most important particulate pattern was the consistently greater PM2.5 and PM10 burden in Clinic 2. Temperature also differed across clinics, while humidity showed a persistent environmental contrast, with Clinic 4 substantially drier than the other clinics. However, the overall findings were as follows:

- The levels of PM2.5 and PM10 showed a significant rise over 30 minutes, suggesting the presence of particle accumulation in the air during the clinical activity.
- Clinic 2 showed the maximum level of particulates and their variability, especially over 30 minutes.
- The temperature showed a significant difference with respect to time; however, the range of temperature was comparatively small after 15 minutes.
- The humidity level was constant, except for some differences between the clinics.
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- T***able 5. Welch one-way ANOVA comparing the four clinics at each time point***

Variable	Time	F-ratio	p-value	Decision	Main pattern
PM2.5	Baseline	112.48	<0.001	Significant	Clinic 2 highest
	15 min	107.98	<0.001	Significant	Clinic 2 highest
	30 min	5.09	0.019	Significant	Clinic 2 highest
PM10	Baseline	170.82	<0.001	Significant	Clinic 2 highest
	15 min	84.04	<0.001	Significant	Clinic 2 highest
	30 min	4.05	0.038	Significant	Clinic 2 highest
Temperature	Baseline	47.39	<0.001	Significant	Clinics differed
	15 min	45.60	<0.001	Significant	Clinics differed
	30 min	64.49	<0.001	Significant	Clinics differed
Humidity	Baseline	458.88	<0.001	Significant	Clinic 4 lowest
	15 min	452.88	<0.001	Significant	Clinic 4 lowest
	30 min	98.24	<0.001	Significant	Clinic 4 lowest

Discussion

Based on the current results, there is clearly a time-related build-up of airborne particulates during regular dental practice with both PM2.5 and PM10 showing roughly similar levels at the baseline and 15 minutes, while significantly rising to the 30-minute mark; the large main effects of both PM2.5 (F = 16.02, p < 0.001, partial $\eta^2 = 0.411$) and PM10 (F = 18.57, p < 0.001, partial $\eta^2 = 0.447$), combined with the generally very high levels and great variability in Clinic 2, indicate that exposure to particulates is not only related to time, but also varies based on specific characteristics of the clinic like procedures performed, source control, room layout, occupancy, ventilation, and extraction efficacy. The latter result is consistent with Nulty et al. [9], who found that dental procedures generating aerosols produced much more PM1, PM2.5, and PM10 without the external HVE and that HVE decreased all measured particle sizes. The relatively low maximum values of 11 $\mu g/m^3$ of PM2.5 and 24 $\mu g/m^3$ of PM10 in their work, versus the much higher ones in the current clinics, may be explained by some procedural and instrumental differences, but the trend is undoubtedly positive. The marked increase of 30 minutes is also supported by Lahdentausta et al. [10], who made prospective observations over 253 procedures and observed significant increases in submicron particles, peak concentration, and aerosol mass when an air turbine was used; overall, these

findings show that the continuous use of high-speed and aerosol-generating devices can lead to accumulation of particles if they cannot be removed as fast as they are produced.
Tang et al. [11] have observed an indoor PM2.5 concentration of 23.31 μg/m^3 with working day concentrations between 2.01 and 114.59 μg/m^3 in a multi-chair clinic and detected dental material elements as well as toxic metals in the particles collected; while the concentration range was far lower than the current PM2.5 concentration levels, their findings support the significance of dental source particulates as a risk factor due to their compositions as well as concentration levels. However, in their work, Islam et al. [12] found geometric mean levels of respirable particles in the range 0.03-0.06 mg/m^3 in three clinics in Norway with no statistically significant difference between clinics ($p = 0.1988$), while in the current research, statistically significant differences were observed between the four clinics in all sampling moments, with Clinic 2 showing the highest values. This can be attributed to variations in sampling type, particle sizes, procedure mix, building ventilation, particle extraction systems, as well as the number and timing of observations. The low increase in temperature together with constant total relative humidity indicates that the increment of particles was associated more with the processes of generating clinical aerosols and poor particle elimination rather than with changes in environmental thermal conditions.

Conclusion

In conclusion, the routine dental procedures caused a considerable accumulation of airborne particles within 30 minutes, with statistically significant increases in PM2.5 and PM10 and considerable variations between the four clinics. Clinic 2 was the most notable source of particulate matter pollution, while temperature varied somewhat and humidity stayed constant on the whole. Thus, it can be concluded that current ventilation and particulate removal are not enough to exclude the possibility of short-term exposure of dentists, dental assistants, receptionists, and patients while performing dental procedures. Therefore, dental clinics need to focus on source extraction, proper ventilation and filtration, monitoring and documentation of corrective actions. Due to the peculiarities of the supplied data, which have shown unexpected correlation where PM2.5 is higher than PM10, the configuration of the device, names and units of the channels, as well as its calibration must be verified.

ISO Framework and Implications

- Implement a system according to ISO 16000-40:2019 for the management of indoor air quality for all clinics with a clear system for responsibilities, air quality goals, monitoring, records, corrective action, and periodic review by management.
- Perform the monitoring of PM2.5, PM10, temperature, and relative humidity at defined locations and intervals; ensure calibration and identification of measuring instrument channels; perform trend analysis; and based on the results, determine whether the measures being taken provide sustainable improvements.
- Incorporate high-volume extraction, good general ventilation, appropriate HEPA filtration, equipment maintenance, and documented performance checks into the clinic operation process.

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