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Use of Direct Reading and Short Term Sampling of Indoor Air Quality in a Veterans Affairs Dental Clinic Laboratory for Select Air Contaminants

Onwuka K. Okorie[1], Rodney R. Larson[1,*], Owen Motter[2] and Matt Thiese[1]

[1]*Rocky Mountain Center for Occupational and Environmental Health, University of Utah, 391 Chipeta Way, Suite C, Salt Lake City, Utah 84108;* [2]*VA Medical Center, 500 Foothill Drive (138S), Salt Lake City, Utah 84148, USA*

Abstract: This screening survey was conducted to assess the concentrations of select airborne contaminants in a Veterans Affairs Medical Center Dental Laboratory. Airborne concentrations were measured for the following contaminants: nitrous oxide (N_2O), carbon dioxide (CO_2), sulfur dioxide (SO_2), and airborne particles or particulate matter (PM). The PM was measured and classified by the aerodynamic diameter of the particulates; specifically as $PM_{0.3}$, $PM_{0.5}$, $PM_{1.0}$, $PM_{2.0}$, $PM_{5.0}$ and $PM_{10.0}$.The gases were measured with a Miran Sapphire, portable infrared analyzer. The particulates were measured using the Fluke 983 Particle Counter. Using these instruments, area monitoring was conducted for concentrations of gases and aerosols as a result of releases from dental activities such as waxing and grinding of dental models. All area monitoring samples were collected within approximately one foot of the breathing zone of dental workers. The results of this survey found the air quality in the dental laboratory was within the regulatory limits for these agents. However, the concentration of SO_2 was found to exceed the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV) on more than one occasion. This was potentially due to room ventilation inadequacies. It is recommended that the dental laboratory's ventilation system be modified and operated to assure more effective dilution and removal of air contaminants.

Keywords: Nitrous oxide (N_2O), carbon dioxide (CO_2), sulfur dioxide (SO_2), and particulate matter (PM).

INTRODUCTION

Dental clinics use a large variety of materials for their clinical procedures; however, limited information exists on the potential adverse health effects of these airborne materials [1]. These materials are commonly used for the manufacture of dental prostheses such as crowns, implants, bridges, frameworks and acrylic dentures. Particulates or dust in dental laboratories may be generated from the following operations: cutting dental models, coarse and fine grinding, polishing, centrifuge casting, soldering, and gypsum works. Specimens involved in such procedures include amalgam dies, gypsum models, porcelain, and alloys for restorative and prosthetic dental procedures of gold, chromium-cobalt, or nickel, as well as denture base materials.

Casting is a procedure by which a wax pattern of a restoration is converted to a replicate in dental alloy. The casting process is used to make dental restorations such as inlays, onlays, crowns, bridges, and removable partial dentures. The dental wax up is the method or process through which dentists can fully visualize the true restorative needs of their patients. Tooth polishing is the act of smoothing the tooth surface. The purpose of polishing is to make it difficult for plaque to accumulate on the tooth surface area.

Particulates generated from these procedures may be within the inhalable and often within the respirable fraction of particles released into the air [2]. The particles may have an aerodynamic diameter of 10 µm or less, thus they are inhalable and will enter the nose and pharynx, or an aerodynamic diameter of less than 5 µm and, therefore, may be considered respirable and reach the deeper alveolar or gas exchange regions of the lungs [3].

Human exposures to some of these materials have caused respiratory diseases, dermatological conditions, and allergies. Since exposure is not limited to one contaminant, combined exposure to several contaminants may be responsible for producing adverse health effects [4].

For this survey, the indoor air was evaluated for N_2O, CO_2, and SO_2, and particulates. The particulate monitoring involved testing using six ranges of particle sizes (monitored by size ranges) namely $PM_{0.3}$, $PM_{0.5}$, $PM_{1.0}$, $PM_{2.0}$, $PM_{5.0}$ and $PM_{10.0}$. This survey involved identifying possible sources for generating select air contaminants as well as resulting air concentrations of the contaminants when generated, and their relationship to dental laboratory activities.

Dentists and technicians exposed to these air contaminants over prolonged periods can potentially experience adverse health effects; therefore minimizing exposure using adequate emission and exposure controls such as use of efficient local and general exhaust ventilation system and use of personal protective equipment is important. As suggested in the guidelines of the "American Dental Association", operators and dental assistants should wear masks, surgical gloves, and safety eyeglasses with lateral protective shields when working with or in the presence of these contaminants [5].

*Address correspondence to this author at the Rocky Mountain Center for Occupational and Environmental Health, University of Utah, 391 Chipeta Way, Suite C, Salt Lake City, Utah 84108, USA; Tel: 801-585-3673; Fax: 801-581-7224; E-mail: rod.larson@hsc.utah.edu

The Occupational Safety and Health Administration (OSHA) have Permissible Exposure Limit (PEL) for most of the agents evaluated in this study and ACGIH has threshold limit values (TLVs) for all of the gases and aerosols monitored. One of the agents monitored was nitrous oxide (N_2O).At present there are no OSHA PEL governing potential exposures to N_2O during the handling and administration by dentists. However, ACGIH does have a TLV for N_2O of 50 ppm 8-hour TWA. It should be pointed out that Boards of Registration in Dentistry in 20 states have instituted recommendations for the use of N_2O and some states have passed legislation to enforce these recommendations. Four of the 20 states; Massachusetts, Tennessee, Wisconsin, and Utah- require the installation and use of scavenger systems to remove the emission of the gas during N_2O administration. No states currently regulate the application of permissible exposure levels for N_2O [6].

In summary, the objective of this survey was to evaluate the indoor air quality of a dental laboratory. The Veterans Affairs (VA) dental laboratory provided the location for this survey.

MATERIALS & METHODOLOGY

The dental laboratory used in this survey is designed to be under negative pressure, but only when the two laboratory fume hoods in this lab are in use. Room dimensions are: 23.5 x 16.0 feet, and height is 10.0 feet. The room has an area of 376 square feet and a capacity of 3760 cubic feet. The laboratory's ventilation system includes two air supplying and four exhaust vents. The exhaust vents comprise two vents that open to the ceiling plenum and two exhaust hoods on the sides of the room with switches on the wall. The hoods dimension is 24 x 48 inches. The air exchange rate when the hoods are on, and based on total exhaust air volume is 13.75 air changes per hour. When the hoods are off, air movement and exchange is based on the air supplied to the lab; which results the lab having positive air pressure and 6.6 air changes per hour. Fig. (**A1**) shows the dental laboratory room diagram.

Initially the procedures carried out in the dental laboratory were observed to assess the potential for exposure from select gases and particulates. The sources were identified as it related to dental laboratory activities, and an assessment of the existing local exhaust and general ventilation system was also conducted. After gaining additional information on activities conducted in the lab, monitoring of indoor air quality was conducted at peak activity periods in the months of August through December. Area sampling was conducted for the measurement of both the airborne gases, and for airborne particulate matter concentrations. Samples were collected at 4.5 to 5.0 feet above the floor: approximately near the breathing zone of most workers.

Measurements for contaminants in air were collected weekly for the following gases: nitrous oxide (N_2O), carbon dioxide (CO_2), and sulfur dioxide (SO_2). These were measured using a real time infrared (IR) analyzer, the Miran Sapphire (ThermoScientific, Franklin Massachusetts). Calibration is performed annually by the manufacturer.

The Miran Sapphire is a single beam, microprocessor controlled, infrared analyzer with a variable pathlength gas cell and an optical filter. A beam of broad spectrum infrared is generated by heating a metal alloy. The beam is modulated and passes through the optical filter which only permits infrared light of wavelength selected by the operator A filter is connected and it zeros itself and the filter is removed before measurements are taken. Fig. (**A2**) shows a picture of the Miran Sapphire.

The Fluke 983 Particle Counter (Fluke Corporation, Everett, Washington), was used to measure the particulate matter. A zero count was used to calibrate this instrument before each use. For calibration and quality control purposes the particle counter display needed to indicate detection of less than one particle of 0.3 µm or greater in size in a five-minute period. Calibration is performed annually by the manufacturer. Fig. (**A3**) shows a picture of the Fluke 983 Particle Counter.

The airborne particle or particulate matter (PM) are measured and classified according to their aerodynamic diameter in microns. This particle count information was converted to particulate mass per unit volume by multiplying the average particle volume for each size range by the particle density and particle count and dividing by the volume of air sampled for the particle count. Particles are monitored in ranges described as $PM_{0.3,}$ $PM_{0.5}$, $PM_{1.0}$, $PM_{2.0}$, $PM_{5.0}$ and $PM_{10.0}$ reflecting particle sizes of less than 0.3 m, 0.5µm, 1.0µm, 2.0µm, 5.0µm and10.0µm respectively.

RESULTS

The indoor gases measured include N_2O, SO_2, $_{\text{and}}$ $CO_{2.}$ Samples for each of these agents were collected once per week, four weeks per month for five months, with a total of 20 sample results for each agent. The air concentrations detected for each of these gases was below the OSHA permissible exposure limit (see Figs. **1**-**3**. and Tables **1** to **3**). However, the concentration of SO_2 was above the TLV of 2 ppm (see Table **2**). Although the concentrations were within the regulatory OSHA exposure limits, the concentrations of the gases were higher in the months of September and October when compared to the other months. This may be due to more dental workers involved in dental procedures in the lab during these months. The results did not show any significant variation in locations that were measured.

The gas measurement results are summarized in Tables (**1-3**). Bar charts of the average concentration of the gases according the locations measured are shown in Figs. (**1-3**).

Particulate results were all well below 0.01mg/m^3. The average concentration of these particulates based on the dental activity and location of sampling is shown in the Tables (**4-7**). There is no significant finding observed when the dental activities were compared and when the locations of sampling were also compared.

AIR CONTAMINANTS LEVELS

Particulate Monitoring Results

The monitoring device used for monitoring particulates in air provided results in particle counts by ranges of particle sizes per unit volume of air. To relate this to recommended air quality standards for particulates in air, it was necessary to convert the monitoring results from particle count per air

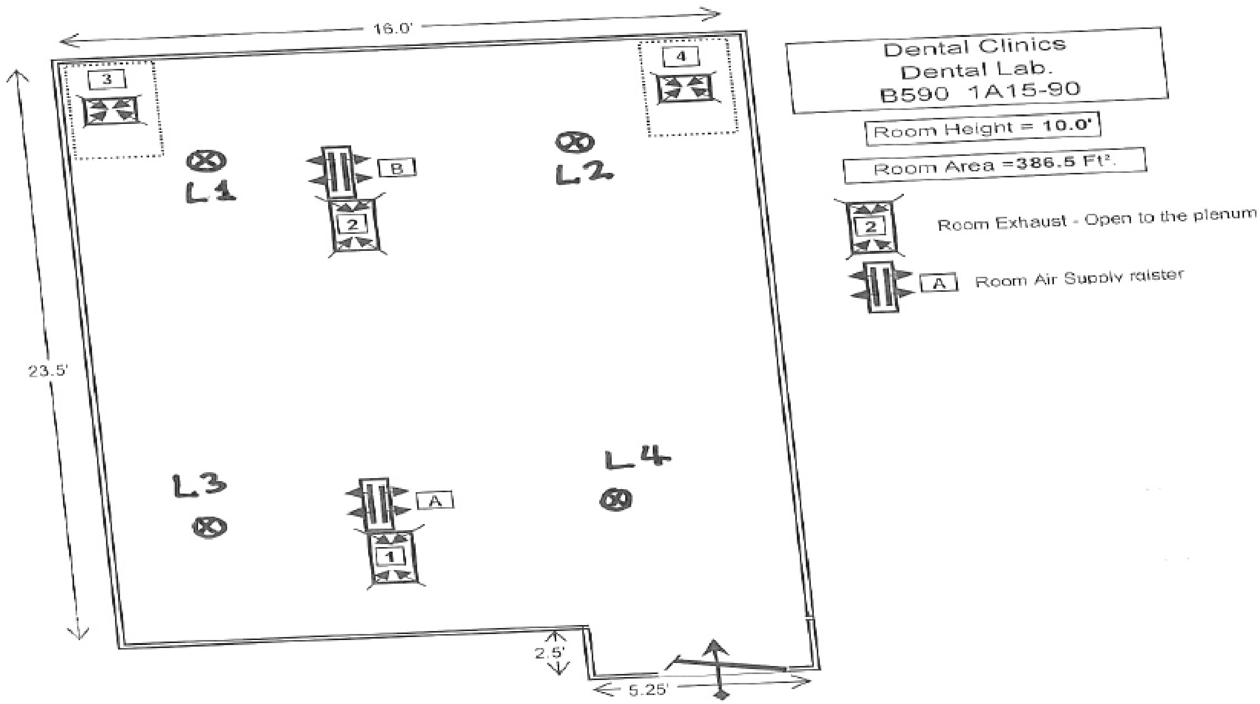

Fig. (A1). Dental Lab Room Diagram.

- L1 depicts sample collection location 1.
- L2 depicts sample collection location 2.
- L3 depicts sample collection location 3.
- L4 depicts sample collection location 4.
- Returns 1 & 2 are open to the ceiling plenum.
- Exhaust 3 & 4 are Exhaust Hood enclosures with switches on the wall.
- Room Air Exchange Rate based on Air Exhaust (Hoods operating): 13.75 Air Changes per Hour.
    - Room Volume =3760 cubic feet,
    - at 862 CFM =51720 CF/HR
        - 51720/3760 = 13.75 Air Changes/HR
- Room Air Exchange Rate based Air Supply (Hoods off): 6.6 Air Changes per Hour.
    - Air Supply = 416 CFM,
    - at 416 CFM =24960 CF/HR
        - 24960/3760 = 6.6 Air Changes/HR

Fig. (A2). The Miran Sapphire.

Fig. (A3). The 983 Fluke Particle Counter.

Table 1. Concentration of Indoor N_2O

Average Concentration of Indoor N_2O OSHA PEL: None; ACGIH TLV: 50 PPM					
Month	**Sample Number (n)**	**Location1 (ppm)**	**Location2 (ppm)**	**Location3 (ppm)**	**Location4 (ppm)**
August	4	0.20	0.22	0.21	0.24
September	4	0.29	0.32	0.35	0.38
October	4	0.38	0.36	0.41	0.33
November	4	0.31	0.24	0.23	0.21
December	4	0.24	0.20	0.25	0.22
Mean (Standard Deviation) N = 20		0.286 (0.063)	0.27 (0.064)	0.289 (0.079)	0.276 (0.070)

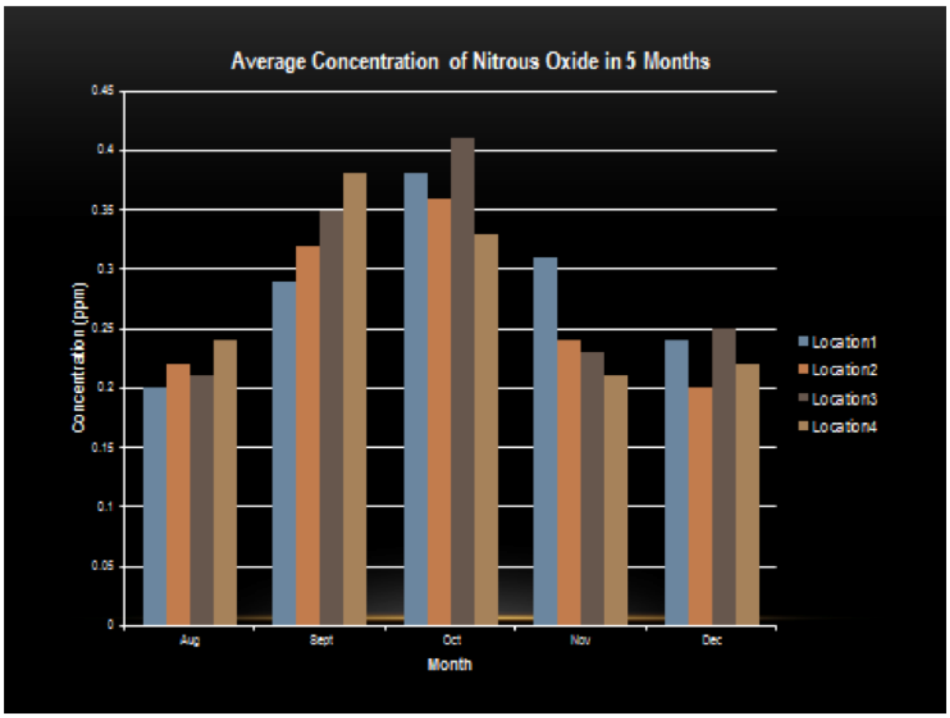

Fig. (1). Bar Chart of the N_2O Concentration.

Table 2. Concentration of Indoor SO_2

Average Concentration of Indoor SO_2 OSHA PEL: 5 PPM; ACGIH TLV: 2 PPM					
Month	**Sample Number (n)**	**Location1 (ppm)**	**Location2 (ppm)**	**Location3 (ppm)**	**Location4 (ppm)**
August	4	3.5	3.3	2.1	1.7
September	4	1.9	1.4	1.1	0.9
October	4	3.4	3.7	3.5	3.5
November	4	3.7	3.6	3.2	3.3
December	4	2.9	3.1	2.2	2.1
Mean (Standard Deviation) N = 20		3.09 (0.68)	3.05 (0.86)	2.43 (0.89)	2.32 (1.01)

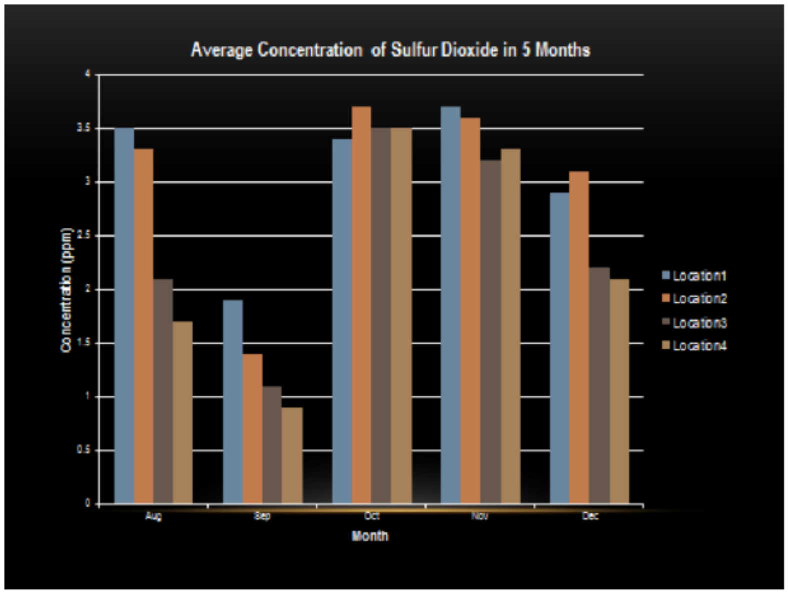

Fig. (2). Bar Chart of SO_2 Concentration.

Table 3. Concentration of Indoor CO_2

Average Concentration of Indoor CO_2 OSHA PEL: 5000 ppm; ACGIH TLV: 5000 ppm					
Month	**Sample Number (n)**	**Location1 (ppm)**	**Location2 (ppm)**	**Location (ppm)**	**Location4 (ppm)**
Aug	4	65	120	51	33
Sep	4	32	40	38	40
Oct	4	30	20	70	50
Nov	4	60	45	28	33
Dec	4	35	32	29	30
Mean (Standard Deviation) N = 20		44.5 (15.7)	51.7 (37.2)	43.5 (16.3)	37.8 (8.2)

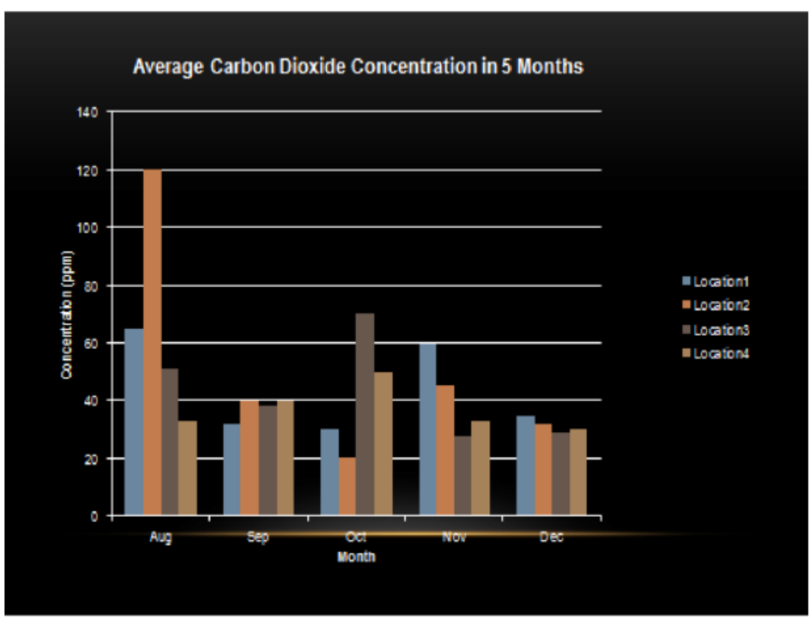

Fig. (3). Bar Chart of CO_2 Concentration.

volume to mass per air volume. This conversion was conducted using the following equation:

1. Particle mass = Particle density x Particle count x Particle volume
2. Particle Volume (based on particle diameter) or $V = (4/3) \times \pi \times r^3$
3. for a 0.3 μm diameter particle, volume = $1.333 \times 3.1416 \times (0.15\ \mu m)^3 = 0.014\ \mu m^3$

Note: Particulate counts are based on liter size samples, and were converted to m^3.

Example: Gypsum mass for $PM_{0.3}$ = 2.3 g/cm^3 x 91378 particles/liter x 0.014 μm^3

4. Density = 2300mg/cm^3 x 1,000,000cm^3 /m^3 = 2,300,000,000mg/m^3 = 2.3×10^9 mg/m^3
5. Particle Volume for $PM_{0.3}$ = 0.014μm^3 x 10^9 μm^3 /m^3 = 1.4×10^{-20} m^3 /particle
6. 91,378 particles/L x 1000 L/m^3 = 91,378,000 particles per m^3 or 91.4×10^6 particles/m^3 = (2.3×10^9 mg/m^3) x (91.4×10^6 particles/m^3) x (1.4×10^{-20} m^3) =0.0029 or 2.9×10^{-3} mg/m^3.

Table 4. Exposure Limit for Particulates

Exposure Limits	Respirable Particulate	Total Particulate
OSHA PEL	5 mg/m3	15 mg/m3
ACGIH TLV	3 mg/m3	10 mg/m3

DISCUSSION

The indoor air contaminants assessed in the VA dental laboratory were found to be lower than the OSHA Permissible Exposure Limits. However, some results for the SO_2 were found to be above the TLV in the four locations assessed. When compared to a study conducted by Helmis CG et al in which total VOCs, $PM_{2.5}$, $PM_{10.0}$, CO_2, NO_X, and SO_2 were measured in a selected dental clinic in Athens over a three month period, high levels of total VOCs, CO_2, and Particulate matter were observed only during operation hours but NO_x and SO_2 remained at low levels for the whole period.

Based on these results, good ventilation is essential in preventing occupants in this dental clinic from inhaling higher than acceptable concentrations of contaminants such as SO_2. For example this is a potential concern for the dentist who spends most of their everyday time in these environments [7].

Regarding the ventilation system, the ventilation for the dental clinic lab is designed to be a negative pressure system for that room but only when the two exhaust hoods are being operated. However, the current installation of these hoods has switches to operate the hoods on their front exterior of the hoods. This result in the operation of the hood being left to the dental worker; he or she needs to remember to place the hoods into operation when undertaking certain procedures. When the hoods are not placed into operation, the room air pressure becomes positive and contaminants that may be emitted can concentrate in the work area and as well as migrate into the adjacent corridor. Therefore, the exhaust ventilation system should be redesigned. Such design in part would require the elimination of the operating switch on the face of the hoods. The redesign should have the operating switches in a maintenance area so the hoods are always on and only switched to the non-operating position for maintenance purposes.

This change would assure the ventilation for this lab area is a constant exhaust volume and assure the area is always under negative air pressure when occupied.

Table 5. Waxing Activity Particulate Concentration

Average Particulate Concentration-Waxing Activity										
PM	Location1		Location2		Location3		Location4		Sample Number (n)	Mean/SD Particle/ liter
	Particle/ liter	Mg/m^3	Particle/ liter	Mg/m^3	Particle/ liter	Mg/m^3	Particle/ liter	Mg/m^3		
$PM_{0.3}$	91378	2.9×10^{-3}	88276	2.8×10^{-3}	88583	2.8×10^{-3}	89520	2.9×10^{-3}	20	89439.7 (12954.4)
$PM_{0.5}$	13473	4.3×10^{-4}	13593	4.3×10^{-4}	13571	4.3×10^{-4}	13416	4.3×10^{-4}	20	13513.5 (3978.7)
$PM_{1.0}$	1707	5.5×10^{-5}	1608	5.2×10^{-5}	1731	5.5×10^{-5}	1642	5.2×10^{-5}	20	1672 (527.7)
$PM_{2.0}$	607	1.9×10^{-5}	602	1.9×10^{-5}	604	1.9×10^{-5}	593	1.9×10^{-5}	20	599 (79.3)
$PM_{5.0}$	42	1.3×10^{-6}	44	1.3×10^{-6}	41	1.3×10^{-6}	42	1.3×10^{-6}	20	42.5 (19.2)
$PM_{10.0}$	12	3.9×10^{-7}	12	3.9×10^{-7}	14	3.9×10^{-7}	12	3.9×10^{-7}	20	12.6 (5.5)

Table 6. Grinding Activity Particulate Concentration

Average Particulate Concentration-Grinding Activity										
PM	Location 1		Location 2		Location 3		Location 4		Sample Number (n)	Mean(SD) Particle/ liter
	Particle/ liter	Mg/m^3	Particle/ liter	Mg/m^3	Particle/ liter	Mg/m^3	Particle/ liter	Mg/m^3		
$PM_{0.3}$	109131	$3.5x10^{-3}$	106843	$3.5x10^{-3}$	109063	$3.5x10^{-3}$	107511	$3.5x10^{-3}$	20	107511.7 (9288.4)
$PM_{0.5}$	10737	$3.4x10^{-4}$	10669	$3.4x10^{-4}$	10679	$3.4x10^{-4}$	10650	$3.4x10^{-4}$	20	10650.4 (1088.9)
$PM_{1.0}$	1320	$4.2x10^{-5}$	1313	$4.2x10^{-5}$	1228	$3.9x10^{-5}$	1253	$3.9x10^{-5}$	20	1275.8 (152.1)
$PM_{2.0}$	543	$1.7x10^{-5}$	548	$1.7x10^{-5}$	560	$1.8x10^{-5}$	557	$1.8x10^{-5}$	20	552.1 (43.5)
$PM_{5.0}$	70	$2.3x10^{-6}$	71	$2.3x10^{-6}$	70	$2.3x10^{-6}$	72	$2.3x10^{-6}$	20	70.8 (3.8)
$PM_{10.0}$	26	$8.4x10^{-7}$	28	$9.0x10^{-7}$	27	$8.7x10^{-7}$	26	$8.4x10^{-7}$	20	26.7 (4.2)

Table 7. Powder Gypsum Dispensing Particulate Concentration

Average Particulate Concentration- Powdered Gypsum Dispensing										
PM	Location 1		Location 2		Location 3		Location 4		Sample Number (n)	Mean(SD) Particle/ liter
	Particle/ liter	Mg/m^3	Particle/ liter	Mg/m^3	Particle/ liter	Mg/m^3	Particle/ liter	Mg/m^3		
$PM_{0.3}$	99464	$3.2x10^{-3}$	99638	$3.2x10^{-3}$	99942	$3.2x10^{-3}$	98601	$3.2x10^{-3}$	20	99411.8 (8044.7)
$PM_{0.5}$	11188	$3.6x10^{-4}$	11518	$3.6x10^{-4}$	11490	$3.6x10^{-4}$	11355	$3.6x10^{-4}$	20	11387.9 (918.5)
$PM_{1.0}$	1796	$5.8x10^{-5}$	1765	$5.8x10^{-5}$	1793	$5.8x10^{-5}$	1767	$5.8x10^{-5}$	20	1780.5 (194.6)
$PM_{2.0}$	750	$2.4x10^{-5}$	772	$2.6x10^{-5}$	765	$2.5x10^{-5}$	766	$2.5x10^{-5}$	20	763.6 (60.7)
$PM_{5.0}$	126	$4.2x10^{-6}$	138	$4.4x10^{-6}$	132	$4.4x10^{-6}$	135	$4.4x10^{-6}$	20	133.1 (9.5)
$PM_{10.0}$	27	$8.7x10^{-7}$	29	$9.3x10^{-7}$	29	$9.3x10^{-7}$	30	$9.6x10^{-7}$	20	28.9 (4.4)

It has been observed that factors such as insufficient awareness of health risks, work habits and cost of controls are possible reasons why dentists do not apply the available and recommended methods of protection against the potential exposure to air contaminants [8]. Education on the importance of using personal protective equipment as a means of reducing exposure is also to be emphasized.

Relative to a worker's use of personal protective equipment (PPE), factors such as comfort or additional body heat, may result in dentists and technicians not to use appropriate personal protective equipment, or at least not consistently, or for long work periods. For this reason, it is important that they understand the potential adverse effects of air contaminants that may be emitted into their work area from the various tasks they perform. This knowledge and awareness would be expected to have them more readily accept and follow appropriate work practices for their own health and safety, as well as for their co-workers. It is recommended that regular workshops and seminars on occupational hazards be organized for all dental personnel periodically [9].

It was observed that the Veterans Affairs Dental Clinic Laboratory has instituted adequate procedural control measures and maintains detailed guidelines for lab equipment and operating procedures. The measurement of air contaminants were within the OSHA permissible exposure limits. However, as mentioned above, the SO2 was found to be above the TLV in the four locations assessed.

The following recommendations are made to strengthen control measures and reduce worker's potential for exposures to air borne contaminants:

1. Modification of the ventilation system to a continuous exhaust and to maintain a minimum of 12 air changes per hour, specifically this can be accomplished by removing the operating switches from the face of the hoods and maintaining the hoods in continual operating mode.
2. The modification described above would also assure the air supply and exhaust system in this lab would be a constant air volume system.
3. Continued periodic education and awareness among dentists and technicians on the potential dangers of exposure to air contaminants and their related adverse effects, and methods they can use to control such exposures.
4. Dental managers and supervisors should continue to ensure workers comply with personal protective equipment during dental procedures that can result in exposure to contaminants (e.g., SO_2).
5. The dental lab room space should be increased to enhance dilution of air contaminants released during dental activities.

CONCLUSION

Indoor air quality will continue to be an issue for the dental clinic laboratory as procedures and activities carried out will ultimately lead to the release of air contaminants that could with prolonged or repeated exposure cause adverse health effects. It is important that measures are taken to ensure exposures are kept at a minimum level. This will be achieved through the hierarchy of controls. Namely: engineering controls, which involves effective use of ventilation; administrative controls; and the use of personal protective equipment such as proper use of chemical resistant gloves and respiratory protection as needed.

CONFLICT OF INTEREST

The author and co-authors of this manuscript do not have any potential competing interests with this project or the funding organization, and no financial support was received by any of the authors for this study.

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