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Nanoparticle concentrations and composition in a dental office and dental laboratory: A pilot study on the influence of working procedures

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ABSTRACT

During material treatment in dentistry particles of different size are released in the air. To examine the degree of particle exposure, air scanning to dental employees was performed by the Scanning Mobility Particle Sizer. The size, shape and chemical composition of particles collected with a low-pressure impactor were determined by scanning electronic microscopy and X-ray dispersive analysis. The average concentrations of nanoparticles during working periods in a clean dental laboratory (45,000–56,000 particles/cm^3), in an unclean dental laboratory (28,000–74,000 particles/cm^3), and in a dental office (21,000–50,000 particles/cm^3), were significantly higher compared to average concentrations during nonworking periods in the clean dental laboratory (11,000–24,000 particles/cm^3), unclean laboratory (14,000–40,000 particles/cm^3), and dental office (13,000–26,000 particles/cm^3). Peak concentration of nanoparticles in work-intensive periods were found significantly higher (up to 773,000 particles/cm^3), compared to the non-working periods (147,000 particles/cm^3) and work-less intensive periods (365,000 particles/cm^3). The highest mass concentration value ranged from 0.055–0.166 mg/m^3. X-ray dispersive analysis confirmed the presence of carbon, potassium, oxygen, iron, aluminum, zinc, silicon, and phosphorus as integral elements of dental restorative materials in form of nanoparticle clusters, all smaller than 100 nm. We concluded that dental employees are exposed to nanoparticles in their working environment and are therefore potentially at risk for certain respiratory and systematic diseases.

KEYWORDS
Dental laboratory; dental materials; dental office; particle exposure

Introduction

Treatment of different dental materials in the dental office or dental laboratory causes a release of tiny particles, including nanoparticles, into the local atmosphere of the working environment. Because of their small diameter, the particles diffusively spread over the entire working environment and are able to enter human body, which puts the dental personnel and patients at risk to their health (e.g., due to inhaling such particles).[1,2]

There are concerns that it may be possible for nanoparticles smaller than 50 nm to pass through the alveolar membrane into the blood circulatory system[3] and are then transported around the body. The main target organs are the liver, spleen, and lymphatic glands, but there are also cases where the heart, kidneys, medulla, and the brain are affected. Some connections are known to exist between nanoparticles and microtrombotic plaques,[3] cardiovascular diseases,[3–5] autoimmune diseases,[6] neurodegenerative diseases (such as Alzheimer's and Parkinson's disease[7]), and tumors. The mechanism of pathogenesis is thought to involve oxidative stress, sometimes also apoptosis, damage of phospholipid double layer, damage to DNA, and cell necrosis,[8,9] which is caused by nanoparticles. Metals that cause oxidative stress in the human body have been identified to have cancerogenic properties.[10]

There are many different sources of nanoparticles, primarily those arising from atmospheric phenomenon[3,5,11] and those that are fugitive emissions from their fabrication as powders (engineered nanoparticles).[12] In the dental office, nanoparticles are side products released during dental abrasive procedures such as reshaping and grinding ceramics, metals, and polymer materials. These procedures are used in all dental disciplines concerned with restoration of missing or damaged teeth, including adjustments of occlusion

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and articulation by grinding with diamond burs as well as reshaping and polishing tooth surfaces. In addition to the mentioned procedures performed in the dental office, treatment of dental materials by grinding and sandblasting with Al_2O_3 particles is frequently used in the dental laboratory, where a large amount of particles, including nanoparticles, are released due to the use of gas burners, various sprays, casting procedures, and computer-aided machining. In some cases, materials themselves are made of nano-compounds (e.g., composites).

In the air of the dental office, high concentrations of submicrometer particles were detected during dental drilling.[1]. The concentration of relatively small particles (<0.5 μm) was found to be much higher than that of particles larger than 0.5 μm.[2] Similar findings were obtained for particles released during grinding composite materials.[13,14] High concentrations of nanoparticles were found to increase during the reshaping of composite restorations.[13,15,16] Chronic exposure to sub-5 μm particles or nanoparticles can cause local and systemic toxicity.[12,17,18]

At present, nanoparticle studies are still in their infancy and there is little information available on nanoparticles released in the air of the dental office or dental laboratory in actual working conditions.

The aim of the study was to investigate the concentration of nanoparticles in the dental office and dental laboratory in three different working environments during working and non-working hours.

Materials and methods

Study design and sampling sites

Our measurements of nanoparticle concentrations in the air were performed during two periods: (i) from July 5–19, 2012 and (ii) from April 11–26, 2013. The measurements were carried out at the Department for Prosthetic Dentistry, Dental Clinic, Ljubljana, Slovenia in three working environments: the dental office as well as the clean and unclean parts of the dental laboratory. In the first period, the workload was lighter due to the beginning of summer holidays, while in the second period, the workload was much heavier. All measurements were repeated in the same working environments.

The dental laboratory is located on the first floor of the Dental Clinic. The clean part of the laboratory has a volume of 60 m^3 and contains 8 working places. There are 6 dental technicians who work 8 hr a day and spend most of the time at their working places. The unclean part of the laboratory has a volume of 30 m^3 and the technicians use it for various times as needed. There are swinging doors between the 2 parts of the dental laboratory. The clean and unclean parts of the dental laboratory are naturally ventilated by opening windows. In addition to natural ventilation in the unclean part of the laboratory, mechanical ventilation is also used. The windows of each part overlook a park.

The dental office of the Prosthetic Department is located on the first floor of the Dental Clinic. It has a volume of 150 m^3 and includes 7 dental working places, a sterilization room and an administration desk. On workdays, the office is filled with dental students and interns as well as prosthodontists and dental nurses. The dental office is naturally ventilated by opening windows. An average number of around 30 patients per day are attending treatment. The working hours are from 7 am to 7 pm on Monday and from 7 am to 3 pm on Tuesday to Friday.

Exposure measurements

The size distribution of nanoparticles was assessed with the Scanning Mobility Particle Sizer (SMPS) consisting of a Differential Mobility Analyzer—DMA (TSI, Model 3080) and a water-based Condensation Particle Counter (TSI, Model 3785 UWCPC). In the first period of measurements, the size range of detected particles was from 14–700 nm, while in the second period, particles between 27 and 982 nm were detected. In both cases, the measurements were performed in subsequent scans in 3- to 4-day long time periods in all 3 locations. Each scan lasted 5 min. All gathered information was analyzed using Wolfram Mathematica 8 software. The diffusion of particles and multiple charge corrections were considered, which are necessary for particles smaller than 100 nm. Normalized number concentration dN/(dlog Dp) is defined as the increment in the number of particles (dN) divided by the difference in the log of the size channel width with midpoint particle diameter (Dp). In the second period, a cascade low-pressure impactor (DLPI-Dekati), which can classify airborne particles into 13 size categories in the range from 30 nm to 10 μm, was used to collect nanoparticles for shape and chemical composition analysis in all 3 locations. To detect particles smaller than 30 nm, an additional stage was used.

The particles were collected on aluminum foils (Dekati, CF-300) and covered with APIEZON L grease. The material collected on 2 selected stages of the impactor was coated with an amorphous carbon layer and studied with a scanning electron microscope (FE-SEM, Supra 35 VP, Carl Zeiss). The X-ray diffraction (XRD) was performed at room temperature with a D4 Endeavor diffractometer (Bruker AXS) using a quartz monochromator Cu-Kα1 radiation source ($\lambda = 0.5406$ nm) and a Sol-X energy-dispersive detector. The 2θ angular range was from 10°–70° with a step size of 0.02° and collection time of 3 sec. The elemental analysis was performed by X-ray energy-dispersive analysis (EDS) in the SEM.

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The data analysis was performed using the SPSS software (The Statistical Package for Social Science SPSS Inc., Chicago, IL, USA). The results for the total particle concentrations were analyzed with the ANOVA test. For multiple comparisons, Bonferroni post-hoc tests were used to determine differences between groups.

Results

Size distribution of nanoparticles

Figure 1 displays sequences of daily measurements of number concentrations and the respective total concentrations. The plots on the left show number concentrations of nanoparticles against time with the highest peaks during working hours. The color scale defines values in the range from 0 (violet) to 100,000 units (red) and higher (white). The values between these limits are mapped by blue, green, yellow, and orange colors. The start and duration of daily measurements varied, which is why the day's data areas have unequal widths. It should be noted that the majority of particles are nanoparticles with size below 100 nm. The plots on the right represent the total concentrations of particles regardless of their size. The average, lowest and highest total concentrations for each environment are shown in Table 1.

The ratio between the number of nanoparticles with the diameter below 98 nm and the number of all particles was obtained from the spectra represented in cumulative concentration units. The difference in number concentration is in a range from 3,000 particles at low pollution and 6,000 particles during the highest pollution. This means that a large majority (97% in number concentration) of the particles with diameter between 14 nm and 730 nm are nanoparticles with diameter below 100 nm. The average, lowest, and highest total concentrations for each environment are shown in Table 1.

According to the chart in Figure 2, the average nanoparticle concentrations are significantly higher during working hours in all three environments and in both measurement periods in comparison to non-working hours. We performed ANOVA with working hours, location and time period as fixed factors. We found statistically significant difference in concentrations for location ($p < 0.001$), time period ($p < 0.001$) and location ($p < 0.001$). Also, all interaction terms were statistically significant with $p < 0.001$. Differences in concentrations between locations were significant overall as well as in pairwise (Bonfferoni corrected) comparisons. During the working hours of the first period (in 2012), the highest average total concentration was measured in the clean part of the dental laboratory, a much lower concentration was found in the unclean part of the dental laboratory, and the lowest concentration was in the dental office. In the second, more intense working period (2013), the highest average total concentration was measured in the unclean part of the dental laboratory, a lower concentration was found in the dental office, and the lowest concentration was in the clean part of the dental laboratory. During non-working hours, the highest average total concentration was in the unclean part of the dental laboratory in both periods, a lower concentration was in the dental office, and the lowest concentration was in the clean part of the dental laboratory.

In the first period, the average total concentrations were lower than in the second period for all three environments, respectively. In non-working hours, the average total concentrations were lower in the first period in all three environments.

Mass concentration

Figure 3 displays graphs of the logaritmic mass concentration measured in the second period in all 3 environments (a, c, e) and the respective graphs of the cumulative mass concentration (b, d, f). The total mass of particles collected by cascade impaction in the clean part of the dental laboratory was 6.9 mg and the corresponding mass concentration was 0.10 mg/m^3. The respective values were 4.6 mg and 0.17 mg/m^3 in the unclean part of the dental laboratory and 2.3 mg and 0.06 mg/m^3 in the dental office. Volume measurements were in m^3 at normal temperature (293 K) and pressure (760 mmHg).

Structural and morphological investigation

An SEM investigation was performed on the particles collected by DLPI on stage 3 (D50% = 0.108 µm) and stage 1 (D50% = 0.03 µm). All nanoparticles from stage 1 were smaller than 100 nm (Figure 4a). This stage was chosen because of its high contribution to the total mass (Figure 3a). Each particle was in fact a cluster of nanoparticles partly submerged into the grease covering the substrate. The energy dispersive spectroscopy (EDS) analysis at 10 keV detected the presence of carbon, potassium, oxygen, iron, zinc, aluminum, silicon, phosphorus, and sulphur. Sulphur could have originated from the APIEZON L grease, aluminum likely came from the substrate, while the other elements belonged to the collected nanoparticles.

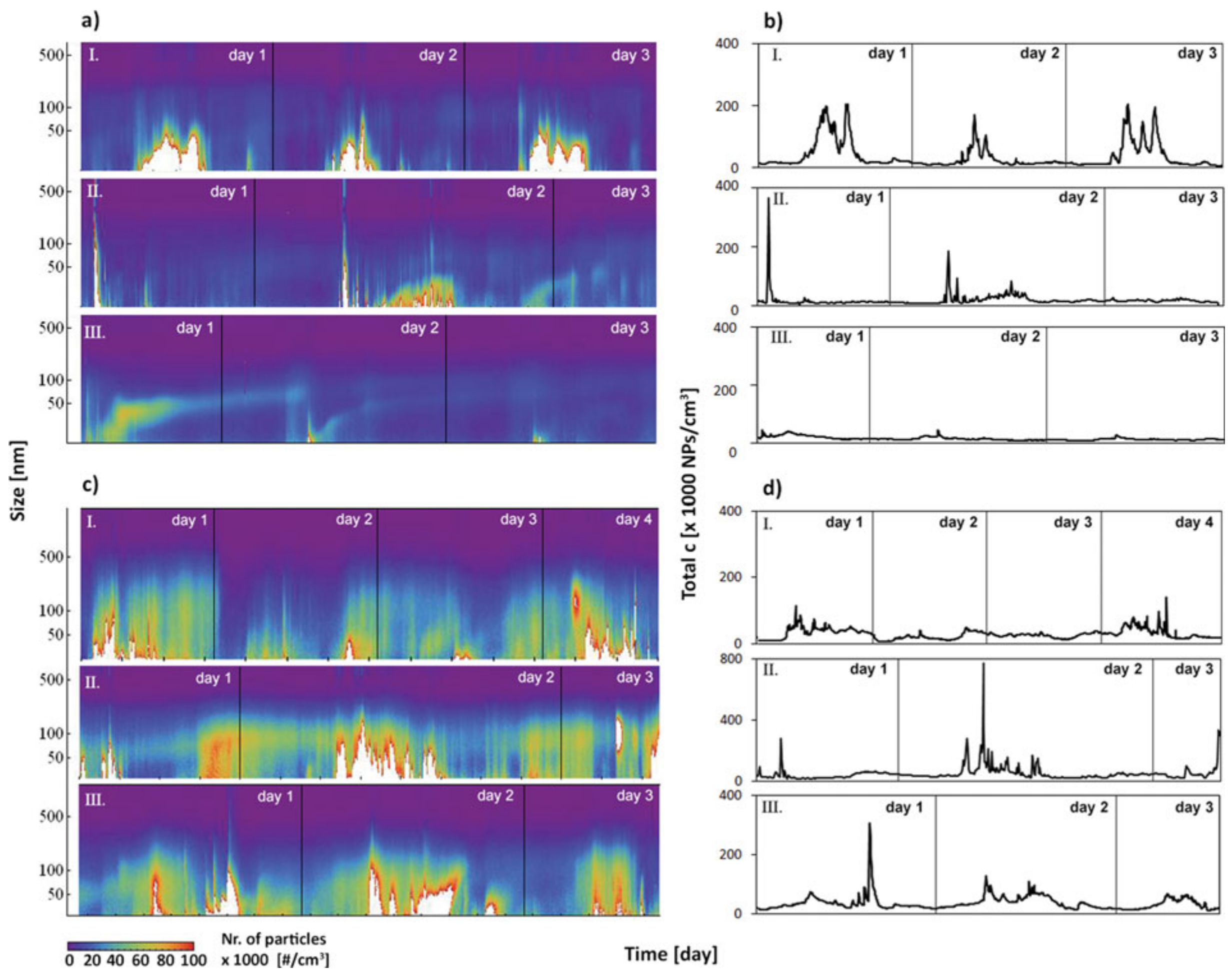

Figure 1. Normalized number concentrations of nanoparticles (a,c) with respective total concentrations (b, d): a, b measured in the low workload period, size ranges between 14 and 700 nm; c, d measured in the high workload period, size ranges between 27 and 982 nm. I, II, and III denote measurements in the clean (I) and unclean (II) parts of the dental laboratory and in the dental office (III).

Discussion

The results of our study demonstrate significantly higher concentrations of nanoparticles in the dental laboratory and dental office during working hours as compared to non-working hours. Working procedures performed in all three environments increase nanoparticle concentrations, and therefore present a potential hazard to dental employees.

We noticed that out of all particles arising due to working procedures, it was nanoparticles whose number increased the most. Plots of time-dependent number concentrations of nanoparticles are shown in Figure 1. In

Table 1. The average total number concentration of particles (pt/cm^3) with standard errors, and minimum and maximum total concentrations for the different workload and for the different working environment.

Period	Environment	YEAR	AVERAGE	STD. ERROR	MIN	MAX
Working	Clean lab	2012	56,283.4	990.0	6,447.6	21,1971.0
		2013	45,351.2	1,547.9	13,240.4	140,644.0
	Unclean lab	2012	28,064.1	1,719.2	6,835.4	364,936.0
		2013	74,073.2	1,938.1	18,639.0	773,050.0
	Dental office	2012	21,142.6	1,414.5	11,502.4	46,601.9
		2013	50,041.2	1,400.1	9,981.2	305,663.3
Nonworking	Clean lab	2012	11,003.8	648.6	3,470.9	13,213.2
		2013	23,549.5	735.9	3,295.2	63,965.0
	Unclean lab	2012	14,499.7	1,177.4	6,979.1	28,799.3
		2013	40,093.6	1,263.0	17,538.2	147,100.0
	Dental office	2012	12,626.0	1,042.2	8,969.0	32,241.4
		2013	26,317.4	1,027.0	14,543.6	129,009.0

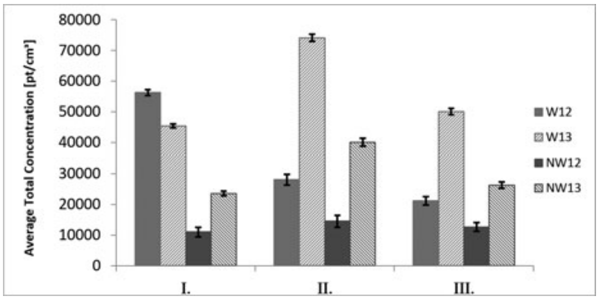

Figure 2. Average total number concentrations of particles in 1 cm^3 of air with standard errors in the clean (I) and unclean (II) parts of the dental laboratory and in the dental office (III) during working (W) and non-working hours (NW) in the years 2012 and 2013.

all three environments, immediately after the beginning of work, the concentrations became significantly higher as compared to non-working hours. All concentrations remained high during the working hours and then gradually decreased as a consequence of diffusional and gravitational deposition of particles on surfaces in the room as well as removal of particles from the room by the ventilation system. In all three sites, the particle concentrations increased when the cleaning personnel entered and conducted housekeeping activities in the dental laboratory.

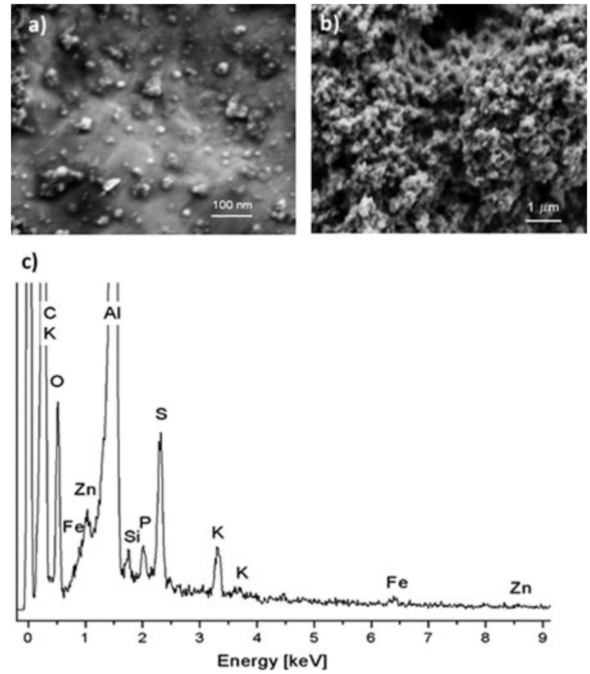

Figure 4. SEM micrographs of nanoparticles on filters 1 (a) and 3 (b) collected in the clean part of the dental laboratory with the corresponding EDS spectrum (c).

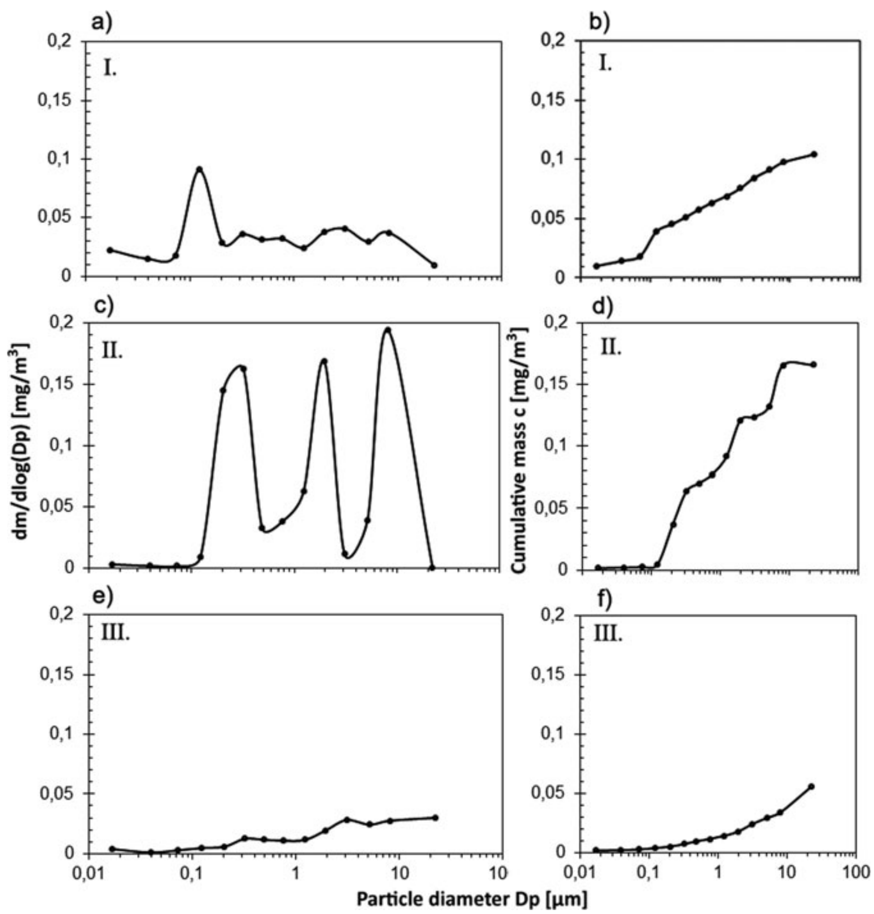

Figure 3. Mass concentrations (a, c, e) and cumulative mass concentrations (b, d, f); (I) clean part of the dental laboratory, (II) unclean part of the dental laboratory, and (III) dental office.

The highest total concentration, 773,000 particles/cm^3, was detected in the unclean part of the dental laboratory in the second period of measurement. In the dental office, the highest concentration, 306,000 particles/cm^3, was registered also in the second period. In the clean part of the dental laboratory, the highest total concentration, 212,000 particles/cm^3, was in the first period. To determine which dental procedures contributed the most to increasing nanoparticle concentrations, all activities were recorded in a logbook. We gathered the information about dental procedures that are expected to be the source of nanoparticles in the logbook, to help us determine which of the tasks contribute the most to the increase in nanoparticle concentration. In the dental office, the most frequent dental procedures in daily practice are abrasive procedures of teeth, composites, acrylic materials, metals, and ceramics. Also, plaster cast processing and metal moulding are most commonly seen in the dental laboratory.

Due to variations in the working procedures and simultaneous work of several people, we could not accurately determine which procedures caused the highest increase in nanoparticle concentrations, with the exception of plaster cast processing and metal moulding. Occasional relatively small concentration increments occurring at night, when there were no personnel in the working places, might be attributed to external factors, such as strong winds blowing outside or heavy transport passing nearby.

In the literature, there is very few data available on nanoparticle concentrations in dental working environments. Van Landuyt et al.[13] showed that procedures involving abrasion of composites are associated with high peak concentrations of nanoparticles (0.1–10^6 particles/cm^3) in the breathing zone of the dentist's environment, with background measurements between 5,000 and 10,000 particles/cm^3. These results are in agreement with the results of our study, considering different location of the measuring equipment. Unlike us, Van Landuyt et al. experimentally simulated the conditions of a dental laboratory and carried out experiments in a chamber with low background contamination. They grounded polymer composite blocks and measured higher concentrations of composite nanoparticles (5×10^6 to 2×10^7 particles/cm^3). Due to a relatively small closed chamber, these results are significantly different to those of the present study. Another study by Sotiriou et al.,[2] reported mainly submicrometer particles, ranging between 0.3 and 0.5 μm, released during dental procedures.

External factors, such as inflow of outdoor air, can also affect the indoor concentration of nanoparticles. The outside environment of the buildings where the measurements are carried out, such as heavy traffic roads or green areas with dynamic background levels or nanoparticles, is another important factor. For example, the background level measured in a rural area in Slovenia was 5,000 particles/cm^3, while concentrations measured near a heavy traffic area in Tivolska Road in Ljubljana were 60,000–80,000 particles/cm^3. In Manchester, UK, nanoparticle concentrations in heavy traffic areas range from 2,000–190,000 particles/cm^3.[11] All these values are low compared to the highest peak total concentrations obtained in the present study. The range of concentrations in those studies were generally higher than the average concentrations in the dental areas assessed in this study. The much higher peak concentrations of nanoparticles detected in the dental laboratory and dental office as well as concentration variations matched up with the working hours lead us to the conclusion that with the majority of nanoparticles arise from the treatment of dental materials.

In the second period of measurement, particles were collected for chemical analysis using a DLPI impactor, which enables the determination of mass concentrations. Even though much more numerous, nanoparticles are extremely light and so their contribution to the mass concentration is much smaller in comparison to micrometer particles. For example, the mass of a 10-nm diameter particle of spherical shape and unit density is only 5×10^{-7} pg, whereas the mass of a 1-μm diameter particle of similar shape and density is 0.5 pg. The highest mass concentrations were measured in the unclean part of the dental laboratory, moderate mass concentrations were in the clean part, and lowest concentrations were in the dental office. Another factor that contributes to the differences in the cumulative mass of particles, apart from different degrees of air pollution, is the duration of measurement (6 days in the clean part of the dental laboratory, 3 days in the unclean part, and 4 days in the dental office). The American Conference of Governmental Industrial Hygienists (ACGIH) defined the safe exposure limit for particle concentrations to be 3 mg/m^3 for particles smaller than 5 μm and 10 mg/m^3 for particles between 5–10 μm in size.[19] Specified safe values were not exceeded in any of the 3 environments.

It is hard to compare our results considering different ways of collecting particles with those of the study by Van Landuyt et al.,[13] where the mass concentration of particles released during grinding of different composite materials was measured with the reported values of 10–80 mg/m^3 for particles from 1–5 μm in size.[1]

The electron microscopic analysis of filters 1 and 3 with the particles collected in the clean part of the dental laboratory confirmed that it is the working procedures and the materials that caused high concentrations of nanoparticles in the working atmosphere. We performed an X-ray dispersive analysis of a selected area of the filters with several particles. We found silicon (SiO_2 is a component of dental ceramics), phosphorus (gallium phosphate), aluminum (aluminum silicate is a component of dental ceramics and aluminum oxide is a material used in sandblasting), iron, and zinc (enter Stellite dental alloys).

Conclusion

Our findings indicate that the dental working procedures cause a significant increase in the nanoparticle concentration in the air of working environments with the highest detected concentration to 773,000 particles/cm^3 in the unclean part of the dental laboratory. Clear connection between level of air pollution and working time was evidenced. Chemical analysis of the collected nanoparticles from the air of dental laboratory confirmed that they originated from dental ceramics and alloys. The highest measured mass concentration of nanoparticle pollution from 0.06 mg/m^3 in dental office to 0.17 mg/m^3 in dental laboratory was found not to exceed the safe exposure limit set by the ACGIH. Taking into account that inhaled nanoparticles may present occupational hazard to human health, it is of great importance to determine the right preventive measures against occupational exposure of dental personnel. Further research is needed to quantify the degree of exposure of dental personnel to various nanoparticles and determine the materials and procedures that cause a significant release of nanoparticles into the dental environment.

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