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ORIGINAL ARTICLE

Exposure to ultrafine particles in hospitality venues with partial smoking bans

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Fine particles in hospitality venues with insufficient smoking bans indicate health risks from passive smoking. In a random sample of Viennese inns (restaurants, cafes, bars, pubs and discotheques) effects of partial smoking bans on indoor air quality were examined by measurement of count, size and chargeable surface of ultrafine particles (UFPs) sized 10–300 nm, simultaneously with mass of particles sized 300–2500 nm ($PM_{2.5}$). Air samples were taken in 134 rooms unannounced during busy hours and analyzed by a diffusion size classifier and an optical particle counter. Highest number concentrations of particles were found in smoking venues and smoking rooms (median 66,011 pt/cm^3). Even non-smoking rooms adjacent to smoking rooms were highly contaminated (median 25,973 pt/cm^3), compared with non-smoking venues (median 7,408 pt/cm^3). The particle number concentration was significantly correlated with the fine particle mass ($P < 0.001$). We conclude that the existing tobacco law in Austria is ineffective to protect customers in non-smoking rooms of hospitality premises. Health protection of non-smoking guests and employees from risky UFP concentration is insufficient, even in rooms labeled "non-smoking". Partial smoking bans with separation of smoking rooms failed.

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INTRODUCTION

Tobacco smoke is known to be the most important indoor source of fine and ultrafine particles (UFPs), usually captured by measuring $PM_{2.5}$,[1,2] which is highly correlated with the nicotine concentration in the air.[3,4] Particles with a diameter <100 nm (commonly called "ultrafine") are inhaled easily into the deep pulmonary tracts and partly enter the vascular system. UFPs decrease coronary flow and accelerate blood clotting and the progression of atherosclerosis by endothelial dysfunction.[5] The smaller the size of particles inhaled, the more severe is their effect on cardiovascular disorders.[6]

Outdoor $PM_{2.5}$ exposure in Vienna, even at relatively low levels, has been related to cardiovascular and cerebrovascular mortality on the same day and the following 14 days.[7] Implementation of total smoking bans lead to significant decreases of indoor particulate matter and nicotine,[8–10] followed by a decrease of coronary events.[11]

In Viennese hospitality venues, very high $PM_{2.5}$ concentrations had been found before.[12] UFPs, however, contribute little to particle mass, and air nicotine concentration correlated higher with chargeable particle surface area (dominated by ultrafines) than with $PM_{2.5}$.[13] Recent insights into harmful effects of UFPs[14] and new possibilities to measure both particle number and chargeable surface area, correlated to lung-deposited surface area (LDSA),[15] initiated this investigation after introduction of a partial smoking ban,[16] which had gone into force in Austria in 2009. Since then owners of hospitality premises have to provide a non-smoking room, an adjacent smoking room had to be separated by a door until July 2010. Various exceptions weaken the already weak law: Owners of venues $<50\,m^2$ do not have to offer a non-smoking room, if they decide on their own that their establishment is a smoking venue. Furthermore, premises $>50\,m^2$ and $<80\,m^2$ may remain without a separated non-smoking room if the building inspection decided that for fire protection or for preservation of a historic building no separation is possible. All other venues were required to reserve the "main room" for non-smoking guests and to provide a separation to the smoking room by a door; however, no specifications on the tightness of the door and on ventilation were given.

MATERIALS AND METHODS

Sampling

The study was carried out between 6 November 2010 and 6 June 2011. Air samples were taken in 134 rooms of 88 hospitality premises in Vienna, which were selected among well-used inns in central districts by chance. Sixteen of those venues were cafés, 51 bars and pubs, 14 restaurants and 7 discotheques. Only 22 establishments were designated non-smoking venues. In 20 venues, smoking was permitted and 46 establishments had designated non-smoking rooms next to smoking rooms. Sampling was performed without previous notice (while having a drink) and lasted 20 min per room sampled, consecutively in central parts of non-smoking rooms and adjacent smoking rooms, and away from spot sources (smoking neighbor, open kitchen) and sinks (open doors, windows).

The air samples were taken when most guests were present (bars, pubs and discotheques in the evening or at night, restaurants at midday or in the evening and cafés in the afternoon). The apparatus was hidden in a bag, in order to avoid selection bias introduced by permission of the owners of the establishments.

All examined hospitality premises were located near the city center (postcodes 1010, 1030, 1040, 1060, 1070, 1080, 1090, 1150, 1180, 1190 and 1200).

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Apparatus

The air samples were taken simultaneously by a Miniature Diffusion Size Classifier (miniDiSC, matter aerosol), model G3_016 and by a Laser-Aerosol-Spectrometer, model 1.108 (Grimm). The miniDiSC was developed for measuring nanoparticles with diameters between 10 and 300 nm. Each second, it stores data on number concentration (range 10^3–10^6 pt/cm^3), particle diameter (nm) and LDSA (μm^2/cm^3).[17]

The Grimm Spectrometer works in the size range of 0.3–20 μm. In a constant airflow of 1.2 l/min, particles are detected by a laser and an optical sensor (range 500–10^6 pt/cm^3). From particle counts, three fractions of particle mass are calculated: PM_{10}, $PM_{2.5}$ and $PM_{1.0}$. An additional sensor gauges the air humidity.[18]

Both devices were calibrated with test aerosols by their manufacturing companies annually. Additional calibrations of the spectrometer were performed with SHS and indoor measurements of SHS compared with those obtained simultaneously by a continuous β-attenuation monitor (Eberline FH 62 I/R) at the same location.[19]

Classification of Venues

Besides time, date and location the number of smoking- and non-smoking guests and the size of the venues were recorded or sometimes estimated and logged. The sampling at locations with important other sources of particles (stoves, flame grills, barbecues) was omitted and burning candles noted. The compliance with the Austrian tobacco law was checked by five items: correct labeling, use of main room for non-smokers, separation of smoking room by closed door, separation in venues without dispensation and >50 m^3, absence of smokers and ash trays in non-smoking room.

Assessment of City Background Concentrations of Particulate Matter

Ambient air pollutants are monitored in Vienna by a network of stations. For comparison with indoor concentrations, we used the outdoor stations 'Taborstraße' and 'Währinger-Gürtel', because their data represent the city background concentrations of the inner city area in which our investigations took place. 'Taborstraße' is a street about 1 km away from the city center, influenced by local traffic in districts 1–9. 'Währinger Gürtel' is located on the opposite site of the city center (about 130 m away from a highway) and represents the urban background also of the other districts sampled. Both stations measure $PM_{2.5}$ and PM_{10} continuously by β-attenuation (Eberline FH 62 I/R), calibrated gravimetrically, and their mean concentrations (corresponding half-hour means) were used for comparison with the indoor concentrations.

Data Analysis

Data stored on memory cards were analyzed by Microsoft Excel and IBM SPSS 17. For each analyzed room, one arithmetic mean was calculated for the particle number concentration, size, LDSA and mass concentration. In non-smoking venues, all data collected followed a normal distribution; however, in smoking rooms and smoking venues, most of the data were not normally distributed. Therefore, medians and interquartile ranges (IQR) were used to describe the distributions.

RESULTS

During the measurements, the relative indoor humidity always remained well below 70%, so an interference with water vapor can be excluded.

The overall median of the number concentration of UFPs of all the 134 measurements was 34,075 pt/cm^3. The correlation coefficient of Spearman showed a significant correlation ($P<0.001$) between the measured UFP number concentrations and the corresponding $PM_{1.0}$, $PM_{2.5}$ and PM_{10} levels. This correlation was identified throughout all the inspected locations.

In six smoke-free venues and seven non-smoking rooms, smoking guests were present. Those locations could not be attributed to "non-smoking" and were therefore excluded from further calculations, together with the seven corresponding smoking rooms.

The exposures of fine and UFPs in smoke-free venues, non-smoking rooms of mixed venues and smoking venues show remarkable differences (Figure 1 and Table 1). Q1

As expected, the $PM_{2.5}$ values and the UFP number concentrations in smoke-free venues (median 7408 pt/cm^3) were found significantly lower than in smoking rooms and venues (Wilcoxon's signed-rank test; $P<0.001$), where a very high concentration of particulate matter was measured (median 66,011 pt/cm^3).

Not only smoking rooms are heavily polluted but also the adjacent non-smoking rooms are not smoke-free as labeled: $PM_{2.5}$ concentrations are significantly higher in non-smoking rooms with adjacent smoking rooms than in smoke-free venues (Mann–Whitney U test; $P<0.001$). During our sampling, an alarming 61.5% of the non-smoking rooms with adjacent smoking rooms exceeded 25 μg/m^3. The Austrian tobacco law prescribes for mixed venues a separation of the smoking and non-smoking room by a door, however, half of the mixed venues left this door open during our entire visit. However, between non-smoking rooms with closed and open door, no significant difference in number concentration (Mann–Whitney U test; $P<0.573$) or $PM_{2.5}$ (Mann–Whitney U test; $P<0.757$) could be detected. The concentrations of UFPs and $PM_{2.5}$ in non-smoking rooms are highly correlated to the ones in the adjacent smoking rooms (Spearman; $P<0.001$). In rooms where smoking was permitted, the median UFP number concentration was 8.9 times higher and the maximum number concentration 6.3 times higher than in non-smoking venues.

The correlation between UFP number concentration and the number of smoking guests was significant (Spearman, $P<0.002$).

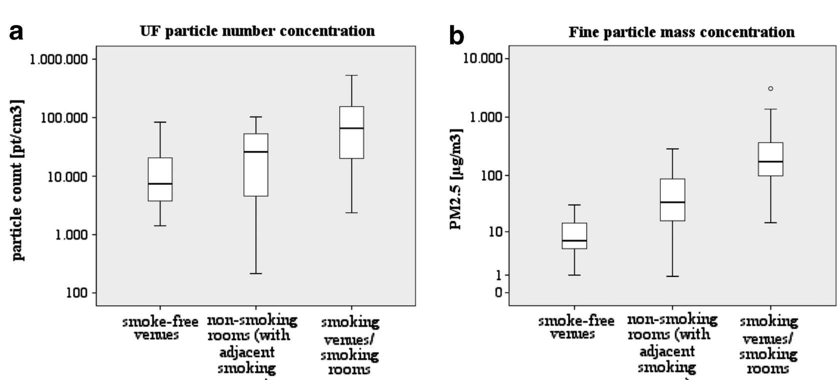

Figure 1. Box plots grouped by smoke-free venues ($N=16$), non-smoking rooms with adjacent smoking rooms ($N=39$) and smoking venues and smoking rooms ($N=59$) showing (a) the distribution of ultrafine (UF) particle number concentration and (b) fine particle mass. Interquartile range (IQR; box) with median (thick line), $1.5\times$ IQR (whiskers), outlier $>3\times$ IQR (circle).

Table 1. Ultrafine particle count and $PM_{2.5}$ particle mass in smoke-free venues, non-smoking rooms with adjacent smoking rooms and smoking rooms and venues.

	Smoke-free venues		*Non-smoking rooms with adjacent smoking rooms*		*Smoking rooms and venues*	
	Ultrafine particles (pt/cm^3)	*$PM_{2.5}$ (μg/m^3)*	*Ultrafine particles (pt/cm^3)*	*$PM_{2.5}$ (μg/m^3)*	*Ultrafine particles (pt/cm^3)*	*$PM_{2.5}$ (μg/m^3)*
N	16	16	39	39	59	59
Median	7408.3	6.7	25,973.3	34.2	66,011.1	172.3
Arithmetic mean	15,834.1	10	32,529.2	68.3	113,427.4	320.9
SD	21,218.4	8.1	30,704.0	79.1	129,574.7	461.2
Minimum	1416.8	1	215	0.9	2368.7	14.7
Maximum	83,563.6	30.7	102,661.4	286.3	529,554.9	3082.2
Lower quartile	3707.3	4.5	4456.0	15.7	18,689.2	89.4
Upper quartile	23,918.3	15.9	56,229.9	88.2	160,172.5	384.3

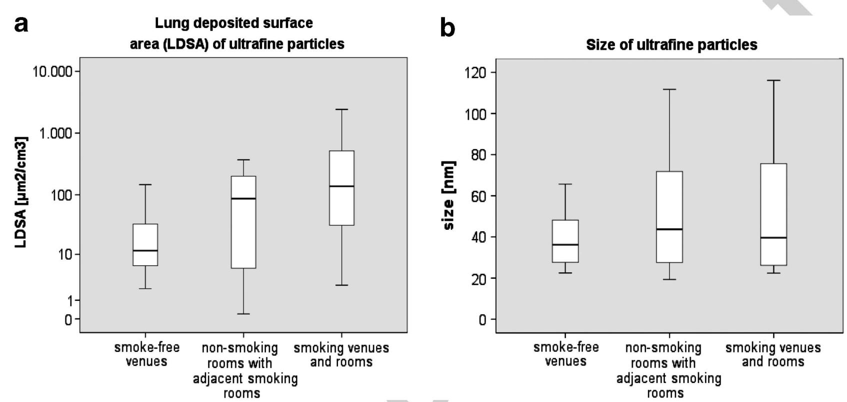

Figure 2. Box plots grouped by smoke-free venues ($N = 16$), non-smoking rooms with adjacent smoking rooms ($N = 39$) and smoking venues and smoking rooms ($N = 59$) showing (a) the lung-deposited surface area of ultrafine particles and (b) the diameter of the measured ultrafine particles. Interquartile range(IQR; box) with median (thick line), $1.5 \times$ IQR (whiskers).

Also the $PM_{2.5}$ in smoking venues and rooms was highly correlated to the number of smoking guests (Spearman; $P < 0.001$).

The LDSA and sizes of UFPs are shown in Figure 2 and Table 2.

LSDA strongly correlates with the UFP number concentration (Spearman; $P < 0.001$). Median/maximum LSDA in smoking rooms and venues was 1.6/6.5 times higher than in non-smoking rooms but 6.5/16.6 times higher than in non-smoking venues.

As expected from previous studies,[12,20] no significant influence of outdoor pollution on indoor $PM_{2.5}$ and PM_{10} concentrations was detected in smoking venues/rooms and adjacent non-smoking rooms.

The median outdoor concentrations of PM_{10} and $PM_{2.5}$ during corresponding times of the measurements in smoking rooms were 12 μg/m^3 for $PM_{2.5}$ and 17 μg/m^3 for PM_{10} at the station "Währinger Gürtel" and 15 μg/m^3 for $PM_{2.5}$ and 21 μg/m^3 for PM_{10} at the station "Taborstraße". These are marginal values compared with those measured indoors (Figure 1). In 96.6% of the time, the indoor $PM_{2.5}$ was higher than the outdoor concentration.

Not all possible sources of fine and UFPs could be investigated. There were only two venues with open kitchens: one non-smoking venue with a median UFP number concentration of 5944 pt/cm^3 and one non-smoking room with 83,789 pt/cm^3.

In 26.9% of non-smoking rooms, burning candles were standing on the tables (except for the table used for sampling). There were no significant correlations (Mann–Whitney *U* Test) between the use of candles and the UFP number concentrations in non-smoking rooms ($P = 0.56$) and non-smoking venues ($P = 0.65$).

In all, 61.3% of the investigated venues violated the law in at least one of the checked items.

The most frequently observed type of contravention was an open door between smoking and non-smoking room, found in 52.2% of the investigated mixed venues. Also, 13.6% of the visited hospitality premises had the sections falsely labeled or had no categorization at all. Fourteen premises had no separated smoking room although being > 50 m^2. In six premises, the main room was designated for smoking guests. Some of the venues violated the law in more than one aspect and actually just one out of seven discotheques was conforming to legal requirements.

DISCUSSION

Not only the immense difference between the outdoor and indoor exposure but also the fact that only the PM2.5 concentration of non-smoking venues was correlated with outdoor concentration underlines that tobacco smoke is the most important source of indoor air pollution by fine particulates in Viennese guest rooms. In smoking rooms and smoking venues to which children have access in Austria, health-threatening exposures to $PM_{2.5}$ had been detected before the partial smoking ban went into force fully.[12] The present study verifies high exposures to $PM_{2.5}$ after the tobacco law had gone into force and, for the first time, quantifies concomitant exposures to UFPs. In non-smoking rooms, particulate pollution from the adjacent smoking rooms was found, even after exclusion of the seven non-smoking rooms

Table 2. Lung-deposited surface area and diameter of ultrafine particles in smoke-free venues, non-smoking rooms with adjacent smoking rooms and smoking venues and smoking rooms.

	Lung-deposited surface area			*Ultrafine particle diameter*		
	Smoke-free venues ($\mu m^2/cm^3$)	*Non-smoking rooms with adjacent smoking rooms ($\mu m^2/cm^3$)*	*Smoking rooms and venues ($\mu m^2/cm^3$)*	*Smoke-free venues (nm)*	*Non-smoking rooms with adjacent smoking rooms (nm)*	*Smoking rooms and venues (nm)*
N	16	39	59	16	39	59
Arithmetic mean	30.7	113.1	347.3	38.6	50.8	49.2
Median	11.8	86.6	137.5	36.2	43.7	39.6
SD	40.5	116.8	451	13.6	26.9	26
Variance	1644.3	13,653.1	203,427.4	186	725.8	677.1
Minimum	2.1	0.2	2.5	22.5	19.3	22.4
Maximum	146.4	370.2	2423.3	65.7	111.7	116.1
Percentile						
25	5.9	5.5	30.7	27.2	27.3	26
75	33.4	214	535.1	49.6	74	76.1

with smoking guests. In 24 of these 39 rooms labeled "non-smoking", where no smoker was present during air sampling, $PM_{2.5}$ concentrations exceeded 25 $\mu g/m^3$ (the WHO guideline for daily mean) and 19 exceeded 35 $\mu g/m^3$ (the US ambient air standard for daily mean).[21,22] In these locations, in which the non-smoking guest feels protected because of the labeling, the median LSDA was found 7.3-times higher than in non-smoking venues. The non-smoking sign in these rooms pretends a safety, which is not given.

Open doors were not found to be the major cause of particle transfer: The lack of a significant difference in number concentration and PM2.5 between non-smoking rooms with closed and open door might indicate that non-smoking rooms are also contaminated from the adjacent smoking rooms with closed doors during the short passage of personnel and guests coming or leaving. The high correlation of particle numbers and PM2.5 in non-smoking rooms and adjacent smoking rooms indicates that the legally required separation failed, because the air masses of these rooms are effectively connected.

The high percentage (61%) of violations of the law is a result of insufficient controls and weak sanctions. In Austria, several parties reject a total smoking ban in hospitality premises. Especially representatives of the tobacco industry try to avert any changes of the existing law, which could reduce tobacco consumption.[19,23] Any effort of the concerned citizens and the Austrian Medical Association to reduce tobacco smoke in public areas is undermined by the Austrian chamber of commerce and dependent politicians.[24] Their argument against the precursor study[12] was that part of the data had been collected before July 2010, the deadline for separating smoking rooms. But the present study was performed 4–10 months after this deadline and found a similar lack of compliance with the tobacco law.

Also the representativity of results was questioned; however, results of both the previous study and the present study are representative of well-frequented hospitality premises in the inner districts of Vienna and covered together a large proportion of these bars, cafes, discotheques, pubs and restaurants, which had been randomly selected. Indoor $PM_{2.5}$ concentrations in hospitality premises in Vienna were found higher than in Zurich city center,[1] which might be due to the longer sampling period from November to May, while premises in Zurich were sampled only during 14 warm days, when many smokers usually sit outside. Nevertheless, similar relationships were found between $PM_{2.5}$ concentrations and the number of smokers sitting inside in another study in 9 of 26 Swiss cantons.[2] The Swiss authors did not measure ultrafines and the comparability of their results to our study is limited, because they announced their sampling, so that selection bias from participation cannot be excluded. However, announced measurements before any smoking restrictions in 28 Bavarian venues had found similar $PM_{2.5}$ concentrations in restaurants, cafés, pubs and bars like in the Viennese smoking venues and even higher ones in discotheques.[3]

Results from the German, Swiss and Austrian studies have been ignored by Austrian politicians, who are in charge of implementing the tobacco law. Instead it was argued, that the majority of the Austrian population would oppose a total smoking ban. This argument was supported only by "public opinion" surveys, which had been commissioned by economical interest groups.[24] In fact, independent survey results indicate that the majority of the Austrian population would approve a total smoking ban and that in other European countries an increase of approval was observed after implementation of the ban.[25] Also, independent studies of the medical universities in Vienna[26,27] and in Graz[28,29] found that the majority of the guests interviewed in hospitality premises are not satisfied with the present partial smoking ban and would prefer a total ban.

In Styria, even the majority of innkeepers were found to be in favor of a total smoking ban,[30] despite of the economic fears stirred repeatedly by the chamber of commerce. Loss of business, however, has been found unrelated to a general smoking ban in the hospitality industry,[31] but rather associated with partial bans shifting smoking customers.[32]

Recently, also in other countries, protection from partial smoking bans was found to be insufficient and failed to provide adequate protection to guests[33] and employees.[34]

The present study is the first which documents UFP exposures in this setting and it contributes to the discussion as to which particle indicators describe the exposure of second-hand smoke best. In indoor air, a higher correlation of the nicotine concentration was found with particle surface than with particle mass: surface $= 10.76 \times$ nicotine ($\mu g/m^3$) $+ 132.57$; $r^2 = 0.8064$).[13] Particle number is associated with certain cardiovascular effects unrelated to $PM_{2.5}$[6] and particle surface in ambient air is correlated with respiratory symptoms and function.[35] The present study found that particle surface also increases substantially in smoking rooms and adjacent non-smoking rooms. This could indicate a respiratory risk for children and a cardiovascular risk for adults.

A limitation of this study is the optical measurement and the use of two different devices for different size ranges. Particles too small for the Grimm monitor, contribute little to particle mass, but the detection limit of the miniDiSC (10 nm) leads to an underestimation of particle number and LDSA. Another reason for underestimation of particle number is optical interference (overlapping small particles seen as one particle, especially at higher concentrations). This leads to an underestimation of the UFP counts in smoking rooms and could also result in some overestimation of median diameter. On the other hand, particles >300 nm were not considered for estimating median diameter. There was no apparent correlation of agglomeration of particles with age, which should decrease UFPs and increase fine particles over time, but from comparison of concentrations found earlier during daytime or later at night we noted an increase of both fractions over time. This indicates that (as long as fresh aerosol is generated by smokers) ultrafine concentrations also increase, despite of the agglomeration process. This process could be the reason why $PM_{2.5}$ was more discriminative between non-smoking venues and non-smoking rooms of mixed premises. Whether the lower underestimation of particle numbers in the non-smoking rooms is offset by a longer aging time and more extensive agglomeration of the particles reaching the non-smoking rooms remains speculative. The present study focused on particles, which are inhaled by the non-smoking bystanders at points in time, when many guests were present, but it cannot give information on the aging of the aerosol over time and the mixing of fresh and aged aerosol in the smoking room and the adjacent non-smoking room.

According to the manufacturer, the miniDiSC readings agreed within 30% with those of a condensation particle counter or scanning mobility particle sizer, with lower accuracy of the miniDiSC, especially in areas with particle concentrations <1000 pt/cm^3. The main advantage of the miniDiSC is a cheap and quick estimation of the LDSA, which might be the indicator of highest biological relevance[17,36] and also most closely related to air nicotine, the specific indicator for tobacco smoke.[13] Furthermore, the miniDiSC's small size and ease of handling allows for inconspicuous utilization. Nevertheless, results should be controlled by more accurate methods of UFP measurement. A bigger sample size would be necessary to quantify the impact of other particle sources like open kitchens and stoves, but these aerosols have a completely different composition than tobacco smoke, so that other health effects are expected.

CONCLUSION

This study confirms very high exposures to fine particles in smoking rooms and partly high exposures in adjacent rooms, which are labeled "non-smoking". In addition, concomitant exposures to UFPs were detected. The protection of non-smokers, including children, by partial smoking bans failed.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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