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Original Article

Measurement of Fine Breathable Particles ($PM_{2.5}$) as a Marker of Environmental Smoke in Catering Establishments in Zaragoza

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ABSTRACT

Objective: To estimate the levels of small breathable suspended particles ($PM_{2.5}$) as atmospheric markers of environmental tobacco smoke in foodservice establishments in Zaragoza, Spain.
Material and method: A cross-sectional, observational study was conducted between October 2006 and April 2008 in various catering establishments in Zaragoza. A SidePack Aerosol Monitor (AM510 model) was used to sample and record the levels of breathable suspended particles ($PM_{2.5}$) indoors and outdoors, and the following variables were collected: smoking policy (smoking allowed, completely banned, or partially banned with non-smoking sections, physically separated or not); percentage of smokers and presence of cigarette butts, ashtrays or smokers in non-smoking sections.
Results: A total of 111 establishments were sampled. The level of $PM_{2.5}$ was eight times higher in smoking venues than in non-smoking ones and also higher than outdoors. The correlation between the level of particles and percentage of smokers was 0.61 ($P < .01$). In the non- smoking sections without physical separation the level of particles was twice as much as outdoors and similar to physically separated smokers sections.
Conclusion: Functional separations do not protect second-hand smoke. Only completely smoke-free areas are shown to lower this risk. The measurement of $PM_{2.5}$ can be a simple method to assess the presence of environmental tobacco smoke.

Medición del nivel de partículas finas respirables ($PM_{2.5}$) como marcador del humo ambiental del tabaco en locales de hostelería de Zaragoza

Palabras clave:
Humo ambiental de tabaco
Partículas $PM_{2.5}$
Trabajadores de hostelería
Contaminación por humo de tabaco

RESUMEN

Objetivo: Evaluar la contaminación por humo ambiental de tabaco mediante la medición de $PM_{2.5}$ en una muestra de locales de hostelería de la ciudad de Zaragoza, España.
Material y métodos: Estudio transversal observacional realizado entre octubre de 2006 y abril de 2008 en locales de hostelería de Zaragoza. Para las mediciones de partículas $PM_{2.5}$ se empleó un monitor *SidePack Aerosol Monitor* (modelo AM510). Se realizó una medición en el interior y otra en el exterior, y se recogieron las siguientes variables observacionales: señalización sobre la permisividad de fumar; división (física o funcional) entre áreas de fumadores y no fumadores; porcentaje de personas que fuman respecto al total; presencia de ceniceros, colillas o personas fumando en zonas y locales de no fumadores.
Resultados: Se incluyeron 111 locales. La concentración de partículas fue casi 8 veces mayor en los locales de fumador que en los de no fumadores y superior a la del exterior. La correlación encontrada entre concentración de partículas y porcentaje de fumadores fue de 0,61 ($p < 0,01$). La concentración de partículas en las

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zonas de no fumadores de los locales sin separación física (separación funcional) fue el doble que en el exterior y similar a la de las zonas de fumadores cuando hay separaciones físicas.
Conclusión: Las separaciones funcionales no protegen frente al humo de tabaco ambiental, sólo los lugares totalmente libres de humo son eficaces para disminuir este riesgo. La medición de $PM_{2.5}$ puede ser un método sencillo para evaluar la existencia de humo ambiental de tabaco.

Introduction

Exposure to secondhand smoke (SHS) produces in adults an increased risk for lung cancer, cardiovascular disease and COPD.[1] In children, it also produces an increase in respiratory and middle-ear infections, as well as an increase in the risk of atopy and asthma and the risk of sudden infant death syndrome.[1,2] According to the World Health Organization (WHO),[3] there is no level of exposure that can be considered safe for our health. However, it is estimated that millions of people in the world, children and adults, are continually exposed to passive smoking either in their homes or in their workplaces.[1]

In Spain in January 2006,[4] smoking was prohibited in all enclosed workspaces, with the exception of the foodservice industry, where smoking limitations were established according to the size of the establishment. Locales with a surface area of more than 100 m^2 could be either completely non-smoking or include smoking areas (always less than 30% of the area of the establishment) physically separated with a closed door and with independent ventilation. Locales less than 100 m^2 in size could be, as decided by the proprietor, either smoke-free or allow unrestricted smoking. As a result of the application of this law, most small establishments under 100 m^2 permitted smoking, while in those where the law allowed for the creation of smoking sections, these wound up being in many cases smoking areas with no type of physical separation, which came to be known as "functional separation". In January 2011, this law was modified so that all public areas were required to be smoke-free.

As for the measurement of SHS, in recent years different environmental markers have been used, such as nicotine in vapor phase and, more recently, the concentration of particles in breathable suspension. The latter, despite not being specific for tobacco smoke, are an air marker resulting from combustion whose most common source in closed spaces is tobacco consumption. The breathable particles are a complex mixture of particles of organic and inorganic substances that are classified according to their diameter as PM_{10} (diameter less than 10 microns) and $PM_{2.5}$ (diameter less than 2.5 microns). The exposure to PM has been associated with a wide range of respiratory and cardiovascular diseases, both acute as well as chronic,[5,6] and therefore different international organisms have established recommendations for the maximal levels of exposure to environmental pollution.[7,8] Various studies[9,10] have shown that, in places where it is allowed to smoke, particle levels are ten times higher than in places where smoking is not permitted. In this regard, Repace studied fifteen foodservice establishments in the state of Delaware and in the city of Boston (Massachusetts) both before and after smoking was prohibited in this type of places, and it was found that approximately 90 to 95% of the pollution by fine particles in said locales could be attributed to tobacco smoke.[11,12] Likewise, other studies that examined environmental levels of nicotine also demonstrated that the levels of SHS of the restaurants and bars where it was allowed to smoke were very high, with the consequent health risk for people working in this service sector.[13] Thus, it was hypothesized that these types of establishments that have smoking areas, with no type of physical separation, present high levels of contamination by tobacco smoke, which could be evaluated objectively by means of simple analysis methods. The aim of this study was to measure pollution by tobacco secondhand smoke by means of the assessment of $PM_{2.5}$ in a sample of different types of locales in the city of Zaragoza, Spain.

Patients and Methods

Ours is a cross-sectional, observational study carried out between October 2006 and April 2008 in food-service establishments in the city of Zaragoza, Spain. Zaragoza is a city with 670,000 inhabitants situated in northeast Spain and is the capital city of the province of Aragon. The ratio of bars or pubs per inhabitant (1/378) is one of the highest in the country (mean bar/inhabitant ratio in Spain: 1/461).[14] The selection of the establishments was done by a non-proportional quota sampling stratified by city districts. Included were bars, coffee shops, restaurant and pubs, both smoking as well as non-smoking, including those that had designated areas for smokers with either physical or functional separations. Excluded were those locales that had open kitchens or had less than five patrons at the time of the measurement. The minimal sample size was calculated for each of the comparisons predicted depending on the type of business and its smoking regulation.

In order to measure $PM_{2.5}$ particles, a *SidePack Aerosol Monitor* (model AM510) was used, whose characteristics have been described in previous studies.[15,16] In all the establishments included in the study, measurements were taken both indoors and outdoors. Given that it is a non-intrusive method, the need to ask for the collaboration of the personnel was not contemplated. In the interior of the locales, the concentration of particles was determined for 30 consecutive minutes, with later calculation of the concentration mean by the monitor itself in $\mu g/m^3$ of air. Outside, a 5-minute measurement was taken.

At the same time, a register worksheet was completed, where data was taken for the date and time of the determination and the characteristics of the premises, together with the following observational variables: signs for smoking being permitted/prohibited; division (physical or functional) between the smoking/non-smoking areas; percentage of the total number of people smoking at the time of the measurement; presence of ashtrays, cigarette butts or people smoking in non-smoking areas or establishments.

Statistical Analysis

The sample size was calculated to reach a power of 80% using the Ene2.0 program. Means and standard deviations (SD) were calculated, as were the averages and interquartile ranges (IQR) of the $PM_{2.5}$ concentrations for each type of establishment and regulation. For the comparison of the mean concentrations between establishments and regulations, the *t* Student's test was used for comparison of the means. The relationship between the quantitative variables was calculated with Pearson's correlation coefficient. In addition, a box diagram was developed to represent the concentration of particles according to the presence of indirect signs of smoking. For all contrasts, $p \leq 0.05$ was considered statistically significant. For the analysis of the data, the SPSS statistical package version 15.0 for Windows® was used.

Results

A total of 111 establishments were included in the study. Out of these, 46 permitted smoking, 26 prohibited smoking, 31 had

Table 1
Distribution of the different types of foodservice establishments studies in the city of Zaragoza, Spain (2006-2008)

Type of establishment	Sample size
Smaller than 100 m², smoking prohibited	11
Larger than 100 m², smoking prohibited	15
Smaller than 100 m², smoking permitted	32
Larger than 100 m², smoking permitted	14
Larger than 100 m², physical separation (smoking/non-smoking)	31
Larger than 100 m², functional separation (smoking areas with no physical barrier)	8
Total	111

Table 2
Mean contamination of fine particles ($PM_{2.5}$) in μg/m³ in smoking and non-smoking establishments and comparison with the outside in the city of Zaragoza, Spain (2006-2008)

Type of establishment	Mean (± SD)	Median (IQR 25-75)
Smoking prohibited (n = 26)	29.49 (45.76)	18.20 (5.20-43.16)
Smoking permitted (n = 46)	228.95 (223.61)	132.08 (87.62-293.80)
Exterior	47.40 (14.87)	49.40 (40.56-53.04)
Ratio interior/exterior	4.83	2.67

Table 3
Contamination of fine particles ($PM_{2.5}$) in μg/m³ in smoking and non-smoking establishments, according to the type of business in the city of Zaragoza, Spain (2006-2008)

	Smoking		Non-smoking		Ratio smoking/non-smoking
	Mean (± SD)	Median (IQR 25-75)	Mean (± SD)	Median (IQR 25-75)	
Restaurants	n = 8 175.11 (151.21)	n = 8 106.6 (66.3-354.12)	n = 12 12.75 (12.51)	n = 12 9.10 (4.68-17.55)	13.73
Bars/coffee shops	n = 33 301.29 (248.25)	n = 33 230.88 (137.54-360.62)	n = 14 11.18 (14.34)	n = 14 3.9 (1.04-18.85)	26.94
Night clubs	n = 5 481.42 (351.59)	n = 5 407.16 (190.84-809.12)	–	–	–

Table 4
Concentration of fine particles ($PM_{2.5}$) in μg/m³ in smoking and non-smoking areas (with physical and functional separation) in the city of Zaragoza, Spain (2006-2008)

Establishments with smoking and non-smoking areas	Non-smoking area, mean (SD)	Smoking area, mean (SD)
Physical separation (n = 31)	26.05 (18.61)	97.81 (45.33)
Functional separation (n = 8)	99.97 (100.75)	334.75 (227.86)

physically-separated areas for smokers and non-smokers, and 8 had functional separation (table 1).

In order to evaluate the differences in the concentration of particles, the establishments were grouped as non-smoking (n = 26) and smoking (n = 46), regardless of the surface area. Table 2 shows that the concentration of particles is almost 8 times higher in the smoking establishments compared with non-smoking ones, and even higher than the outside pollution. As shown in Table 3 the greatest concentration of particles is found in night clubs, where no non-smoking alternative was found. The lowest concentration was in restaurants, with bars/pubs and coffee shops at intermediate levels. In restaurants as well as in bars and coffee shops, the ratio between smokers and non-smokers shows that the contamination by particles is quite higher en smoking areas (13.7 in restaurants and 26.9 in bars/pubs and coffee shops).

Figure 1 shows a relationship between the concentration of $PM_{2.5}$ and the presence of external signs of smoking (ashtrays, cigarette butts, people smoking) in non-smoking establishments or in areas where is was not allowed to smoke (26 non-smoking establishments, and 39 non-smoking areas) although statistical significance is not reached. The correlation found between the concentration of particles and the percentage of smokers present was 0.61 ($p < 0.01$).

Table 4 demonstrates that non-smoking areas of establishments that have functional separations have a concentration of particles similar to that of smoking areas when there are physical separations. If the separations are functional, the contamination in the non-smoking areas is twice that of outside. If they are physical, the contamination is half of what is measured outside.

Discussion

This study shows that the concentration of $PM_{2.5}$ in foodservice establishments where smoking is permitted is greater than the outside and almost 8 times higher than in non-smoking locales. Where smoking is permitted, the mean concentration of fine particles is much higher than the level established by the *Environmental Protection Agency* (EPA) to define good air quality (15 μg/m³), with concentrations higher than 251 μg/m³, a level at which the EPA considers the air quality to be dangerous for the health of the people exposed.[7]

These results are similar to those communicated by Hyland et al., who produced the largest comparative study measuring particles in bars, restaurants and other public places in 32 countries between 2003 and 2007 with a similar methodology. In total, they evaluated 1,822 establishments, broken down by foodservice sector.[17] According to the type of establishments, our results also coincide with those of Hyland, detecting the highest concentration of particles in coffee shops, followed by restaurants. Our study, however, included nightclubs that showed even higher particle contamination, with a mean concentration 10 times higher than in the street (481.42 μg/m³ compared with 47.40 μg/m³), an aspect that has already been reported by other authors using environmental nicotine as a marker.[18] Along this same line, the study by Rosen et al. in Israel also showed very high concentrations of particles in bars and pubs, levels that decreased after 2007 when the new smoking regulations took effect in that country.[19] The effect of the limitations for smoking in public spaces on air quality in leisure venues had already been communicated,

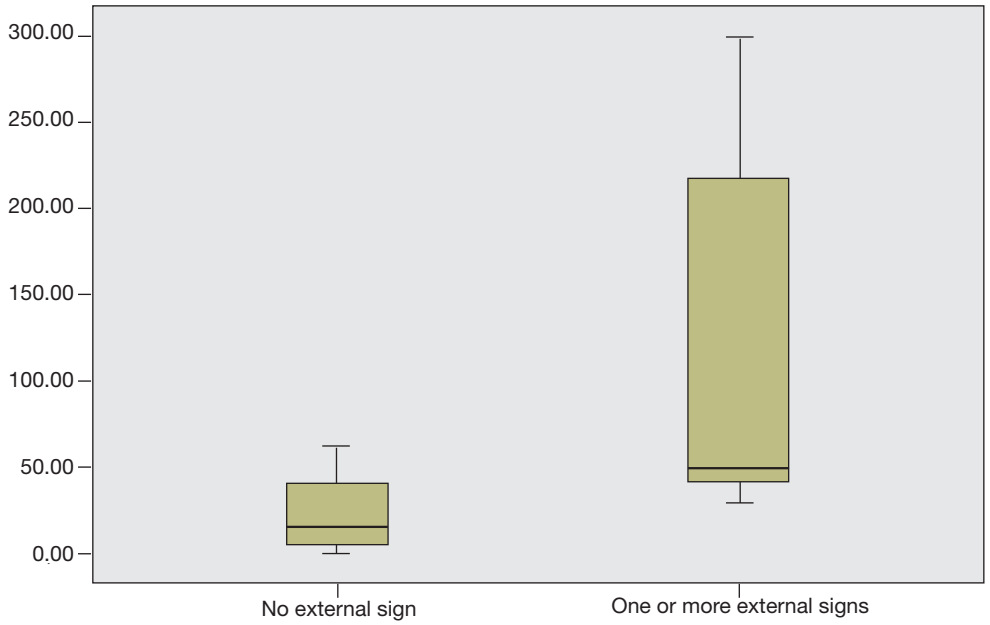

Figure 1. Concentration of fine particles ($PM_{2,5}$) in $\mu g/m^3$ and presence of observed signs of tobacco consumption in establishments or areas where smoking is not permitted (n = 65). Zaragoza, 2006-2008.

using environmental and biological markers, in previous studies in Norway, Scotland, Italy, Ireland and the United States,[11,20-22] all of these being countries that had incorporated regulations in recent years in the foodservice sector. Specifically, using the concentration of particles in a study carried out in Delaware, Repace found a reduction of 91% after the new smoking limitations had taken effect.[11] Later, Valente et al. in Italy and Goodman et al. in Ireland confirmed this decrease in the concentration of particles after new regulations came into effect in those countries.[22,23] Our results also show the existence of a statistically-significant positive correlation between the concentration of particles and the percentage of smokers present in the establishment. All these data support the use of fine particle level determination as a marker for environmental tobacco smoke.

As for the separation of smoking areas, we observed that the ratio between the smoking and non-smoking areas is similar whether the separation is physical or functional (3.75 vs. 3.35). However, in the case of the so-called functional separations, the non-smoking section has a concentration of particles similar to the smoking areas of those establishments that have physical separation, with levels that define the air quality of these spaces as unhealthy (between 66 $\mu g/m^3$ and 150 $\mu g/m^3$), according to EPA standards. These data manifest the inefficacy of functional separations for reducing tobacco smoke contamination in public places and coincide with those found by Vardavas et al. in Greece.[24] Our paper provides relevant data as it demonstrates that the "Spanish model"[25,26] in place up until January 2011, characterized by establishing limitations for smoking in public establishments according to square meters, is not effective to protect against second-hand smoke. Our results provide objective arguments for introducing and consolidating smoke-free policies in public places. The tobacco industry, on the other hand, presents the Spanish legislation of 2005 as a model to be followed, in spite of being ineffective for public health. The strategies used by the tobacco industry for impeding smoking control policies are similar in all countries. In Spain, in fact, the industry has repeatedly insisted that the partial limitations established in the law 28/2005 be maintained as it favors the smoking industry's interests.[27]

Our study presents some limitations that need to be commented. Regarding the selection of the sample, it was not possible to randomize the sample as there was no reliable list available of the establishments in the city, as happened in other studies.[17,27] On the other hand, this presents the advantage that the number of locales evaluated in the restaurant/bar sector is one of the largest studies published to date in one single country. Another limitation of the study lies in the use of a marker that is not specific for secondhand smoke (SHS). Nevertheless, as has been mentioned in the Patients and Methods section, in order to minimize the possibility of other sources of $PM_{2.5}$ emissions other than SHS, we excluded those establishments that had kitchens open to the space occupied by the patrons, given that the combustion that they produce can result in suspended particles. Once other possible sources of particle emission have been controlled, data favoring the use of this marker include the fact that its determination is simple, economic and non-intrusive. For these reasons, it is a useful marker for monitoring the presence of SHS in routine practice as it does not require complex analysis infrastructure. In addition, it gives real-time data of the exposure, although in some cases a momentary measurement can also be conceived as a limitation because it is influenced by the conditions of that specific moment.

Regarding compliance with the law, although this was not the objective of this study and despite the fact that the sample does not allow us to extrapolate data, the results of this study reveal a deficient implementation of the law of 2005 in Spain. Taking into account that 80% of the establishments were not regulated by the law of 2005, it is estimated that only 7-14% of all the foodservice businesses were smoke-free.[28] The presence of different indirect signs of smoking in places where it was not allowed to smoke and the existence of an association between these signs and the concentration of particles, although without reaching statistical significance, make the insufficient compliance of the law objectively apparent. On the other hand, the existence of establishments larger than 100 m^2 where smoking was allowed or the existence of areas without physical separation where people smoked (functional separation) were situations that clearly did not comply with the legislation. Studies show that countries that have incorporated total smoking restrictions in public spaces have more social support, including from an ample percentage of smokers, than when the restrictions were partial or incomplete.[29] This aspect is also important because it is possible to think that the compliance with the restrictions will improve once

public spaces are made 100% smoke-free with no exceptions, which poses the need for further studies.

In short, the mean concentration of particles that we found in the bars, restaurants and coffee shops where smoking was permitted is similar to that detected in such establishments in other countries where there are no smoking restrictions while being much higher than levels in those countries that do have strict restrictions, like Ireland.[17] The evaluation of environmental smoke using the determination of particles can be a simple method for evaluating not only health risks, but also the compliance with and the implementation of smoking restrictions in public places. The increased health risk of second-hand tobacco smoke in foodservice workers of those countries that contemplate such a setting as an exception to smoking limitations is totally avoidable. Functional separations do not protect against environmental tobacco smoke and only completely smoke-free places are effective in reducing this risk. Policies for controlling the consumption of tobacco should establish, with no ambiguities or exceptions, public smoke-free settings, which are supported by the majority of the population.

Conflict of Interest

The authors declare having no conflict of interest.

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