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The effect of São Paulo's smoke-free legislation on carbon monoxide concentration in hospitality venues and their workers

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ABSTRACT

Background Studies have shown that there is no safe level of secondhand smoke (SHS) exposure and there is a close link between SHS and the risk of coronary heart disease and stroke. Carbon monoxide (CO) is one of the most important components present in SHS.

Objective To evaluate the impact of the smoking ban law in the city of Sao Paulo, Brazil, on the CO concentration in restaurants, bars, night clubs and similar venues and in their workers.

Methods In the present study we measured CO concentration in 585 hospitality venues. CO concentration was measured in different environments (indoor, semi-open and open areas) from visited venues, as well as, in the exhaled air from approximately 627 workers of such venues. Measurements were performed twice, before and 12 weeks after the law implementation. In addition, the quality of the air in the city during the same period of our study was verified.

Results The CO concentration pre-ban and post-ban in hospitality venues was indoor area 4.57 (3.70) ppm vs 1.35 (1.66) ppm ($p<0.0001$); semi-open 3.79 (2.49) ppm vs 1.16 (1.14) ppm ($p<0.0001$); open area 3.31 (2.2) ppm vs 1.31 (1.39) ppm ($p<0.0001$); smoking employees 15.78 (9.76) ppm vs 11.50 (7.53) ppm ($p<0.0001$) and non-smoking employees 6.88 (5.32) ppm vs 3.50 (2.21) ppm ($p<0.0001$). The average CO concentration measured in the city was lower than 1 ppm during both pre-ban and post-ban periods.

Conclusion São Paulo's smoking-free legislation reduced significantly the CO concentration in hospitality venues and in their workers, whether they smoke or not.

BACKGROUND

Several recent studies clearly show that there is no safe level of exposure to secondhand smoke (SHS). The Conference of the Parties to the Framework Convention,¹ the WHO International Agency for Research on Cancer,² the US Surgeon General³ and the UK Scientific Committee on Tobacco and Health⁴ all agree that SHS exposure is associated with a range of diseases, including cardiovascular heart disease and many types of cancer. For example, SHS exposure increases the risk of coronary heart disease by 25–30% and the risk of lung cancer by 20–30%.⁵

Previous experiences in other countries and cities show a reduction in cardiovascular events after the implementation of a smoking ban law in those

places. This reduction is thought to be mainly associated with a reduction in SHS.^{5–9} Based on these experiences, the São Paulo state government approved smoke-free legislation in 2009, forbidding the consumption of all tobacco products in enclosed and partly closed collective sites, including public and private places, such as working environments, cultural establishments, pharmacies, bars, restaurants, movie theaters, theatres, hotels, supermarkets, nightclubs, schools, museums, cabs, banks, health institutions and others. The exception includes private residences, religious cult venues in which the tobacco product is part of the ceremony and sites specifically and exclusively designated for tobacco consumption.

After the smoking-ban law became public, it was necessary to create a campaign named “Tobacco-free and healthy environments” to show the viability of eliminating smoking from indoor and partly closed places, through coordinated actions between the São Paulo State Center of Surveillance and the Consumer Protection Agency. The main objective of this campaign was to visit the hospitality venues to inform and solidify behaviour changes that would make feasible the practice of the smoking-ban law. The Sao Paulo State Center of Surveillance was responsible for the measurements of CO in the hospitality venues and in their workers.

CO is a toxic, odourless, colourless, tasteless and non-irritating gas. CO is one of the most important pollutants in cigarette smoke and is exhaled by smokers during and after having smoked tobacco products. We chose CO as a biological marker of SHS because it is easy to measure, has a good correlation with SHS and it can be measured in both the environment and in the exhaled air of individuals at the same time.

The atmospheric concentration of CO is generally below 0.001%, but it may be higher in metropolitan areas. It is formed from incomplete combustion of organic material and hydrocarbon combustion at high temperatures with an insufficient oxygen supply. Other common sources of CO generation include combustion of petroleum derogates by cars and coal ovens. The CO concentration in São Paulo city is monitored by the Environmental Agency of São Paulo (CETESB).

When inhaled, CO joins successfully with oxygen in the bloodstream to form carboxyhaemoglobin (COHb). CO can remain in the blood stream for up



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to 24 hours, depending on a range of factors including physical activity, gender and inhalation intensity. The half-life of CO in a person who breathes regular air is about 5 hours.

CO measurement is commonly used in smoking cessation programmes and is also used to evaluate the quality of the air in indoor social places, as it was observed in the study of Waring *et al*,¹⁰ which analysed bars in Austin, Texas, before and after smoking ban.

In spite of CO not being specific of cigarette smoke, in indoor places tobacco smoke is the most important source of CO, as showed by Goniewicz *et al*¹¹ Their study evaluated secondhand smoke in Polish bars by measuring CO concentration and concluded that the main source of CO is tobacco smoke.

Tual *et al*¹² analysed the impact of tobacco control policies on exhaled CO in almost 59 000 non-smokers in 27 European Union countries and noticed a strong link between antismoking policies and the exposure to passive smoking. The mean exhaled CO was 1.6 ppm in Ireland, which has a strong antismoking police, and 6.6 ppm in Greece, without any antismoking police.

Some studies^{13 14} show a strict relation between the CO concentration and the risk of cardiovascular events and have noted a reduction in hospital admissions due to cardiovascular events after smoking-ban laws having been implemented.

Despite the evidence of cardiovascular event reduction after smoking-ban laws, few studies have quantified the reduction of the SHS components, which can justify such events. Here, we have evaluated the CO concentration in hospitality venues and their workers before and after the smoking-ban law.

METHODS

The ethics committee for Research Project Evaluation (CAPPesq) of the Hospital das Clinicas, School of Medicine, University of São Paulo approved the study.

The first phase included the period prior to the implementation of the tobacco-free policy (from 23 July to 2 August 2009), and the second phase was performed approximately 12 weeks after the banning law was introduced (from 29 October to 7 November 2009), using the same agents, same places, on the same day of the week, same time of the day and with the same workers as were analysed in the first visit.

Approximately 100 agents from the Sao Paulo State Center of Surveillance were trained to use a CO monitor, to obtain a signed informed consent and to conduct data collection. They visited bars, restaurants, nightclubs and similar venues collecting data from the environment and from some workers at these places (two smoking and two non-smoking workers whenever possible). They were instructed to apply the informed consent to smoking and non-smoking workers of these venues and then to measure their exhaled CO. Ascertained workers were, preferentially, those working in closed spaces of the visited venues.

Study sample

According to the São Paulo Hotels and Restaurants Syndicate,¹⁵ there are more than 30 000 restaurants, bars, nightclubs and similar places in the city of São Paulo. A total of 585 hospitality venues inside the city of São Paulo were visited before and after the tobacco-free policy was implemented. The sites were a sample of convenience. They were selected over a geographical range of the city, sampled from a large number of entertainment establishments in all five geographical zones: north, east, south, west and centre. The measurement of CO was done indoors, in partly closed spaces (semi-open), and in open spaces of the venues. The CO measurement of open areas was done in front of the main door of the establishment, keeping a close contact with

the indoor area. The samples were obtained during the busiest period of the week—on Thursdays, Fridays or Saturdays between 21:00 and 03:00.

Measurements of exhaled air in venue workers, smokers or not, were also done. Only workers in good health were invited to participate in the study, and all of them provided written informed consent. We planned to get at least one smoker and one non-smoker from every establishment. They were questioned about their smoking status (non-smoker, have never smoked or is an ex-smoker (without smoking for at least 30 days); eventual smoker, have smoked at least one cigarette in the last 30 days; regular smoker, smoke every day), mean number of cigarettes smoked per day, sex and age.

CO monitors

The samples were collected with two types of portable CO measuring devices. The monitors use a sampling method that channels the gas sample directly over the sensor during the test. This ensures that the electrochemical sensor is exposed to the gas sample for the required length of time to give an accurate reading. The electrochemical sensor is designed to react to the presence of carbon monoxide and produces an output current proportional to the level of CO. This is then read by the microprocessor and converted to display the equivalent parts per million (ppm). The first monitor used was the ToxCo (Bedfont Scientific; Rochester, England), a small portable device to measure environmental CO concentration, which has a display with two numbers—the first one shows the CO measure on real time and the second one shows the highest level achieved in the present measure. The second one was the PiCo (Bedfont Scientific; Rochester, England), which has a similar mechanism as the ToxCo, but measures exhaled human CO concentration. The measures in visited venues were done in real time, and were done in the centre of the establishments, avoiding contamination by ovens. Before starting the test, the person was instructed to hold his/her breath for 15 seconds and then exhale slowly into the mouthpiece. They were calibrated according to manufacturer's instruction. The CO monitors are certified by The National Physical Laboratory of the UK.

Data collected from venues were compared with data obtained by the CETESB in nine automatic stations located in different parts of São Paulo, covering the same area of our collected data. These automatic stations measure CO and other pollutants in the streets. Here, these data were used to test whether possible reductions in CO could be influenced by other conditions, like meteorological elements.

Statistical analysis

Descriptive statistics were calculated for CO level in both the pre-ban and post-ban periods across the whole dataset and then subdivided by location within the venue and venue type. Data are presented as means±SE. Pearson's correlation coefficients were used to explore correlations between different environments of a particular venue.

Differences in the pre-ban measurements according to venue type and measurement location were analysed by one-way and two-way analysis of variance. Differences between pre-ban and post-ban concentrations were analysed by one-way and two-way analysis of variance for repeated measures. Differences in expired CO concentrations in venue employees were analysed by a two-way analysis of variance for repeated measures (using time and smoking status as strata). Probability values of ≤0.05 were considered statistically significant. Statistical analysis was carried out using SPSS V.13.0.

RESULTS

Venue level information

We were able to collect data on 585 venues during the pre-ban period and on 559 venues during the post-ban period. No significant difference in pre-ban indoor CO measurements between venues that were or were not visited in the post-ban period was observed (mean value in venues visited twice 4.56 (3.69); mean value in venues visited only in the pre-ban period 4.42 (4.97); p value = 0.86). The main reason for not obtaining a paired visit was because some venues went out of business during the follow-up period.

A wide range of venue types was ascertained. In table 1 we present information regarding venue type and pre-ban and post-ban CO measurements in the three different environments sampled. We observed a significant difference between pre-ban measured CO levels and venue type only regarding closed environments ($p=0.04$), and not in semi-open and open environments ($p=0.08$ and $p=0.23$, respectively). This difference was due to higher mean CO levels in closed environments in bars and nightclubs compared with restaurants (5.02, 4.91, and, 4.01, respectively).

Regardless of venue type, a significant difference was verified regarding closed, semi-open, and open environments ($p<0.001$ for mean difference between environments, adjusted for venue type). As expected, significant correlations were observed between the studied environments in the pre-ban period (Pearson coefficient between closed and semi-opened: 0.84; closed and opened: 0.57; and semi-opened and opened: 0.70, all with a p value <0.001).

In the post-ban period, significant reductions in all study environments were observed (figure 1, table 1). As can be observed, and expected, although all reductions were highly significant, the absolute and relative reductions observed for closed environments, regardless of venue type, were higher than those observed for open spaces. In closed environments, in the pre-ban period 180 (30.8%) venues had CO concentrations above the level of 4.5 ppm (associated with increased overall health risk). In the post-ban period, only eight (1.4%) venues had CO measurements above this threshold.

Interestingly, for closed environments a significant interaction between CO reduction and venue type was identified ($p=0.01$ for the interaction term). This was observed owing to a higher CO reduction observed in bars and nightclubs compared with that observed in restaurants. One interpretation of this result is that in the post-ban period, no significant difference was observed between venue type and closed environment CO levels ($p=0.39$), as opposed to the pre-ban period, where bars and nightclubs had significantly higher values. In fact, in the post-ban period survey no significant difference between CO levels and environment (open, semi-open and closed), or venue type (restaurant, bar, nightclub or other) was observed any longer, thus suggesting equalisation with outdoor levels (table 1).

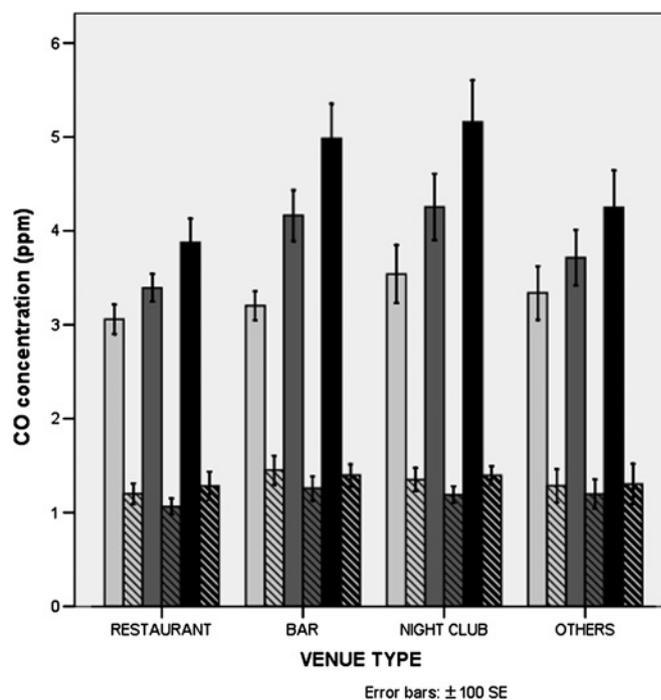


Figure 1 Absolute values on measured environment CO concentrations before and after ban implantation according to venue type and environment type.

The quality of the air in the city during the same period of our study through the air quality databank from the Environmental Agency of São Paulo (CETESB) was as follows: in study days of the pre-ban period: 0.94 ppm (0.075 SE, CI 95% 0.77 to 1.12, minimum 0.31, maximum 1.59 for mean levels, and min 0.1, max 2.4 for individual data points), in the study days of the post-ban period 0.66 ppm (0.073 SE and CI 95% 0.49 to 0.83, min 0.09, max 2.40 for mean levels, and min 0.0, max 3.2 for individual data points).

Individual level information

Our survey design was able to collect information of CO level on 627 employees in the pre-ban period, 359 non-smoking and 268 smoking employees. Employees were mainly male (147 vs 39 for smoking; 232 vs 45 for non-smoking). Mean age was 33.8 (10.1) years for smoking and 34.2 (11.5) years for non-smoking employees. In the post-ban period, we were able to re-ascertain the CO levels of 464 employees, 277 non-smoking and 187 smoking employees. The mean number of cigarettes in the pre-ban period was of 14 (SD 10), and 12 in the post-ban period (SD 9), $p=0.02$.

The main reason for not obtaining a higher rate of repeated measures of CO level was because of the survey design, in which venues were re-visited at the same time and day of the week of

Table 1 Pre-ban and post-ban mean CO level according to venue type and sampled environment

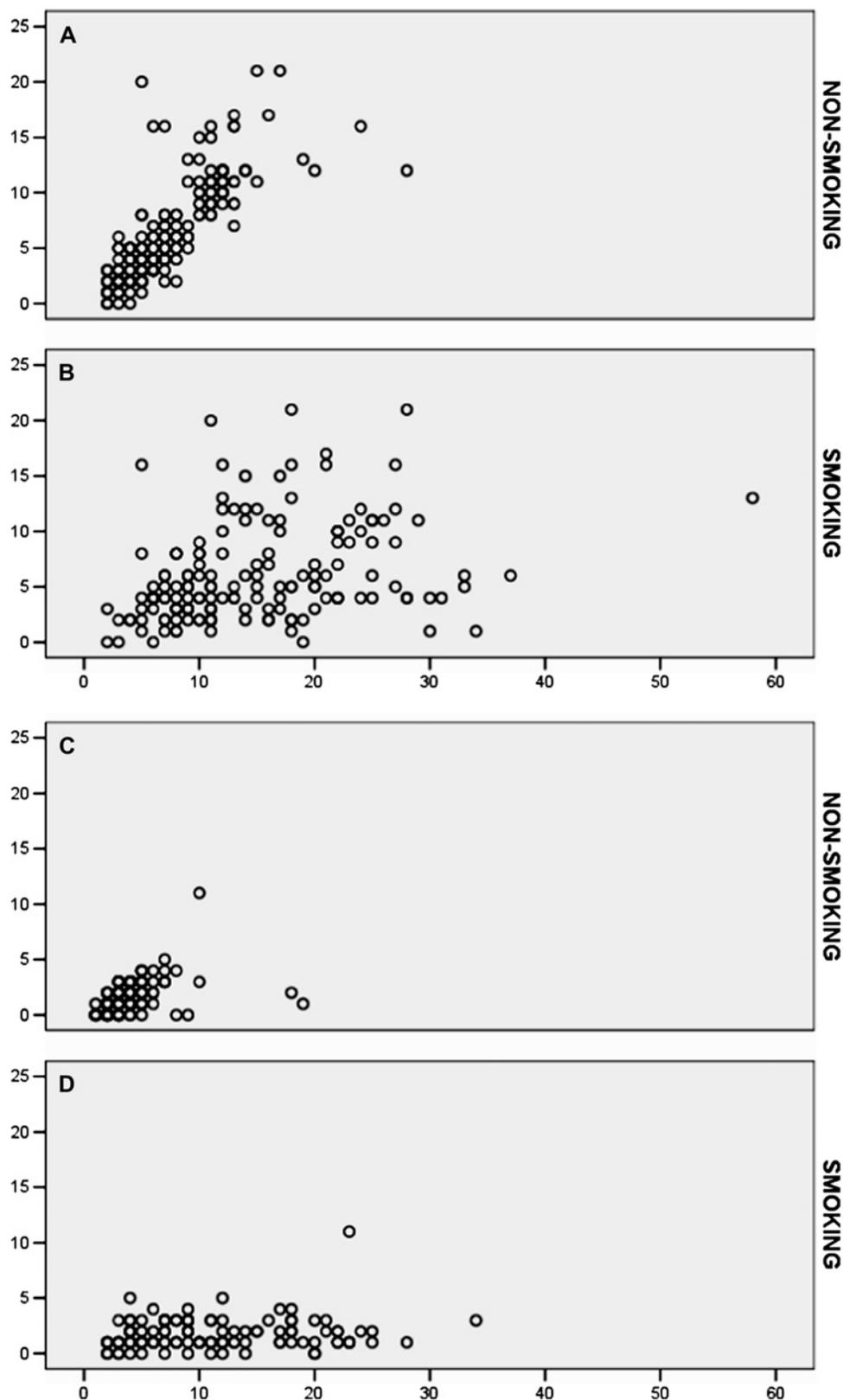
Venue type	Environment														
	Closed pre-ban		Closed post-ban		p Value	Semi-opened pre-ban		Semi-opened post-ban		p Value	Open pre-ban		Open post-ban		p Value
	Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Restaurant	4.01	3.39	1.29	1.66	<0.001	3.49	2.09	1.11	1.06	<0.001	3.16	1.98	1.22	1.30	<0.001
Bar	5.02	4.27	1.35	1.22	<0.001	4.14	3.02	1.21	1.37	<0.001	3.23	1.74	1.43	1.68	<0.001
Nightclub	4.91	3.21	1.30	.82	<0.001	4.01	2.70	1.15	.73	<0.001	3.50	2.33	1.33	0.97	<0.001
Other	4.64	3.94	1.67	2.87	<0.001	3.58	2.32	1.21	1.16	<0.001	3.74	3.23	1.31	1.25	<0.001
Mean value	4.57	3.7	1.35	1.66		3.79	2.49	1.16	1.14		3.31	2.2	1.31	1.39	

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the pre-ban survey, and many surveyed individuals in the pre-ban survey were off-duty on those days or some of them were no longer employed at the venue. It should be mentioned that no significant difference in mean CO levels between individuals who were revisited or not revisited was observed ($p=0.23$, CO mean level of 10.47 and 11.44 for revisited and not revisited individuals, respectively).

As expected, a significantly higher mean CO level was observed in employees who smoked than in employees who did not smoke ($p<0.001$ in the pre-ban survey; $p<0.001$ in the post-ban survey). In the pre-ban period, significant correlations were observed between measured CO level in indoor environments and expired CO levels in both smoking ($p<0.001$) and non-smoking employees ($p<0.001$). It is interesting to note, however,

Figure 2 Relation between exhaled CO levels in smoking and non-smoking venue employees (X axis) and environment CO levels of visited venues (Y axis). (A) Non-smoking employees pre-ban period; (B) Smoking employees pre-ban period; (C) Non-smoking employees post-ban period; (D) Smoking employees post-ban period.



that the correlation coefficient was much higher in non-smoking than in smoking employees (0.79 and 0.32, respectively), thus suggesting that the indoor environment was important in predicting expired CO levels in both smoking and, especially, in non-smoking employees (figure 2).

Table 2 presents data on the pre-ban and post-ban periods for both smoking and non-smoking employees. Overall, a significant reduction in CO levels was observed for both smoking and non-smoking employees after the smoking-ban ($p < 0.001$). This occurred irrespective of venue type ($p = 0.58$ for the interaction term between survey time and venue type). Interestingly, the degree of CO reduction was also independent of the smoking status (figure 3).

If the correlation structure of smoking status and environmental CO levels is dissected, an interesting pattern can be seen in the post-ban period. For non-smoking employees a significant, but much weaker, correlation existed between environment CO levels and expired CO levels ($p = 0.001$, correlation coefficient 0.22). On the other hand, for smoking employees one could no longer observe any correlation between environment CO levels and expired CO levels ($p = 0.17$, correlation coefficient 0.11). This can be better observed in figure 2 (A and B for the correlation structure in the pre-ban period, and C and D for the correlation structure in the post-ban period).

Another important point regarding exhaled CO concentrations after the ban is that CO reductions were verified even in smoking employees that continued to smoke after the ban implementation (although a higher reduction was observed, as expected, in smoking employees who reduced the number of cigarettes). This suggests that reduction of expired CO after the ban was regardless of changing smoking habits in venue's employees (figure 4).

DISCUSSION

The association between active smoking and cardiovascular disease has been known for many decades, and more recently SHS has also been recognised as a risk factor for coronary disease. Reducing public exposure to cigarette smoke can have immediate implications on human health. In the last two decades, some studies⁵⁻⁹ have shown a significant reduction in cardiovascular hospital admissions after the implementation of smoking-ban ordinances.

The current study analysed the effects of the smoking ban on levels of CO in restaurants, bars and similar venues in the city of São Paulo, Brazil. There was a clear reduction in the concentration of CO in almost all visited places. Measured CO reductions were especially significant in indoor areas, but were also seen in semi-open and open areas of these sites. Regarding cooking stoves, although they can influence CO measurement, a significant difference between the first and the second measurement was observed even in restaurants, where this

Table 2 Pre-ban and post-ban CO measurements at the individual level

Venue type	Smoking status	Pre-ban period		Post-ban period	
		Mean	SD	Mean	SD
Restaurant	Smoking	15.67	9.8	11.48	8.38
	Non-smoking	6.32	3.49	3.44	2.02
Bar	Smoking	16.47	10.39	10.75	7.25
	Non-smoking	7.22	5.85	3.75	2.85
Nightclub	Smoking	17.73	11.61	13.49	6.97
	Non-smoking	6.94	6.69	3.29	1.68
Other	Smoking	10.61	3.79	7.18	3.03
	Non-smoking	7.91	3.32	3.5	2.01

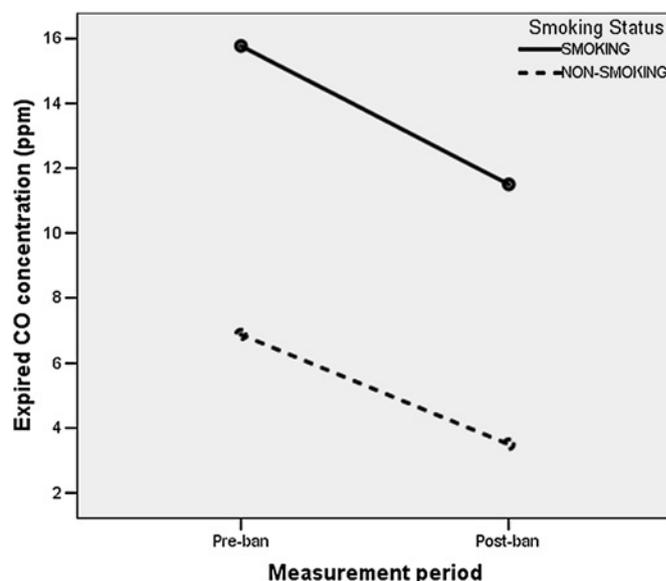


Figure 3 Exhaled CO reduction after ban implementation in venue employees according to smoking status.

confounding effect is more common. An interesting fact is that restaurants were the places with the lowest pre-ban CO average among all venues types. These data were corroborated by Erazo *et al*¹⁶ who analysed the air nicotine concentration in bars and restaurants in Chile and noticed a lower concentration of nicotine in restaurants compared to bars in Santiago, Chile.

Some studies have used other biological markers of SHS pre-smoking ban and post-smoking ban.¹⁷⁻¹⁹ They analysed other components of SHS like particulate matter concentrations, volatile organic compound and cotinine levels, and they found

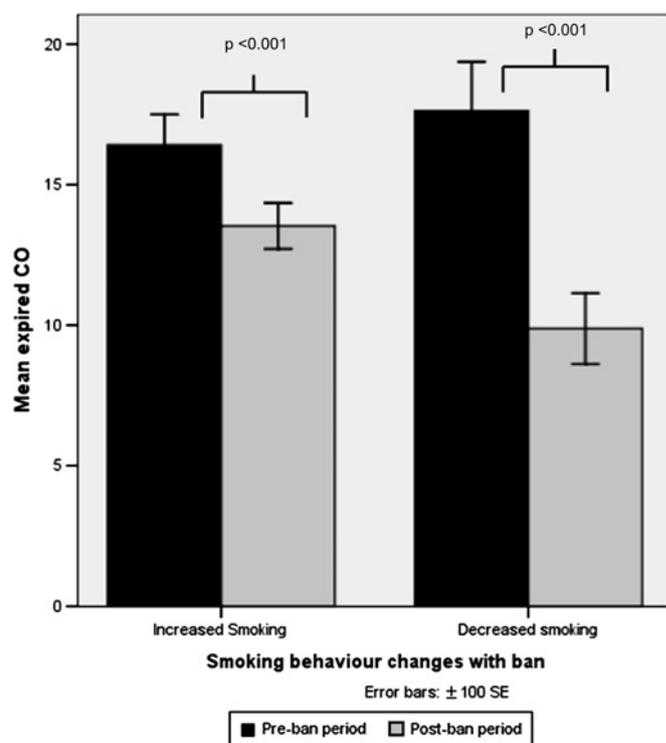


Figure 4 Mean expired CO levels in smoking employees before and after ban implementation according to changes in smoking behaviour after the ban.

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significant reductions in all these products. In fact, these studies have also shown that there is a tight correlation between reductions in exhaled CO and smoke-related particulate matter, suggesting that the use of exhaled CO is, indeed, a good surrogate in studies with a large number of places and individuals studied. Goodman *et al*²⁰ showed the effects of the Irish smoking ban on respiratory health of bar workers and in the air quality in Dublin pubs, studying particulate matter in 42 pubs and exhaled CO and salivary cotinine of 81 barmen, before and after the ban law. They showed a significant reduction of 83% in particulate matter concentration, a reduction of 79% and 81% in the exhaled CO concentration and in salivary cotinine of non-smokers and ex-smokers, respectively. No changes were seen in current smokers, but there were clear sample size limitations for this analysis.

Specifically, this study showed that after the ordinance, there was a reduction of 70% in the CO concentration in hospitality venues. The reduction was close to threefold in enclosed areas. By comparing the values of CO concentration in the streets monitored by CETESB during the same period of the study, it is possible to understand that the CO concentration reduction observed in such places cannot be attributed to external factors like climatic changes or season variability. The average CO CETESB streets concentration before and after the smoking-ban law was lower than 1 ppm in the study periods. In fact, it is interesting to observe that in the post-ban period CO concentration in closed, semi-open and open venue areas became similar to the measured in streets monitored by CETESB.

Other important observation of this study was that the exhaled CO for the non-smoking workers became similar to the levels observed in regular non-smoking citizens who live in São Paulo city according to Issa *et al*,²¹ but the most relevant observation was that even among smokers who increase cigarette consumption after the ban law we found significant reductions in the CO concentration of exhaled air, proving that the SHS influence on the CO concentration in smokers was independent of changes in cigarette consumption.

There are some potential limitations. Owing to our sample size we were not able to conduct measures of other biological markers of SHS, such as particulate matter concentrations. In addition, interesting data regarding behavioural changes that led to smoking habit changes in smoking employees were not obtained and we could only measure the result of these changes in the number of cigarettes smoked. Finally, we have little health

information on studied individuals, which precluded the use of more complex regression models adjusting for potential confounders of the observed changes (eg, prevalent pulmonary conditions, smoking history, etc).

The consequences of the observed CO reduction are not well known, but it clearly indicates the unequivocal influence of SHS in CO exhaled air concentration in individuals who work in these venues. Thus, one can speculate that the significant reduction obtained in CO concentrations after adoption of tobacco smoke-free legislation could be causally related to the reduction in cardiovascular events incidence observed in many places where this law has already been adopted.

In conclusion, our findings are consistent both at the environment and individual levels and they reinforce the necessity for supporting the campaign for tobacco free environments.

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Competing interests JI has consulted for Pfizer and has been principal investigator for clinical trials of smoking cessation medications funded by Pfizer and other clinical trials funded by Lilly. The other authors report no conflicts.

Patient consent Obtained.

Ethics approval This study was conducted with the approval of the CAPPEQ ethics committee for research project evaluation of the Hospital das Clínicas, School of Medicine, University of São Paulo.

Provenance and peer review Not commissioned; externally peer reviewed.

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What is already known on this subject

Cardiovascular events are reduced a few months after smoking-ban laws are implemented. Although carbon monoxide (CO) is one of the most important components present in SHS, few studies to date have aimed at quantifying the reduction of CO exposure after smoking-ban laws.

What this paper adds

We were able to describe significant environment and individual reductions in CO concentrations. The effect of the smoke-ban law was detectable in all environments of visited venues and, most importantly, in both non-smoking and smoking employees.

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