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Emergency visits and mortality caused by ischemic heart disease attributable to fine particulate matter during the COVID-19 pandemic in Chile

Visites aux urgences et mortalité dues aux cardiopathies ischémiennes attribuables aux particules fines pendant la pandémie de COVID-19 au Chili

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Abstract

Background. – A reduction in PM$_{2.5}$ was reported worldwide during the COVID-19 pandemic lockdown. Santiago, the capital and largest city of Chile, is characterized by high concentrations of PM$_{2.5}$, being vehicular traffic a major contributor. Its air quality was improved as a collateral effect of the lockdown imposed in the second quarter of 2020. We aimed at highlighting an ensuing decrease of emergency visits for treatment of acute myocardial infarction (AMI) and deaths due to ischemic heart diseases (IHD) attributable to PM$_{2.5}$, comparing equivalent periods in 2019 and 2020.

Methods. – In Santiago, air quality monitoring is carried out by nine monitors located in nine communes: Cerro Navia, Cerrillos, El Bosque, Pudahuel, Independencia, La Florida, Quilicura, downtown Santiago and Las Condes (ranked from highest to lowest in terms of multidimensional poverty). We described average daily PM$_{2.5}$ concentration with time-series graphs of means and standard deviations. AMI-emergency visits and IHD deaths were reported for each quarter by year. To estimate the impact of PM$_{2.5}$ excess, we estimated the population attributable fractions (PAF) for AMI-emergency visits and IHD-related deaths.

Results. – Daily average PM$_{2.5}$ decreased in eight out of nine communes in Santiago. However, the reduction was significant in only three communes. AMI-emergency visits and IHD-related deaths attributable to PM$_{2.5}$ decreased slightly but significantly in these three communes. The PAF in other communes remained similar to 2019 despite the lockdown.

Conclusions. – A significant reduction of PM$_{2.5}$ PAF potentially responsible for AMI emergency visits and IHD deaths was observed only in communes with a significant reduction of the daily average concentration of PM$_{2.5}$ during the COVID-19 pandemic.

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visites aux urgences pour IDM et les décès dus à une CPI ont été analysées de façon trimestrielle pour chaque année. Pour estimer l’impact de l’excès de PM$_{2.5}$, les fractions de risque attribuables (FRA) pour les visites aux urgences pour IDM et les décès pour CPI ont été calculées.

Résultats. – La moyenne quotidienne des PM$_{2.5}$ a diminué dans huit des neuf communes de Santiago. Cependant, la réduction n’a été significative que dans trois communes. Les visites aux urgences pour IDM et les décès par CPI attribuables aux PM$_{2.5}$ ont diminué légèrement mais significativement dans ces trois communes. Les FRA dans les autres communes sont restées similaires à 2019.

Conclusions. – Une réduction significative de la FRA des PM$_{2.5}$ pour les décès par CPI et les visites aux urgences d’IDM n’a été observée que dans les communes avec une réduction significative de la concentration quotidienne moyenne de PM$_{2.5}$ pendant la pandémie de COVID-19.

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1. Background

Air pollution (AP) is a major and modifiable public health risk factor worldwide. The Global Burden of Diseases Study 2015 shows that AP is the fifth ranked risk factor, accounting for 7.6 % of total deaths and 4.2 % of total DALYs, globally [1]. The most recent report of the Chilean Ministry of Environment (year 2019) concluded that 3640 deaths due to cardio-respiratory causes and 1563 hospital admissions due to cardiovascular diseases were attributable to excessive PM$_{2.5}$ exposure per year in Chile [2]. These outcomes could be avoided if the recommendations of the World Health Organization (WHO) – yearly mean of 10µg/m$^3$ and daily mean of 25µg/m$^3$ – were met ; currently, the Chilean norms for yearly and daily means of exposure are 20µg/m$^3$ and 50µg/m$^3$, respectively.

There is strong evidence that PM$_{2.5}$ increases the incidence and mortality due to ischemic heart diseases (IHD) [3-6]. The mechanisms involved include increase in systemic inflammation, oxidative stress, endothelial dysfunction, and promotion of hypercoagulability [7, 8]. In a recent systematic review, which included 28 primary studies, the overall risk ratio for acute myocardial infarction (AMI) was 1.02, which means that by each 10µg/m$^3$ increase of PM$_{2.5}$, the risk of myocardial infarction increases by 2 % (95 % CI, 1 %-3 %) [9]. In another recent study, which took into account spatial and temporal variability, the risk of ischemic heart disease mortality increased by 2.1 % (95 % CI, 0.2 %-4.1 %) with each 10µg/m$^3$ increase of PM$_{2.5}$ [10].

Although its overall contribution varies, traffic is one of the main sources of urban PM$_{2.5}$ worldwide [11,12]. In China, during the pandemic, traffic reduction secondary to mandatory lockdown decreased the level of outdoor PM$_{2.5}$ by 5.9 % [13]. It is likely that the lower level of exposure will reduce the incidence of cardiovascular and respiratory causes, thereby lessening the number of related hospital admissions and premature deaths [14-16]. In Chile taken as a whole, the main sources of PM$_{2.5}$ emissions are industry, energy production and transportation, but in Santiago, the capital, the major contributor (above 90 % of PM$_{2.5}$ emissions) is the transportation sector [11]. That is why, due to the lockdown occasioned by the COVID-19 pandemic, AMI and IHD incidence may have decreased as a result of reduced PM$_{2.5}$ concentration.

The key question is whether the decrease in PM$_{2.5}$ observed during the lockdown – a kind of “natural experiment” – would be enough to impact cardiovascular diseases (acute coronary events and short-term mortality). We consequently aimed at comparing the PM$_{2.5}$ population attributable fraction (PAF) of AMI emergency visits and IHD-related mortality before and during the COVID-19 pandemic in the major metropolitan city of Santiago (Chile).

2. Methods

2.1. Population and study design

The Chilean Metropolitan region – located in the country’s central zone at 33°S, 70°W – is divided into six provinces, Santiago, being the most populated, including thirty-two urban communes and with 5,764,105 inhabitants (approximately 31 % of the total Chilean population).

Air quality monitoring is carried out by nine monitors of the National Air Quality Information System (SINCA) of the Chilean Ministry of Environment. These monitors are located in nine communes of Santiago : Cerrillos, Cerro Navia, El Bosque, Independencia, La Florida, Las Condes, Pudahuel, Quilicura, and downtown Santiago (Figure 1). The selected communes differ widely. Las Condes, located in the foothills of East Santiago [11,17] features numerous green spaces (normalized difference vegetation index, NDVI : 0.38) and is one of the most affluent territories in the country. The NDVI ranges from -1 to +1. Values above 0.1 indicate the presence of vegetation, and the higher the value of this index, the greener the surroundings. The other six communes range from middle class (La Florida, Cerrillos and Quilicura) to largely deprived areas such as Pudahuel and Cerro Navia in the northwestern flat lands, with scarce green space (NDVI : 0.24) and poor ventilation.

In these nine communes, we contrasted the average daily concentrations of PM$_{2.5}$, emergency visits due to AMI and IHD-related deaths during the first (summer) and second quarter (autumn) of 2019 – denoting a regular non-pandemic year – and 2020, which stands for the pandemic period. Lockdown was imposed independently for each commune at different times during the second quarter of 2020.

2.2. Data Sources

**Short-term exposure to PM$_{2.5}$ :** Average daily concentration of PM$_{2.5}$ was estimated using the hourly data collected by the National Air Quality Information System during the first and second quarters of 2019 and 2020. PM$_{2.5}$ is assessed in atmospheric samples using gravimetric methods ; the samples are directly collected by monitors located in sites representative of exposure status in the urban area, according to the Chilean Ministry of Environment [18].

**Health data :** Emergency visits caused by AMI (I21-I22) in public healthcare facilities and total deaths due to IHD (I20-I25) were obtained from the Health Statistics and Information Department (DEIS) of the Chilean Ministry of Health. Death certificates are required by law, and all deaths are consequently registered. In addition, doctors are responsible for filling out death certificates, which guarantees proper recording of the cause of death. There also exists a mandatory emergency room consultation registry, but only for public health care facilities ; therefore, we only included emergency visits in the public sector, which serves almost 80 % of the Chilean population.

Both databases (emergency room visits and deaths) are freely accessible through the DEIS webpage. Although the validation process of death certificates usually takes nearly two years to be completed, due to the COVID-19 pandemic the DEIS implemented an accelerated process to obtain valid information in record time. We computed the total sum of emergency visits and the total sum of deaths for the first (summer) and second (fall) quarters in 2019 and 2020 so that the seasonality effect on PM$_{2.5}$ and IHD could be taken into account.

**Health impact assessment :** To estimate the impact of the PM$_{2.5}$ excess on emergency visits and deaths, we used the PAF [19] to
quantify the contribution of the change in PM$_{2.5}$ to the burden of disease, according to the following formula:

$$\text{Events attributable to PM}_{2.5} = \frac{\text{Total health events}}{\exp(\beta + \Delta \text{PM}_{2.5})}$$

Where,

- Total health events = total sum of AMI-emergency visits or IHD deaths per quarter;
- $\beta$ = logarithm of risk ratio per 10$\mu$g/m$^3$ of increase in PM$_{2.5}$; risk ratio for risk of AMI was obtained from Farhadi et al. [9] and of risk of death due to IHD was obtained from Dabass et al. [10]. We selected these risk ratios because they are the most specific and updated association measurements available in the literature. While the WHO has recommended other risk ratios for global burden studies, they are largely focused on total cardiovascular diseases [20];
- $\Delta$PM$_{2.5}$ = difference between average daily concentration and the short-term exposure recommendation of the World Health Organization of 25$\mu$g/m$^3$.

2.3. Statistical analysis

We described daily average PM$_{2.5}$ concentration with time-series graphs of means and standard deviations for each quarter in 2019 and 2020. We performed paired t-test to compare average concentrations of PM$_{2.5}$ in each quarter by year.

The total sum of AMI emergency visits and IHD deaths are reported in the first and second quarter each year. PAFs for AMI emergency visits and IHD deaths and their 95% confidence intervals (95%CI) were estimated for the second quarter and compared by year using a one-tailed paired test of proportion with a significance level of 0.05. We used R version 4.0.2. for data analyses.

3. Results

During the first quarter of both years, no commune exceeded 25$\mu$g/m$^3$ of mean average daily PM$_{2.5}$; in the second quarter of both years, Las Condes, one of the wealthiest communes, was the only one that met the recommendation of mean average daily concentration less than 25$\mu$g/m$^3$.

Compared to the same period in 2019, the mean daily average concentration of PM$_{2.5}$ during the first quarter of the pandemic year 2020 decreased significantly (p-value <0.05) in three out of the nine communes (Independencia, Las Condes, and Santiago), and in four (Independencia, La Florida, Las Condes, and Santiago) the reduction occurred in the second quarter. In the pandemic year, La Florida showed a higher daily average concentration of PM$_{2.5}$ in the first quarter only, but this difference did not reach statistical significance (Table 1). According to seasonality, mean average daily concentration increased in the second quarter (fall) compared to the first quarter (summer).
When comparing the first and second quarters of 2020, we observed the usual seasonal increase in PM$_{2.5}$ concentration observed in 2019, but of a lower magnitude.

Taken as a whole, i.e. the sum total of events in the nine communes, 221 (rate = 9.9 per 100,000 inhabitants) emergency visits occurred during the first quarter of 2019 due to AMI, while in 2020 that number reached 239 (rate = 10.4 per 100,000). Regarding the second quarter of 2019 and 2020, the numbers of emergency cases were 192 (rate = 8.6 per 100,000) and 213 (rate = 9.4 per 100,000) respectively. In the first quarter, IHD-related deaths were 186 (rate = 8.3 per 100,000 inhabitants) in 2019 and 173 in 2020 (rate = 7.6 per 100,000 inhabitants) ; whilst in the second quarter, deaths were 222 (rate = 9.9 per 100,000 inhabitants) and 244 (rate = 10.7 per 100,000 inhabitants), respectively.

When considering the nine communes, we did not find a common pattern among them, either for cardiovascular emergency visits or for deaths from AMI-related deaths (Table 2).

As expected, the communes that had a higher level of PM$_{2.5}$ in 2019 and experienced a significant reduction during the pandemic year (Independencia, La Florida, and Santiago), showed an appreciable reduction of the PAF for emergency visits and deaths ; while La

| Table 1 | Mean and standard deviation of PM$_{2.5}$ by quarter and year for each monitor |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                | First quarter   | Second quarter  |
| year           | mean  | sd   | p-value | mean  | sd   | p-value |
| Cerrillos 2019 | 15.61 | 4.84 | 0.636   | 35.51 | 17.30 | 0.959   |
| Cerrillos 2020 | 15.95 | 4.20 |         | 35.64 | 13.02 |         |
| Cerro Navia 2019 | 18.74 | 5.19 | 0.241   | 42.86 | 21.03 | 0.097   |
| Cerro Navia 2020 | 17.83 | 3.95 |         | 38.56 | 16.60 |         |
| El Bosque 2019 | 20.23 | 7.05 | 0.238   | 38.21 | 15.85 | 0.154   |
| El Bosque 2020 | 18.99 | 5.28 |         | 34.82 | 12.60 |         |
| Independencia 2019 | 19.79 | 7.38 | 0.004   | 32.60 | 13.34 | 0.011   |
| Independencia 2020 | 16.62 | 3.79 |         | 27.45 | 9.27  |         |
| La Florida 2019 | 15.91 | 5.43 | 0.096   | 33.03 | 12.67 | 0.001   |
| La Florida 2020 | 17.26 | 5.41 |         | 26.60 | 9.17  |         |
| Las Condes 2019 | 21.81 | 4.87 | <0.001  | 22.75 | 9.52  | <0.001  |
| Las Condes 2020 | 21.89 | 3.98 |         | 17.60 | 8.41  |         |
| Pudahuel 2019  | 15.87 | 6.07 | 0.429   | 37.77 | 18.95 | 0.271   |
| Pudahuel 2020  | 15.15 | 3.83 |         | 34.64 | 14.82 |         |
| Quilicura 2019 | 16.36 | 5.29 | 0.878   | 31.89 | 13.17 | 0.340   |
| Quilicura 2020 | 16.24 | 4.66 |         | 30.05 | 11.74 |         |
| Santiago 2019  | 21.02 | 6.76 | <0.001  | 33.40 | 14.47 | <0.001  |
| Santiago 2020  | 16.16 | 4.16 |         | 26.75 | 9.21  |         |
Florida and Santiago showed a significant (p-value < 0.05) reduction of the PAF for emergency visits and deaths. Independencia showed borderline reductions (p-values < 0.1) (Figures 3 and 4). Since Las Condes did not exceed the recommended short-term exposure in both quarters, the impact on PAFs was nil. The highest PAF for emergency visits was observed in Cerro Navia in 2019 (3.8 % 95 % CI 0.1–8.7), while in 2020 the PAF was 2.9 % (95 %CI 0.1–6.7) CerroNavia also had the highest PAF for IHD-related deaths, reaching 3.6 % (0.1–10.3) and 2.8 % (0.1–7.9) in 2019 and 2020, respectively.

4. Discussion

This study reviewed the fraction of AMI-emergency visits and IHD-related deaths attributable to PM2.5 during the COVID-19 lockdown. Consistently with our hypothesis and despite increases in the absolute number of emergency visits and deaths, the PM2.5-attributable events decreased in most of the studied communes during the second quarter, when the lockdown came into force. The lockdown was not imposed simultaneously in all communes; in fact, it started the end of March 2020 with a wealthy commune (Las Condes) and

Table 2
Emergency visits due to AMI and deaths due to IHD per trimester for each commune in 2019 and 2020

| Year | First quarter | Second quarter |
|------|---------------|----------------|
|      | deaths emergency visits | deaths emergency visits |
| Cerrillos 2019 | 9 5 | 9 3 |
| Cerrillos 2020 | 4 8 | 11 9 |
| Cerro Navia 2019 | 13 9 | 27 7 |
| Cerro Navia 2020 | 14 16 | 20 11 |
| El Bosque 2019 | 20 20 | 26 23 |
| El Bosque 2020 | 21 15 | 20 17 |
| Independencia 2019 | 11 13 | 15 6 |
| Independencia 2020 | 9 24 | 18 8 |
| La Florida 2019 | 37 57 | 33 54 |
| La Florida 2020 | 26 51 | 40 36 |
| Las Condes 2019 | 29 3 | 34 3 |
| Las Condes 2020 | 34 6 | 29 9 |
| Pudahuel 2019 | 25 18 | 28 13 |
| Pudahuel 2020 | 20 11 | 19 15 |
| Quilicura 2019 | 9 6 | 10 13 |
| Quilicura 2020 | 13 3 | 9 10 |
| Santiago 2019 | 33 90 | 38 91 |
| Santiago 2020 | 32 105 | 45 77 |

AMI: Acute myocardial infarction; IHD: Ischemic heart diseases

Figure 3. Population attributable fraction of AMI emergency visits due to PM2.5 excess in the second trimester of 2019 and 2020

AMI: Acute myocardial infarction
the city center (downtown Santiago and Independencia) where the pandemic had sprouted, following by the other communes [21]. Although PM$_{2.5}$ decreased during lockdown, a fact possibly attributable to a decline in vehicular traffic, the daily average was still high in most of the studied communes. Las Condes is located at the foothills of the Metropolitan Region [11,17]. It has plenty of green space (NDVI : 0.38) and was the only commune in which exposure to PM$_{2.5}$ was less than 25µg/m$^3$ throughout the two years; as a result, no event could be attributed to PM$_{2.5}$. The other six communes, which began the lockdown in early May, present largely middle socioeconomic class (La Florida, Cerrillos, Quilicura and Pudahuel) and low class (El Bosque and Cerro Navia) populations. The last two are located in the northwestern flatlands, which have little green space (NDVI : 0.24), and are among the most disfavored communes in the city (34.6 % of multidimensional poverty) [22].

Total count of emergency visits for AMI decreased in La Florida and Santiago, but not in Independencia. However, deaths caused by IHD increased during the pandemic year in these three communes, as reported in other studies [23]. As expected, the communes in which the level of PM$_{2.5}$ significantly decreased during the second quarter of the pandemic year (i.e. Independencia, La Florida, and Santiago), achieved significant reduction of PM$_{2.5}$ PAF for both IHD deaths and AMI emergency visits.

While the lockdown decreased the level of PM$_{2.5}$, the reduction was not homogeneous among the nine communes. More precisely, the reduction did not suffice to avoid health events in communes other than Las Condes. Air quality improvements were likewise registered in other zones such as the Yangtze River Delta Region (China) where air quality changes during the COVID-19 lockdown were attributable to modified activity patterns. In forty-four cities, air quality improved due to travel restrictions occasioned by the lockdown. During the pandemic, on average, the following five pollutants (PM$_{2.5}$, PM$_{10}$, SO$_2$, NO$_2$, and CO) decreased by 24.7 %, 13.7 %, 6.8 %, 5.9 %, and 4.6 %, respectively [24]. In Kolkata, India, a 17.5 % reduction in PM$_{10}$ and PM$_{2.5}$ was reported during the lockdown, and was presumably related to a drastic reduction in vehicular traffic [25]. According to Seguel et al., air quality in communes belonging to the Metropolitan Region improved secondarily to a reduction in PM$_{2.5}$ and NO$_2$ [26].

Emergency visits may have decreased for various reasons such as health service access difficulties, which were secondary to the health system’s struggles to cope with COVID-19, and/or fear of contagion from other patients. Numerous studies have shown a reduction in

**Figure 4.** Population attributable fraction of IHD deaths due to PM$_{2.5}$ excess in the second trimester of 2019 and 2020

IHD : Ischemic heart disease
admissions due to acute coronary syndrome [27–30] and an increase in time of symptom onset to reperfusion [31].

What needs to be defined is whether there was a reduction in the actual incidence of cases or an underdiagnosis during the pandemic for the reasons stated above. If this was the case, we might expect an increase in out-of-hospital mortality due to IHD, information that we do not have to date, but which should be clarified with future studies. On the other hand, coronary patients and/or those with risk factors are more susceptible to complications from atherosclerotic and thromboembolic plaque, associated with the inflammatory process caused by SARS-CoV-2 infection, for which we might even expect that consultations and deaths would have increased during the pandemic [7,8]. Moreover, care of patients with risk factors was also affected, along with long periods of lockdown with less exercise and increased levels of overweight and obesity, which may also have had an impact on the development of IHD [32].

Our results provide evidence regarding the mechanism involved in reducing acute coronary events, demonstrating a relationship with the decrease in environmental pollution by PM2.5 due to prolonged lockdown [4]. The verification of our hypothesis in this COVID-19 lockdown model, with a consequent decrease in environmental pollution by PM2.5, as well as other pollutants associated with the incidence of IHD, points to an objective that must be addressed in prevention of ischemic heart disease.

Our study has several limitations. First, we do not have information on the place of occurrence of deaths, so we cannot assess any change in out-of-hospital mortality. Second, the certification of deaths due to IHD that occurred outside of health service could have been overestimated, especially in elderly patients [33]. Third, we have no information on type of AMI, whereas other investigations have shown an overall reduction in the incidence of hospital admissions for both STEMI and non-STEMI myocardial infarction (STEMI) and non-STEMI (NSTEMI) [29]. Fourth, there are a number of individual risk factors — e.g., acute mental stress, depression, chronic heart disease disruption, indoor contamination — and contextual characteristics (temperature, noise, health access) related to the incidence of IHD-related deaths and AMI emergency visits — that we did not have access to analyze in the study period. It is noteworthy that the total count of emergency visits for AMI and IHD-related deaths in each quarter of 2019 and 2020 was quite small, as was PAF attributable to PM2.5. Apparently, it would not be a potential limitation to compare the two years in places such as Santiago and La Florida, but it could limit the comparison of communes such as Independencia. A fifth limitation was the risk ratio we used for our estimations insofar as Fahradi reviewed hospitalization risk and not emergency visits; that said, due to the fact that emergency visits were indicated by ICD-10 code I21, all of them entailed mandatory hospital admission unless death ensued, whichever occurred first. Finally, for emergency visits, all of our information came from the public sector, introducing a selection bias.

These results could be helpful as support for an IHD prevention model that would consider environmental factors at the population level and promote early access to medical care, especially during days with high levels of fine particulate matter.

In conclusion, our results show a significant reduction of PM2.5’s PAF of IHD and AMI emergency visits only in those communes with a significant reduction of the daily average concentration of PM2.5, which could be a consequence of the lockdown imposed during the COVID-19 pandemic.

Author statement
CN and MV conceived of the presented idea. MV performed the statistical analysis. All authors wrote the manuscript. FA and PP critically revised the article. All authors discussed the results, contributed to the final manuscript, and approved the final version.

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